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Biodiversity in Africa: Potentials, Threats and Conservation

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Preface

Biodiversity refers to variations inherent in macro- and microorganisms as presented in their genotypic, phenotypic, and other characteristics as well as life forms and cycles. There is a strong connection between human progress and the state, threats, and potentials of biodiversity, and nowhere is this link more fragile than in the African continent. This connection is influenced by a variety of drivers, outlooks, and emerging features. To sustainably manage these links, it is pertinent to identify and document associated value systems, drivers that might cause biodiversity decline or loss, and potential adaptation, mitigation, and intervention strategies. Moreover, the majority of Africa's biodiversity exists outside native and non-native protected areas and has continuously been threatened albeit largely undocumented. The most pressing issue is development, which is currently unsustainable in most parts of the continent and is causing a slew of problems, including restricting biodiversity potentials and increasing challenges to their use and conservation.

The present book entitled *Biodiversity in Africa: Potentials, Threats and Conservation* is a broad collection of reviews written by scholars and experts within and outside the continent on the values of biodiversity, drivers of biodiversity decline and loss, and sustainable conservation strategies of native and naturalized biodiversity associated with the continent. The book focuses on vegetation, mammals, birds, reptiles, amphibians, fishes, insects, microorganisms, etc. On the aspect of biodiversity utilization in Africa, the book addresses food, medicine, constructions, local value systems, etc. A major cause of biodiversity loss in Africa is the alteration of biological processes, to suit social, political, and economic systems. Also, direct human exploitation is a leading cause of biodiversity loss, but so are pollution, urbanization, habitat fragmentation, invasive species, and human population growth, which were considered in the section on biodiversity threats. Various conservation strategies with recent advances in science and technology, and trends and scenarios are also part of this book. Legislations and laws concerning biodiversity conservation in Africa were also considered. Hence, the main sustainability goal would be to organize a public outreach program aimed at informing Africa's populace about ongoing biodiversity loss. This will help the continents meet the intended potential of biodiversity in the region.

This book will be useful to students (undergraduates and postgraduates), academics, researchers, environmentalists, ecologists, agricultural scientists, biodiversity experts, policymakers, conservationists, and industries interested in biodiversity conservation of native flora and fauna in the area.

Yenagoa, Nigeria Sylvester Chibueze Izah
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Part I
Introduction

Chapter 1
An Overview of the Potentials, Threats and Conservation of Biodiversity in Africa

Matthew Chidozie Ogwu, Sylvester Chibueze Izah, and Adams Ovie Iyiola

Abstract There is a clear link between human developmental strides and biodiversity status on the African continent. The link exists in the form of drivers, outlooks, emergent properties and multiple feedback dimensions. To sustainably manage this relationship there is a need to identify priority and critical areas for investment and interventions, such as biodiversity and biome-level conservation area analysis that combines climate change and deforestation threats to ensure the preservation of high-value biodiversity and cultural heritage. The result will manifest in the form of a robust monitoring plan as well as adaptation to and mitigation of key stressors, threats and risks. Most of Africa's biodiversity is found outside the limit of native and non-native protected areas and continue to face dynamic threats. Development is the main threat and unless it becomes sustainable will harbour generic issues related to limiting biodiversity potentials and increasing the threats to their use and conservation. This book is a collection of works on the potentials, threats and conservation of biodiversity in Africa and is divided into four sections - an introductory section and other sections on the values of biodiversity in Africa, drivers of biodiversity loss in Africa and trends, scenarios and governance in relation to biodiversity conservation in Africa. This introductory chapter presents an overview of perspectives presented in the book toward a common agenda. Many people only know Africa from the perspective of its unique biodiversity and the values of African biodiversity may be considered from two perspectives—either the whole value or the value of the components. The proximate driver of biodiversity loss in Africa may be biological but the ultimate cause is socio-ecological and economic processes. The major reason

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for this biodiversity loss is not only direct human overexploitation but also due to pollution, urbanization, habitat fragmentation, invasive species, novel diseases and human population growth. A key sustainability target would be to regularly organize public outreach programmes aimed at informing Africa's populace about the ongoing biodiversity loss. Also, knowledge-based sustainable utilization, strategic monitoring and assessment of threats, and technology-driven innovative conservation practices should be the used to define all future developmental plan that pertains to Africa's biological resources.

Keywords Biodiversity value · Sustainable use of biodiversity · Biodiversity conservation · Human development · Africa

1.1 Introduction

There is a clear link between human developmental strides and biodiversity status on the African continent. According to Lawler et al. (2021), this link incorporates several other considerations, which include biodiversity utilization and conservation and diverse ecosystem facets, like policy development and implementation, functioning, processes and services. Evidence is presented in the work of Brockerhoff et al. (2017) on the connected relationship between biodiversity and optimal ecosystem functioning that ultimately leads to the provision of services. Hence, human–biodiversity links in Africa exist in the form of drivers, outlooks, emergent properties and multiple feedback dimensions that are evident in land-use systems and changes, agricultural intensification, alien species, wildlife trade, climate change events, like flooding, erosion, habitat loss and fragmentation, as well as biodiversity changes from deforestation, afforestation, urbanization, immigration and emigration, etc. (Ogwu 2019a; Ogwu et al. 2014). Therefore, this defining relationship may be designed and/or managed to hold the requisite amount, type and variety of biodiversity to sustain livelihood (Scherr and McNeely 2008). To effectively establish this sustainable relationship there is a need to identify priority and critical areas for investment and interventions, such as biodiversity and biome-level conservation area analysis that combines both climate change and deforestation threats to ensure the preservation of high-value biodiversity and cultural heritage (Tabor et al. 2018). The result will manifest in the form of robust monitoring plan and adaptation to and mitigation of key stressors, threats and risks. The response to rising population and agricultural effects on biodiversity, culture and the environment is an example.

In the long term, it would be necessary to focus on human capacity development as a means to address biodiversity and environmental woes in Africa. On a small scale, the work of Schuit et al. (2021) presents this perspective using the coffee sector in Ethiopia wherein enhancing human skills led to efficient production, more profitability and numerous environmental gains. This strategy will work considering humans mostly perceive environmental and biological resources from a utilitarian standpoint and continue to explore ways to maximize benefits from these resources. The win-win scenario will be all the more important in Africa where human–

biodiversity–culture seems most intricately connected. Below-ground processes and activities, such as fertilizer use and farming, have above-ground impacts through modification of soil capacity to support and maintain the biodiversity and environment (Nyam-Osor et al. 2021). Therefore, the human capacity development approach to maximize the environmental potential, meet current and future biodiversity threats, as well as their conservation in Africa, can improve through the incorporation of contemporary techniques. For instance, the decline in large carnivores, reduction of forest covers and crude extraction in the pristine environment would benefit from technological cum technique changes. Through the revision of existing practices (using unmanned aircraft systems or drones and satellite imagery) and policies in Africa's large carnivore conservation, there would be a shift in stakeholder perception and attitude (Franchini et al. 2021; Mulero-Pázmány et al. 2017; Di Marco et al. 2014).

Most of Africa's biodiversity is found outside the limit of native and non-native protected areas and continue to face dynamic threats. The quality and quantity of this "outside environment" is increasingly changing and may not be able to sustain Africa's unique biodiversity in the future. Development is the main threat and unless it becomes sustainable will harbour generic issues related to limiting biodiversity potentials and increasing the threats to their use and conservation. A risk assessment framework, such as those recommended in Butler et al. (2007), for predicting species-level conservation status in the light of projected population growth and agricultural intensification on the African continent is paramount. In the opinion of Vogt (2021), improving intrinsic biodiversity values and outcomes requires dissecting all the interactions within the realm of the human natural environment. Gap analysis of this realm can be used to develop a set of measurable and immeasurable indicators for understanding progress and preparing strategic action plans for native and non-native areas and indicator species found therein (Dudley et al. 2005). The recent work of Vogt (2021) provides a conceptual approach for ensuring productive systems of human-managed wild and non-wild coupled systems. This model, a transboundary dynamic approach with rational options to address issues related to environmental issues, biodiversity conservation and human or social challenges, is pertinent to improve the understanding and economic value of natural resources with communal participation and decision making (Ferguson et al. 2013).

This book is a collection of works from diverse global scholars, academics and professionals, practitioners, experts, etc., on the potential, threats, and conservation of biodiversity in Africa. It is divided into three sections—Values of Biodiversity in Africa (Part II), Drivers of Biodiversity Loss in Africa (Part III) and Trends, Scenarios and Governance in Relation to Biodiversity Conservation in Africa (Part IV). This introductory chapter aims to present an overview of perspectives presented in the book toward the common agenda.

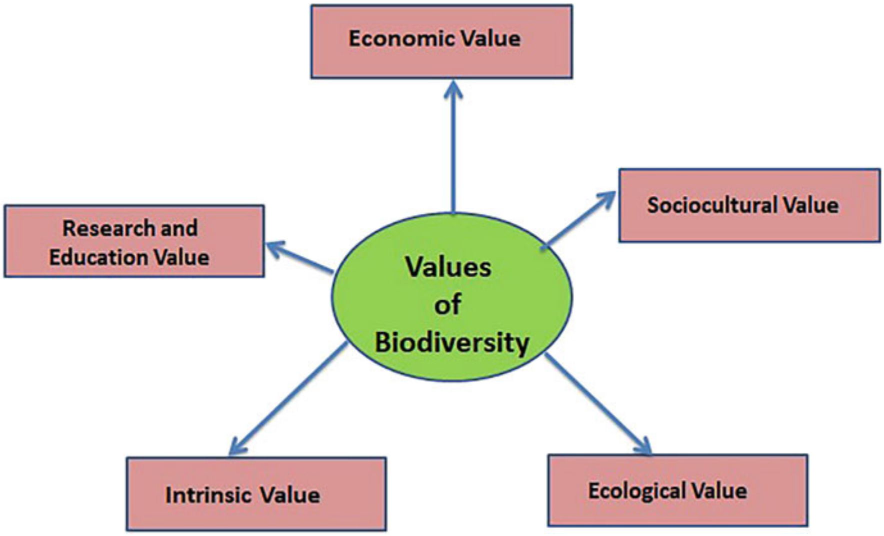

Fig. 1.1 Values of biodiversity in Africa

1.2 Values of Biodiversity in Africa

Biodiversity refers to species and genetic variability within and between populations and their distribution in time and space and their evolutionary histories (NRC 1999). Biodiversity conservation has a unique position to the actual and potential sustainable development of Africa, but diverse human and non-human induced threats are threatening the roles and values of biodiversity on the continent. Nonetheless, efficient planning, effective management and relevant value-based policies guiding the use and conservation and ecological compensation at different scales may protect the position, value and contribution of Africa's biodiversity to the sustainable development of the continent. The trade-off considerations (such as in species and ecosystem conservation and productivity) may help integrate biodiversity into social strategies for the development of sustainable human–biodiversity–culture systems (Schroth and McNeely 2011). This may be in the way of focusing on biological mechanisms and economic cum environmental drivers. In the past, ecological modelling combined with remote sensing data has been used to predict ecological processes and species conservation (Wegmann et al. 2014).

The values of biodiversity may be considered from two perspectives – whole biodiversity value or value of the components of biodiversity, i.e. genes, species or taxa, and it may be of direct or indirect value. Moreover, biodiversity value may also be viewed from the benefits of the following standpoints (Fig. 1.1):

1.2.1 Economic Value of Biodiversity

Biodiversity is the backbone of many economic products. The economies of many countries in the Global South depend heavily on biodiversity, including tourism. Without biodiversity, there will be no agriculture system. Biodiversity used as food drives the demand and supply of many sectors. The economic value of biodiversity focuses on the quantified cost or estimated cost and benefits of the biological resource and the market for part or the whole biodiversity or associated materials (Osawaru and Ogwu 2020; Evivie et al. 2020; Ogwu 2019b; Naidoo and Adamowicz 2005). The demand and supply of biodiversity can influence the conservation value, policy and strategies.

1.2.2 Sociocultural Value of Biodiversity

Many cultures on Earth are defined by the biodiversity found in their environment and Africa is a prime example. Non-consumptive benefits of biodiversity are included in this category. Preserving biodiversity is for everyone to enjoy and access both locally and globally and is essential for understanding life and may be considered the single most important sustainable development target (Neergheen-Bhujun et al. 2017).

1.2.3 Ecological Value of Biodiversity

The goods and services derived from biodiversity function, processes and services are the realm of the ecological value of biodiversity. The environment will not be the same without biodiversity in it. They also serve as ecological monitors and may be used to manage polluted environments (Ogwu 2019c).

1.2.4 Intrinsic Value of Biodiversity

These are the intangible or existential values of biodiversity and include aesthetic value. Not all the values of biodiversity are known or understood, but these are included here. Spiritual and religious roles of biodiversity are also included here as well as many traditional uses of biodiversity, like in herbalism (Ogwu et al. 2017).

1.2.5 Research and Educational Value of Biodiversity

Biodiversity components may contribute valuably to knowledge systems either as a transformative or informative vehicle for technological, scientific or societal innovations (NRC 1999). The educational value of biodiversity increases our social, economic and ecological value and belief systems. Determining the status and trend of biodiversity is key to making a reliable decision about species management, utilization and conservation as well as ecosystem restoration and rehabilitation (McNellie et al. 2020).

It is important to add that all the individual values of biodiversity function as a unit with each value connected to the other and vice versa resulting in either direct or indirect benefits. Examples of connection-based direct value of biodiversity are products and services obtained from biodiversity, like food, timber and environmental protection, whereas non-monetary, non-consumptive, option and existential benefits, like aesthetic, are examples of connection-based indirect biodiversity value.

Many people only know Africa from the perspective of its unique biodiversity especially wildlife, like lions, elephants, cheetahs, etc., and wide-open spaces from the north to south and east to west of the continent. This is also why Africa excites different categories of professionals, like naturalists, systematists, explorers and conservationists (Huntley 1988). However, speciation and extinction are ongoing at different scales in the continent with around 23% of African mammals being threatened with extinction according to the IUCN Red List (Schipper et al. 2008; Huntley 1988). The IUCN Red List serves as an invaluable resource for conservation planning and monitoring but gaps especially with plants, fungi and invertebrates limit application and widespread acceptance (Bachman et al. 2019, 2020; Eisenhauer et al. 2019; Rodrigues et al. 2006). A large proportion of Africa's biodiversity is categorized either as data deficient or least concerned because they have not been properly assessed. Such consideration led to a policy response by scientists that culminated in the publication of a Sampled Red List Index that outlined the need to prioritize detailed fieldwork, especially in certain locales and on aspects of natural history to produce a more robust categorization system (Brummitt et al. 2015a, b).

Since Africa got separated from South America over 140 million years ago in the Gondwanaland supercontinent, dinosaurs and other animals and vegetation systems comprising vast rainforests and deserts have characterized Africa's environment and biodiversity (Huntley 1988). Today, Africa's biodiversity and environment are only a tiny legacy of what existed originally mainly due to the priority effect of humans—hunter, gatherer, fire maker and developer. Using satellite-borne imagery, Di Marco et al. (2014) classified species extinction risk on the continent to be driven by species distribution state, human pressures, conservation response and species biology.

A total of 20 biogeographic units have been defined for the African continent comprising seven centres of endemism, including Guineo-Congolian, Zambezian, Sudanian, Somali-Masai, Cape, Karoo-Namib and Afro-montane (Huntley 1988). In sub-Saharan Africa, ca. 45,000 unevenly distributed plant species have been documented from 29 million km^2 with the most diversity reported from the southern part of the continent and the western part being the poorest (Linder 2014). However, the comparatively small amount of plants supports a significant number of cultures, civilizations and human and animal populations. Their benefits are not well known.

Sosef et al. (2017) suggested that the exploration of tropical Africa flora is not complete and highlighted priority areas for future sampling efforts to include Tanzania, Atlantic Central and West Africa. Same as in other parts of the world, plant conservation in Africa is not attracting the urgency or funding that characterizes animal protection (Corlett 2016). Bird diversity is estimated at 1595 species and is defined mainly by rainfall and vegetation and are impacted mostly by annual burning and intensive livestock grazing since they occur mostly as isolated populations (Huntley 1988; Maphisa et al. 2016). The great lakes of Africa – Victoria, Tanganyika and Malawi hold around 1073 fish species more than the numbers recorded for larger lakes in the Global North (Huntley 1988). Nonetheless, much remains to be discovered about Africa's biodiversity. For instance, to date, there is no accurate record of the amount and variety of biodiversity in the river Nile (Allan et al. 2019). Major threats to fishes are invasive fish species, poor water quality, water abstraction, changes in land use, impoundments, and modification of aquatic habitats (Chakona et al. 2022). It must be noted that Africa has the largest area of wetland sites and are particularly affected by pollution, biological resource use, natural modifications, aqua and agriculture (Xu et al. 2019).

Biodiversity distribution data of species on the continent will foster an understanding of biodiversity patterns and processes (Farooq et al. 2021). Understanding biodiversity distribution patterns and factors that influence them, such as climate change, pollution, fire regimes and invasive species, is a key prerequisite for sustainable utilization and conservation of biodiversity (Sosef et al. 2017; Chown 2010). In Africa, plant functional diversity is controlled by precipitation, whereas that of animals is regulated by temperature, which is indicative of a bottom-up and top-down climatic control in plant–animal interactive networks (Albrecht et al. 2018). Besides distribution data, the value of Africa's biodiversity can be enhanced with better survey, monitoring, systematics, biogeography, ecology and conservation. Distribution models are necessary to identify hotspot areas for biodiversity conservation as well as to assess the impacts of climate change on indicator species and to assign a red list category (Soultan et al. 2019). Further, this may help capture the salient needs of the continent's biodiversity as enumerated in Huntley (1988), which includes the following:

- Biological classification system for Africa's biodiversity
- Assessment of the protected area range and cover for Africa's biodiversity
- Address gaps within native and non-native protected area networks
- Establishment of a recurrent survey and monitoring systems
- Maintaining an institutional support system with experts for Africa's biodiversity

After all, according to Chown (2010), spatio-temporal changes in biodiversity and institutional failure to address them hinders conservation efforts. van Breugel et al. (2015) expressed this as "finer-scale" biodiversity conservation decisions to stem the continuous biodiversity deterioration in Africa using taxa-level baseline data in ecoregions for a more transparent and informed translation of biodiversity conservation priorities.

1.3 Drivers of Biodiversity Loss in Africa

The proximate driver of biodiversity loss in Africa may be biological, but the ultimate cause is socio-ecological and economic processes (NRC 1992). The IUCN Red List status of (larger) animals, like lion (*Panthers leo*) and Rhinoceros (both black (*Diceros bicornis*) and white (*Ceratotherium simum*)) are attracting more attention than plants and landscapes. Background biodiversity extinction rates are high in a continent where very little is known about their biodiversity richness and distribution. The major reason for this biodiversity loss in Africa is not only direct human overexploitation but also a result of pollution, urbanization, habitat fragmentation, invasive species, human population growth, etc. (Ogwu 2019d, 2020; Ogwu et al. 2014; Osawaru and Ogwu 2014). No doubt human activities and processes are altering the ecosphere and defining aspects of biodiversity loss and recovery in some cases. The rate of biodiversity decline is exponential in this sixth extinction era, especially of genetically distinct population and in some cases beyond where they can retain environmental functionality (Ehrlich 1988). This is a pertinent environmental problem within the African continent and the African Union is yet to establish elaborate targets and tracking systems that are similar to those of the European Union's 2000, 2020, 2030 and 2050 NATURA, EUROPE 2020, Climate Target Plan, Green Deals, European Climate Foundation, etc. Just as in the European Union, these systems and projects would help to decarbonize the economy, cut emissions by up to 50 % and protect 30 % of land and sea areas in a bid to restore ecological integrity, effectively manage threatened species, move towards climate neutrality and provide substantial biodiversity and ecological investments for public-private partnerships (Wolf et al. 2021; Meles et al. 2020; Hermoso et al. 2019). Some member states of the Africa Union have taken the initiative to set targets and monitor threatened species within the continent. Despite being a low carbon emitter, Africa is experiencing significant disruptions tied to climate change, including biodiversity loss and environmental degradation. The decline in certain groups of biodiversity, like plants, is difficult to quantify because of their richness, large number of undiscovered taxa and absence of a standard template for risk assessment (Brummitt et al. 2015a, b). This is threatening approximately 22% of Africa's plant diversity. For such groups, extinction risk may be heightened if unchecked but may be stemmed by constant monitoring and application of the findings of Brummitt et al. (2015a, b), i.e. the application of IUCN Sampled Red List Index for robust monitoring and assessments and measuring performance in line with Goodhart's Law as a baseline for understanding current and future changes.

One way to view biodiversity loss is that of Hanski (2005), which is that there is no actual loss when there is a clear decline in species abundance. While that view incorporates losses due to natural fluctuation because there is no global indicator of spatial scale biodiversity loss, it does not hold for what is not observable and background losses. A transdisciplinary approach towards developing a better understanding of mechanisms of biodiversity loss and the impacts on the ecosystem and livelihood is the way forward. At the moment, the variety of approaches, methods, scales and hypotheses applied has led to a huge body of predictions that can rarely be easily applied (Bellard et al. 2012). An obvious effect of biodiversity loss is pathogen emergence, such as COVID-19, which has direct and indirect effects on the ecosystem and livelihood (Erinle et al. 2021; Schmeller et al. 2020; Hosseini et al. 2017). The connection with pathogen emergence is found in human modification of the environment that encourages the transmission of infectious diseases from animals to humans in the absence of the "diluting effects" of biodiversity through other susceptible hosts (Platto et al. 2021). Human drivers of biodiversity disease threat include habitat encroachment and destruction, human behaviour, biodiversity loss and human-assisted disease spread (Cunningham et al. 2017; Young et al. 2017). Among other things, this shows the interdependence of sustainability on each member of the human–biodiversity–culture link. Human well-being and health disruption of ecosystems are much more diverse, ill-understood and unstudied (Alves and Rosa 2007). Moreover, the findings of Stephens (2015) highlight the contributions of organismal research to the conservation effort, mitigation response and clear decline of the lion population in West and Central Africa.

Military and political conflict has been mentioned as an immediate cause of environmental degradation and indirect cause of biodiversity loss in Africa as well as poverty by NRC (1992). Others are trophy hunters, food and income insecurities, lack of policies, inefficient resource management and allocation systems, immigration and emigration as well as climate change. There is a need to rethink and refocus biodiversity priorities on the continent if current trends are to be halted. The unprecedented rate of ecosystem decimation through unsustainable agricultural intensification, watershed disruption, emission of greenhouse gases, deforestation for shifting cultivation and other practices should be halted. Chanyandura et al. (2021) recommended the following:

- Organized stakeholder and community participation
- Informed and planned species and environmental management approach
- Legal structures and enforcement that involve surveillance technologies
- Public awareness campaigns
- Good management of information repository

Also, a spatial scale approach that is large enough to encourage mega- and metapopulations to regain functionally relevant density might help stem biodiversity loss in the continent (Norris et al. 2020). In such a system-based approach, the sensitivity of variables that respond to biodiversity change and other abiotic and anthropogenic factors is considered invaluable indices with functional consequences (Norris 2012). To directly address biodiversity loss in Africa, the African Union may adopt an approach that recognizes remote responsibility and promote a shift in economic development towards activities with low biodiversity impacts (Marques et al. 2019).

1.4 Towards Sustainability in African Biodiversity Utilization and Conservation

Maximizing the potential and reducing the threat to Africa's biodiversity will require a consistent policy that is supported by qualitative and quantitative transdisciplinary research records. Research data sourced from a combination of techniques have often proven invaluable for biodiversity conservation and to evaluate specific sectors within the conservation and utilization system (Khan et al. 2013). The sustainability vision for Africa's biodiversity would be to maintain a valuable threshold of biodiversity to retain a constant supply of ecosystem services, functioning and processes as well as a healthy continent. This will require an increase in conservation efforts for endangered and threatened species, protection of existing ecosystem fragments like a disrupted watershed, and sustainable extraction of resources and tourism activities to retain environmental integrity (Locke et al. 2019). Monitoring of access to biodiversity and the environment may promote the culture of sustainable custodianship of the resources and foster human–biodiversity–culture links. Sustainable food production should also be targeted because the production of food to meet Africa's rising population might need agricultural intensification involving the conversion of natural ecosystems and use of pesticides, herbicides and fertilizers (Koch et al. 2019). According to Koch et al. (2019), a systems approach is needed to elucidate the different dimensions of a food production system and value chain in order to make it sustainable. Also required might be the careful study of the complex, multi-variables, non-linear and cross-scale interactions, and how these are changing through time (Liu et al. 2007).

The IUCN Red List of Ecosystems is a powerful tool that provides important insights on the ecosystem risk status and key assessment outcomes for accurate and consistent decision making that can affect biodiversity with the each natural system (Rodríguez et al. 2015). The document provides a baseline category that also applies to African ecosystems and includes collapsed, critically endangered, endangered, vulnerable, near threatened, least concern, data deficient and not evaluated categories. An ecosystem that has not been assessed as is the case for most of Africa is likely to be included in the data deficient or not evaluated category which may also affect sustainability efforts. In that case, it is impossible to attract much-needed attention and may continue to suffer from background collapse risks and decline in quality. The work of Rodríguez et al. (2015) listed a risk assessment process that could be adapted for biodiversity that includes describing the limiting units and their declining distribution status (Criterion A), risk rate from threatening processes (Criterion B), rate of degradation of non-biotic processes on which the biodiversity units depend (Criterion C), impacts of or relationship with other biodiversity units (Criterion D), Criterion E that is an adaptation to collapse, i.e. extinction rate in relation to minimum viable population and finally the synthesis of results from all assessment criteria (A–E) to ascertain and report the outcome (Criterion F) (Fig. 1.2). The output from this straightforward approach may be used to rank biodiversity into one of the nine IUCN Red List categories or even better, for establishing an adapted

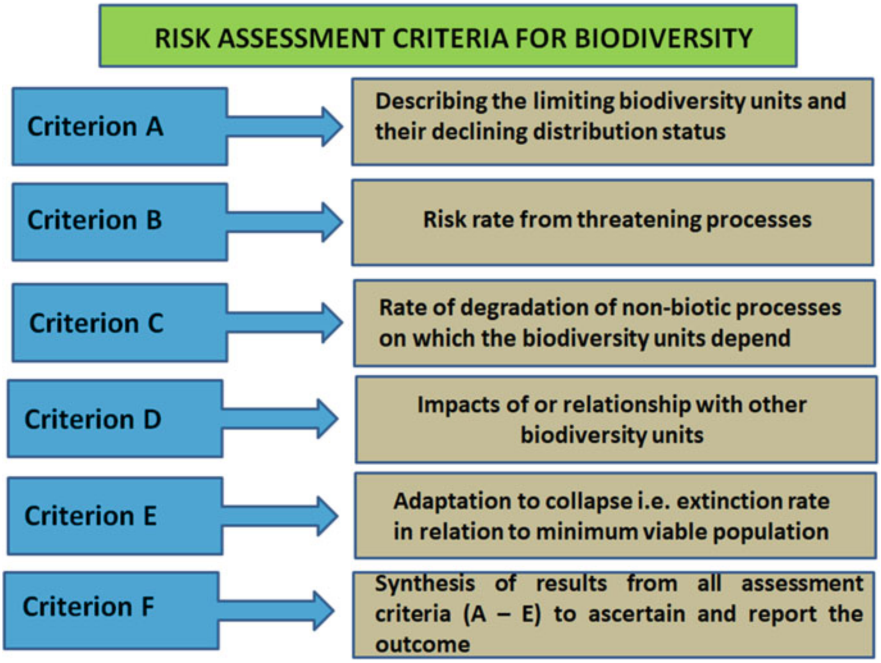

Fig. 1.2 Risk assessment processes for biodiversity

categorization that suits local needs. Moreover, these assessment criteria can impact biodiversity conservation from diverse dimensions, most importantly decision making, scientific knowledge, enhancing awareness among stakeholders and value chains, assigning priorities, funding and other resources, and legislation and policy formulation and implementation (Betts et al. 2020).

For the sustainable use and conservation of Africa's biodiversity, major interventions and a strategic approach are required to reduce risk, set evidence-based priorities to ensure limited resources are maximized (Scherer et al. 2020). Moreover, strong leadership will be necessary to nurture a sustainable coupled human–biodiversity–culture link by integrating biodiversity and environmental needs with social, economic and cultural growth into the governance system (Owethu and Buschke 2019). Data accessibility to ensure informed decision making on human natural resource management should be maintained on an open, simple and easily accessible platform or databases (Stephenson and Stengel 2020). The findings of Raatikainen et al. (2021) suggest that achieving sustainability requires incorporating diverse people's views, emphasizing the place value of nature in development and adopting a transdisciplinary approach. The sustainable management of African wetland and aquatic biodiversity would require management and efficient policies, monitoring, knowledge, restoration and funding (Xu et al. 2019).

Research studies are important to sustainability in biodiversity conservation and understanding evolutionary processes. This is also mentioned in the work of

Gristwood (2020) wherein among others it was stated that it contributes to understanding biodiversity distribution, phylogeny, diversity, taxonomy and categorization. In the light of the report of Bradshaw et al. (2021), which suggests that the science underlying the rapid loss of biodiversity is strong but is often weakened by large scale poor awareness, as well as a lack of appreciation of the enormity of the problem. These innate challenges can threaten sustainability efforts and need urgent actions to address and this can be done through educational programmes, media advertisements, town hall meetings and exhibitions. It is also important to reduce uncertainties and failures about biodiversity responses to conservation management while emphasizing effectiveness and biodiversity recovery (Nicol et al. 2019). Therefore, a multiscale effort aimed at informing the populace and a call for action will be needed as a first step. As Africa, strive towards more sustainable development, it would be pertinent to popularize the link between human–biodiversity–culture. This is necessary because human health and social economy are tied to biodiversity and the environment. It is documented in Novacek (2008) that engaging people in biodiversity issues provides the avenue to foster communal understanding and empowerment and action that is driven by reliable recommendation.

1.5 Conclusion

It is not always necessary to increase land use to maximize economic benefits from biological resources in Africa but vital to adopt environmental friendly approaches to safe guide the future of human–biodiversity–culture connection. Knowledge and practices are the supporting structure for future developmental directions of Africa's biological resources to meet desired potentials, threats and conservation needs of the continent. Moreover, the introduction, innovation and acceptance of contemporary techniques for biodiversity conservation are needed in Africa. A cross-sectional and multi-stakeholder stress and threat indicator and response system is necessary to manage Africa's biodiversity. The establishment of such a framework will accurately measure biodiversity status and predict changes associated with unsustainable developmental activities, guide policy and management decisions and set meaningful targets to prevent or reduce the threat to biodiversity while promoting conservation and sustainable utilization. Ideal biodiversity protection in Africa would require decision makers to incorporate population analysis to assess management efficiency and effectiveness as well as the perception of species and ecosystem threat (Di Minin et al. 2013). Africans have a unique relationship with biodiversity and their environment that can meaningfully contribute to conservation strategies. Behavioural perspective influences biodiversity conservation strategies and goals. This can also be relevant in stemming the transmission risk of disease vectors due to gaps in biodiversity by understanding the link between host behaviour and communal transmission (Herrera and Nunn 2019).

The entire environment of the African continent should be treated as a corridor for the protection and preservation of the continent's biodiversity heritage. The protected area network of Africa presents a usable template but should be expanded to increase the connectivity, size and biodiversity focus. Sampling biases continue to affect data on biodiversity distribution and status on the continent and can benefit from a robust approach and sampling area completeness that focuses on and address species (and other)-level difference. Sustainable utilization and conservation of Africa's biodiversity will need the participation of the populace and government encouragement to prevent conflict and to empower communities for sustainable livelihood. This may be considered a form of the ten human heritage-centred conservation tenets presented in Montgomery et al. (2020). Such a traditional approach to biodiversity conservation has been a part of Africa since time immemorial. However, it is important to increase investment in Africa's biodiversity.

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Part II
Values of Biodiversity

Chapter 2
Industrial Applications of Biodiversity Potentials in Africa

Oluwafemi Emmanuel Ogundahunsi, G. E. Akpan, T. A. Ayorinde, O. P. Babafemi, and A. A. Ayodele

Abstract Biodiversity is fundamental to development, for improving food security, conservation, industrialization, and ecosystem services in Africa. Biodiversity's contributions to development are usually effective and reliable by the existence and conservation of a range of different species and genetically diverse populations within species. Africa's potential biodiversity and ecosystem service are huge, combined with the vast indigenous and local knowledge is sufficient to sustainably develop the region. The food, water, energy, health, and secure livelihood needs available in the rural areas directly satisfy the needs of over 62% of the population. Bioprospecting refers to the industrial exploration and application of these biodiversity potentials for social and economic value. Research shows that low percent of species provide basic resources for societal development when compared with the entire species available in Africa. Therefore, there is a need for the application of modern technologies for the industrial exploration of unidentified and enormous species for the benefit of humanity. In this chapter, the declination of biodiversity in Africa concerning Sustainable Development Goals (SDGs) will be discussed. Also, the biodiversity potentials and its industrial exploration and application will be

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expounded. And the benefits of industrial application of biodiversity potentials in Africa will be captured in this chapter.

Keywords Biodiversity · Bioprospecting · Biomimetic · Biomonitoring · Bioremediation · Ecotourism · Sustainable Development Goal · Industrial integration

2.1 Introduction

Biodiversity involves various species of living organism which includes plants, animals, and microbes with diverse genetic formation in an ecosystem (Rawat and Agarwal 2015). Africa is greatly populated with vast biodiversity of living organisms which consist of about one-fourth of the world's biodiversity. This helps the earth's major collections of animals that are located in Africa (UNEP-WCMC 2016).

It was assumed that widespread of non-conventional species was used by Africans as they have quite ecological knowledge which aid the sustenance and conservation of the ecosystem (Myers 1983; Malaisse 1997). This trending assumption of overexploitation of all bioresources in Africa has been faulted by a recent research showing that the entire group of organisms only entails an insignificant part of the whole species in Africa leaving a vast number of other groups of species, e.g., microbes and invertebrates.

There are a wide range of importance of the exploration of biodiversity for the production of new products in the industries in meeting diverse human needs such as foods, medicines, cosmetics, fibers, and construction materials (Wilson 1992; Torsvik et al. 2002; Crawford and Crawford 1998; Eisner 2003). Scientific and innovative advantages in the utilization of African's biodiversity increase the biological solutions proffered to general human problems and allowed people to acquire knowledge from evolutionary configurations existing through diverse species (Rolf et al. 2018).

This chapter therefore explores the biodiversity declination in Africa with respect to SDGs. It also studied the biodiversity potentials and its industrial applications and the benefits of the industrial application in Africa.

2.2 Declination of Biodiversity in Africa with Respect to Sustainable Development Goals

The continuous declination of biodiversity due to human and industrial activities together with population increase has affected different aspects of life resulting in the extinction of different species of plants and animals in the ecosystem, climatic change crisis, food scarcity, and other related challenges (Mader and Scheyvens 2020). Biodiversity is relevant in achieving several SDGs but any threat to biodiversity directly affects the realization of those goals. The 2030 agenda of the 15th

Sustainable Development Goal aimed at "protecting, restoring, and promoting sustainable utilization of terrestrial ecosystems, address desertification, terminate and reverse land dilapidation, and terminate biodiversity loss (FAO 2020).

Biodiversity was extensively discussed at the Sustainable Development World Summit which was held in Johannesburg in 2002. The conclusion of the Summit which was also adopted by the United Nations Convention on Biological Diversity aimed at achieving a substantial reduction in the degree of biodiversity declination across all levels to reduce poverty and to care for the well-being of humanity and the ecosystem in general (United Nations 2015). The conclusion emphasizes that biodiversity is essential for sustainable development and the necessity for an organized policy that addresses biodiversity declination.

2.2.1 Biodiversity and Sustainable Development Goals

The SDGs numbers 2, 4, 5, 7, 9, 11, 12, 14, 15, and 16 protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Goal numbers 4, 6, 7, 13, and 18 focused on addressing issues on food security, improved nutrition, and promoting sustainable agriculture (United Nations 2015). Goals 8, 11, 14, and 15 are targeted towards ensuring the availability and sustainable management of water and sanitation. Goals 2, 4, 6, 7, 14, and 16 promote sustained, inclusive, and sustainable economic growth, and full and productive employment. Goal numbers 2, 6, 7, and 14 deal with poverty alleviation. Goals 8, 13, 14, 16, and 18 are aimed at ensuring healthy lives and promoting well-being. Goals 1, 4, 6, 7, 8, and 19 ensure sustainable consumption and production patterns. Goals 2, 5, 10, 14, 15, and 17 take urgent action to combat climate change and its impacts. Goals 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 15, 17, and 19 conserve and sustainably use the oceans, seas, and marine resources for sustainable development (Obrecht et al. 2021). The SDG numbers 14 and 15, respectively, focused on life below water and life on the land surface but beyond that, biodiversity and a safe environment provide vital resources and ecosystem services that support different societal and economic activities, such as agriculture, forestry, fisheries, and tourism.

The 17 SDGs aimed at addressing the essentials of the ecosystem (United Nations 2015). The effective operation of the ecosystem is crucial for the entire well-being and resilience of humans (United Nations 2015; Naeem et al. 2016). Achieving the aim of Sustainable development goals (SDGs), the bedrock of the entire ecosystems which includes the quality of life (for a plant, human, and animal), economy, and the environments will be carter for. SDG pyramid shown in Fig. 2.1 reveals that biosphere is the bedrock of economies and societies. It is also the basis of all SDGs. Such an idea uses a combined view of social, economic, and ecological growth.

Population increase and climatic change which led to a high consumption rate instigated our community to demand and depend on natural resources than before

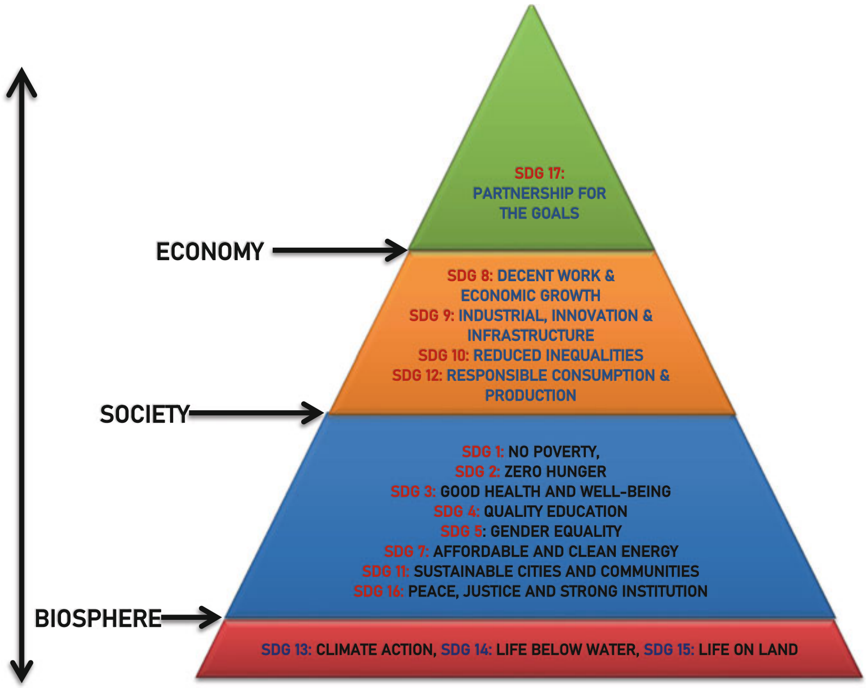

Fig. 2.1 The SDG pyramid. Adopted from: Obrecht et al. (2021) and United Nations (2019)

causing overexploitation and increasing dependency on biodiversity which resulted in the present global biodiversity degradation. The extinction rate of biospecies and declination of the ecosystem services are quite alarming. Most especially, the supporting and regulating services which include climatic change regulation, disease, and pest control, and hygienic water supply (Díaz et al. 2019; IPBES 2019).

2.2.2 *Effect of Biodiversity on Sustainable Development Goals Interactions*

The effective synergy of SDGs goals and their actualization can sustain the economy, benefit society, and ecology. Different research on the SDGs interactions shows that the actualization or deactualization of some precise goals has a supportive or destructive effect on the progress of other SDGs (Baer et al. 2017). These results buttress the point that the policies needed to accomplish the goals need the understanding of synergistic interactions between the goals (OECD 2019; Balmford et al. 2005).

Based on the co-benefits of SDGs, goal numbers 14 and 15 which focus on biodiversity are more essential in accomplishing progressive sustainability. Pham-

Truffert et al. (2020) showed in an investigation that the co-benefits of the biodiversity-oriented goal numbers 14 and 15 result in the actualization of several other SDGs and also protect negative interaction. With this, the implementation of SDGs 14 and 15 reinforces several synergistic interactions across the 2030 Sustainable Development Agenda but entails an insignificant risk of conflictual interaction. On the contrary, the actualization of SDGs that focuses only on the economic or social dimension and neglects the ecological dimension of sustainable development has a high tendency of leading to the declination of human life (Díaz et al. 2019). Also, there is possible collateral damage if SDGs are implemented without considering the negative effect on natural resources (in goals 6, 12, 14, and 15) (Pham-Truffert et al. 2020). Considering the existing data, the conflictual interactions between the aims of biodiversity and SDGs are majorly associated with the supply and removal of natural materials, like food and water (Díaz et al. 2019).

2.2.3 Measures-Taking Importance for Accomplishing the Focused Biodiversity of SDGs 14 and 15

SDG 14 The biodiversity richness, particularly in the seas, is affected negatively by changes in climate, overexploitation, pollution, and ocean acidification. To conserve and restore resources of marine and ecosystems, action is needed. An important safeguard against environmental changes that leads to negative effects, such as acidification of the ocean, is healthy biodiversity in terms of abundance and numbers of species (Rastelli et al. 2020). Global fisheries are estimated for over 800 million people to provide livelihoods, enable income provided to 60 million individuals, and are a 6.8% protein source consumed by people. Globally, 87.5% are via marine sources (FAO 2020). Furthermore, the environment of marine is a largely untapped genetic resources reservoir with opportunities for biotechnology and business (Arrieta et al. 2010). Thus, long-period smart investments in social stability and prosperity of the economy are an effort to manage marine biodiversity sustainably and preserve conservation for areas of coast and marine.

SDG 15 Sustainable forests management and afforestation are essential keys in restoring biodiversity and promoting ecosystems sustainable usage (freshwater and terrestrial), sustainable forests management, fight desertification, halt the degradation of land, and loss of biodiversity (Díaz et al. 2019). Systematic approaches are required to resolve biodiversity driver loss, to integrate biodiversity values and ecosystems into decision making that is national and local, and to widespread biodiversity into other areas. This highlights the particular ecosystem’s merits, including wetlands, mountains, and forests (CBD 2018). Most ecosystems require restoration and protection (IPBES 2019). The framework of post-2020 global biodiversity is expected to aim to conserve and protect at least by 2030, planet (30%), with the target areas important for biodiversity (Díaz et al. 2020). By 2030, the challenge of Bonn focuses on bringing hectares of 350 million degraded and deforested lands into restoration (Bonn 2020). Nature-based solutions and sustainable management should be at the front position of actions to resolve processes such as degradation of land and desertification. When the benefit with the other SDGs has been attained, there will be long-lasting, efficient, more reliable, and most effective solutions.

2.3 Potentials of Biodiversity in Africa

Agriculture has increased food production significantly in recent decades, but this has been accompanied by loss of biodiversity, considerable misuse of natural resources and inputs that are non-renewable, and ecosystems degradation, particularly in functions that support and regulate Africa. While long-distance transportation and industrial agriculture that is high input have boosted the refined edible oils and carbohydrates affordability and availability, it has also resulted in a diet's simplicity and reliance on a small number of energy-dense foods. Obesity and non-communicable disease (Popkin 2002) are on the rise, and in coexistence, they are seen with undernourishment or malnutrition in the same community or family. Reliance on fewer crops can lead to the depletion of plant genetic resources as well as an increased danger of widespread illness whenever a variety becomes vulnerable to the different diseases of plant, resulting into food shortage. Genetic degradation appears to occur more in grains, accompanied by vegetables, nuts and fruits, and legumes of food, according to a review of 104 country data (FAO 2010).

If we are to accomplish the stated objectives of better productivity, livelihood and equity, environmental sustainability, and nutrition and health over the next 30 years, considerable modifications in agricultural production systems will be required. Systems will need to become more adaptable, multipurpose, and option-rich to provide different services while also dealing with change and uncertainty. As climate changes, negative effects worsen and external resources that are non-renewable become scarcer, resilience, and adaptability will become increasingly critical. The use of chemical fertilizer and reduced water will be required to achieve gains in production, therefore, essentially increases in productivity. To do so, manufacturing systems will need to rely more on processes (ecological) that provide positive feedback on production and sustainability. Agricultural system adaptation also is necessary to increase the security of food by guaranteeing consistent production of nutritionally diverse crops that contribute to equity and human well-being, particularly in Africa's disadvantaged rural areas.

Agricultural systems that rely on processes (biological) and natural agroecosystem features to offer provision, regulation, support, and cultural services can be found all over the world. Most conventional production systems possess these qualities. They are typically (simplistically) linked to low production, inefficient farming techniques, and practices that cannot keep up with current demands. They are, however, a feature of a variety of distinct novel agricultural production systems that aim to higher revenue of farmers with long-term sustainability and balance productivity. Integrated management of pest, conservation, and eco-agriculture are all examples of often successful attempts to achieve productivity comparable to that of intensive agriculture that is conventional by maximizing the efficiency of agroecosystems' inherent biological functions rather than by applying external inputs unconstrained. Over the last few decades, a rising number of agricultural production models have arisen that focus on combinations of plants, animals, soil organisms, and communities rather than on a single species at a time. In the management of various components of agroecosystems, greater integration entails plants, soil, water, and nutrients management changes in such a way that there are interactions between these various components, via accountability, such as diversity of soil organisms and its abundance use, to achieve greater efficiency of production and higher yields via effects of synergy among these resources. Animals are additional resources that must be managed in a complimentary manner when they are part of the farming system. Rather than focusing all efforts on a single aim, such as profitability or yield, such ecologically oriented production methods expressly embrace several purposes (Altieri 1987).

The ability to build a wide and sound ecosystem, the framework that is integrated based on the diversity maintenance in the system of production, including the diversity component of humans, will be critical to the widespread acceptance of ecological approaches (biocultural diversity). Flexible solutions that boost productivity at the level of the ecosystem will be the focus of such a framework rather than efficiencies within isolated systems of production or single commodities. Some of the decades-old ways of thinking about production will have to shift. Ecosystem and landscape productivity will be more significant than production per hectare of certain crops. In addition to the volume of extractable goods, the system's functionality in terms of supporting and regulating services must be examined. Crop, livestock, fish, and agroforestry production will all need to be considered, which will necessitate integrated approaches. New conceptions will be required, for example, to appropriately depict how a regional food system may meet overall nutritional and food needs while also supporting the well-being and health of humans in more volatile weather situations.

Previously, efforts to increase productivity and yields were made within a framework, with the target to control conditions and ensure uniformity in the environments of production through less or more unrestricted input use, rather than leveraging on and utilizing, the highly complex, diversified, and sometimes limiting conditions of farming that exist in different parts of the world. As a result, a small number of crops, breeds, and management approaches that are well-suited to high-input farming have been developed and promoted. It has also resulted in the emergence of a wider range of systems, organisms, genes that yield better performance of productivity, environmental sustainability, and economic viability in the farming environments majority, particularly in impoverished countries such as Africa.

2.3.1 Scales, Linkages, and Connections

To present, management of diversity has tended to look into small-scale, localized treatments for single animals or crops, or specialized components such as improved management of soil or pollinator availability. Agricultural biodiversity interventions, on the other hand, must consider a variety of components holistically: animals and plants' inter- and intraspecific diversity, interactions that are ecological between species cultivated and wild, below-ground, above-ground diversity that is aquatic, and the yielding services of the ecosystem should not be viewed as stand-alone components, but as players that are interacting in processes that sustain production of long term, ultimately. Taking use of dynamics of diversity allows systems of agriculture to attain a high level of production and profitability while using fewer or no external, costly, and increasingly limited inputs. A wider complementarity set, including biodiversity maintenance and use for agriculture and food, emerges when one shifts to this more understanding of the efficiency ideas of an ecosystem, holistically. This method of thinking about productivity and production is easily linked to issues like dietary health and nutritional diversity, as well as the recognition that the health of an ecosystem and that of humans are intertwined with larger biological diversity concerns. Food systems, which are oriented ecologically, enable the production of food that is safe with a decreased risk of contamination from chemical residue and a lower input fossil fuel per food unit. A broader variety of nutrients are available in human diets as a result of higher diversity in food crops. Closer connections between producer and consumer are common in sustainable food systems, which means more direct foods marketing to local consumers (through farms supported by the community, markets of farmers, cooperatives of farmers, and other means), low energy for food transportation, and more opportunities income for small-scale communities of farming.

Systems of agriculture that employ biodiversity and rely more heavily on biological processes to accomplish goals of sustainability and productivity should place a higher emphasis on the agro-interconnections ecosystems and connections. Production systems should be managed at scales big enough to incorporate elements that are natural and cultivated, taking into consideration the services they give to agriculture and their interactions, even in distant fields, because ecosystems provide services to humans at different scales (Sherr and McNeely 2008). Decisions of land-use management, which are local processes and currently concentrated on a few "key-stone" species, will need to encompass a broader variety of ecological processes to preserve structurally complex and dynamic agroecosystems. Diversity maintenance, which underpins the capacity of a system for transformation or resilience while compensating for high-intensity management and acting as a buffer against the risk of economic and environment, is the most common way to achieve the necessary structural and functional complexity (Naeem et al. 2016).

A more biologically based agriculture will require the ability to work across scales. Biodiversity-based alternatives differ by biome, soil, and climate, as well as the agro-nature ecosystems and rural populations' behaviors and traditions. To develop meaningful problem-solving approaches, it will be necessary to include local knowledge and practices, as well as to foster approaches that are more grass-roots that draw on experiences and institutions of a local community, as well as ecological aspects. These should be included in a framework that considers both dimensions of landscape and national requirements and concerns. Small-scale farmers who need to optimize the few resources available to them and who lack access to external inputs due to financial or infrastructural constraints are typically said to benefit most from the sustainable use of agricultural biodiversity. While farmers of small scale can benefit significantly from improving agricultural biodiversity, large-scale farmers' negative impacts (clearing of land, run-off of pesticides, and the push toward monocultures) are much greater. Large-scale benefits can be achieved by concentrating on changes that are relevant to large commercial farmers; conservation agriculture has already proven to be effective in this regard.

2.3.2 Overcoming Skepticism in Biodiversity Utilization in Agriculture

Inevitably, there is skepticism about the feasibility of widespread adoption of agricultural production systems that incorporate a larger use of biodiversity for food and agriculture, as well as a greater focus on ecosystem function. People's thinking is constrained by two basic geopolitical facts. To begin with, modern farming in industrialized countries is heavily subsidized, and all aspects of the agricultural and food industries are, to some extent, entangled in this highly subsidized system. Second, there is an ongoing commitment to keep food prices low and make essential consumables affordable to all segments of society, particularly the poorest. Both of these factors contribute to a lack of interest in agricultural production systems and act as a significant impediment to the development of new production methods, no matter how vital they may be. The adoption of ecological agricultural practices has been criticized as reflecting a romantic and backward-looking mindset.

Other concerns include the fact that large-scale implementation is economically impossible and will necessitate even higher subsidies, as well as the fact that the required production level for a rising global population cannot be met. It has also been said that the strategy is labor and weighty knowledge, as well as difficult to administer and understand for both farmers and consumers. Agriculture's continued development based on lower inputs will necessitate the creation of new ways and innovation as customers have control over their consumption and more access to information, they demonstrate significant discriminatory power in regard to foods containing GMOs, Fairtrade products, and organically produced foods, for example. While using diversity requires a large amount of knowledge, high-quality farming systems all over the world have the capacity and skills to optimally maintain and utilize biodiversity. More study will be required, with an emphasis on solving production difficulties in biodiversity-rich systems in labor-saving methods rather than a production systems simplification and yields per key crops of cereal hectare that is ever increasing.

Finally, most analyses that are of cost-benefit, comparing systems of high-input to sustainable systems of agriculture, tend not to account for the broader societal benefits range those systems of agriculture can provide, because these are externalities and are not pinpointed into the prices paid by consumers or producers, which are often lower for high-input system products. Excluding negative and positive externalities from prices influence the market by improving activities that are expensive to society but have appreciable private advantages, such as systems of agriculture based on a limited productivity, and yield short-term understanding. It prevents other systems development that might provide considerable societal benefits (e.g., reduced spending on the restoration of the landscape, water sanitation, health care, etc.) but do not utilize private gains, maximally. Low grocery store prices create the impression that our food is inexpensive, but they do not account for the cost of removing farm pollutants, for example, or the cost of massive government subsidies to agriculture. Consumers, particularly in industrialized countries, are embracing sustainability increasingly and are willing to pay extra for the production of food by farming systems that are ecologically oriented.

2.4 Industrial Applications of Biodiversity Potentials in Africa

Industrial exploration and application of underutilized species for the development of new products were documented at the 1990 meeting of the International Society of Chemical Ecology in Goteborg, Sweden, in the Gote-borg Resolution (Eisner and Meinwald 1990).

Bioprospecting incorporates the usage of a wide collection of species by a wide variety of industries (Ten Kate and Laird 1999; Beattie and Ehrlich 2004). The resource potential gains in species stressed to date have different natures.

Modern discoveries are usually realized through areas of applications of the needed product where some organisms are identified, explored, and applied. For an instant, the negative effect of heat on enzymes triggered research on the exploration of heat-tolerant industrial enzymes, which enhances industrial processes and the development of better products (Moss et al. 2003).

2.4.1 Pharmacological Bioprospecting

Recently, the need for modern innovative products from biological diversity varies with abatement in pharmacological bioprospecting by huge associations,

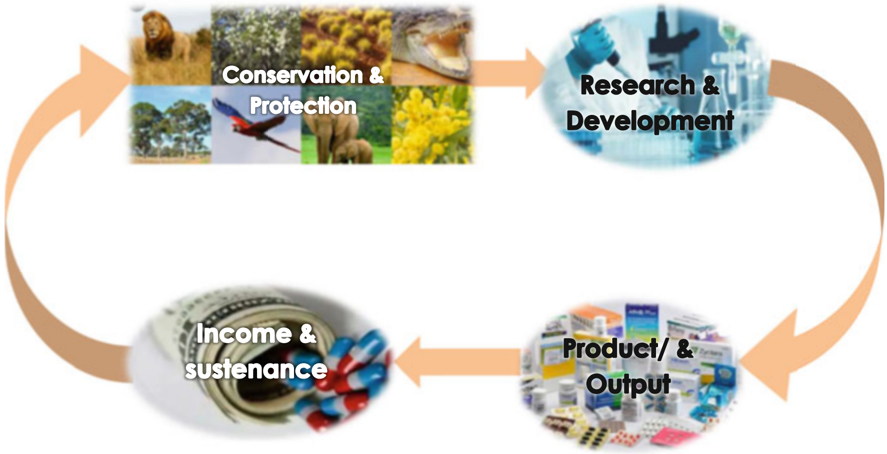

Fig. 2.2 Pharmacological bioprospecting cycle

notwithstanding the way that resurgence is typical (Chapman 2004). Although some major drugs like aspirin, quinine, chloroquine, mefloquine, doxycycline, and artemisinin were obtained from biodiversity (i.e., from tissues of different species), industries devoted a great time for the exploration of an ecosystem to investigate economically profitable drugs (Jack 1997; Bailey 2001).

The high rate of antibiotic resistance in humans has also stirred in-depth research in pharmacological bioprospecting which resulted in new drug discoveries (Wessjohann 2000; McGeer and Low 2003; Newman et al. 2003).

Henkel et al. (1999) documented a wide-ranging organism from which new drugs have been obtained. Some of these organisms are bacteria and fungi in both terrestrial and aquatic plants, algae, and different invertebrates which include insects, worms, and mollusks. Munro et al. (1999) investigated the usefulness of diverse organisms for the production of anti-cancer drugs. Ortholand and Ganesan (2004) and Chapman (2004) believe that pharmacological bioprospecting researches are will further lead to discoveries.

Figure 2.2 shows the pharmacological bioprospecting cycle indicating how the use and research in conserved biodiversity can bring about novel pharmacological product leading to improved economy in the country which can be channeled towards further financing the conservation of biodiversity.

2.4.2 *Cosmetics Industries*

Cosmetics industries use the diversity of biological raw materials from plants and various organisms for the production of cosmetics, hair products, baby care, deodorants, skincare, and fragrances. These types of cosmetic products are usually licensed and labeled as organic products. The use of biological resources in cosmetics industries is gaining more attention as it proves to be more effective and has higher economic value than cosmetics from other sources (Crawford and Crawford 1998).

2.4.3 Biomonitoring

Biomonitoring is an industrially developed response needed to reduce sources of pollution in the ecosystem. This involves the use of macro and microorganisms to regularly examine the environment. Examples of these are aquatic biodiversity of filter-feeding organism, in which its collection for laboratory tests does not affect its population (Boyle 1987; Rosenberg and Resh 1993). Biomonitoring can as well be applied for detecting soil pollutants using diverse test organisms such as bacteria, algae, and earthworms (Rosenberg and Resh 1993).

2.4.4 Biomimetics

This involves extensive biodiversity-inspired technology using different species of organisms as the model for novel manufactured products (Mann et al. 1989). The modern high-tech ceramics used for manufacturing automobile parts and industrial crystals are produced from shells and teeth of different species of mollusks. Recently, a novel high tensile fiber was produced by applying the characteristics of spider silk (Mann 2001; Craig 2003).

The application of biomimetics in different fields, such as engineering and technology, manufacturing, and construction industries, generates huge revenue for the industries (Beattie and Ehrlich 2004).

2.4.5 Bioremediation

This is a recently developed industrial application of biodiversity potentials. It is majorly used in the treatment and restoration of the environment in which mining and heavy industrial activities have been carried out (Crawford and Crawford 1998). Bioremediation can be achieved either through the alteration of the environment to permit the proliferation of benefiting organisms or through the expansion of the environment by adding newer benefiting microbes. These approaches utilize diverse microorganisms as pollutant-tolerant species and as metabolizing organisms that reduce their destructiveness and appropriate them into the environment. An example of this is the increase in the application of microbes in remediating oil spills which has shown a promising result (Mueller et al. 1992). Another example is the use of bioremediating fungi (known as white rot fungi) which gives a bleached appearance to dark-colored wood. Demain (2000) reviewed the industrial applications of biodiversity potential of microbial and novel technology known as bioaugmentation was discovered which involves the addition of microbes to polluted soil for its remediation.

2.5 Benefits of Industrial Application of Biodiversity Potentials in Africa

There is a large and varied variety of industrial applications that use biologically based techniques to improve system productivity in sustainable ways. These mainly entail bettering biodiversity's use for agriculture and food by combining variety (intra- and interspecific) in ways that boost the function of the ecosystem, resilience, and production. They typically result in higher farmer returns, improved ecosystem services, and, in some cases, increased higher-quality products production. They demonstrate the potential advantage of biodiversity of agriculture and highlight areas where further improvements could be made. A current study in several of these areas has already shown that more potential sustainable production increases can help with food security and climate change adaptation.

Agricultural biodiversity has many structural, compositional, and functional components, including (a) agriculture and food genetic resources; (b) biodiversity components that encourage services of ecosystem on which agriculture is based; (c) socioeconomic and cultural dimensions; and (d) abiotic factors. In this section, we will go over a few of the advantages of using Africa's biodiversity potentials for agriculture and food to boost the production of agriculture. The goal is not to provide a list that is exhaustive of all the benefits of using biodiversity potentials in the industry to achieve desired security of food and agricultural production goals, but rather to give instance on the possibilities, factor some of the existing approaches, provide a foundation for further exploration, and identify likely benefits research areas.

The information and innovations that may be drawn on for models of sustainable agriculture are built on tight collaboration among researchers, services of extension, farmers, and NGOs. Farmers found issues or limits while integrating modern methods of agriculture that are of high input, to their specific ecological and socioeconomic environments, prompting the development of these practices. Variations in soil type, terrain geography, holding size, labor, cash or other constraints, pest and disease concerns, market failures, and other factors all influence the inventions.

They are more strategies, which are adaptive, and that are inductively formulated frequently, and they are effective option to the introduction of validated solutions on a small or few near-ideal conditions operating locations, as in the case with much of today's research-oriented invention in agriculture.

In practice, the systems of livestock and crop that are frequently the focus of improvement on agriculture are elements of a greater landscape which entails diverse feral, weedy, and wild species which perform critical roles in ecosystem function and in the food production. Pollinator species, crop wild relatives, and soil biota are examples of wild species that are required for agriculture. Wildlife in the form of bush meat-eating animals, species of wild fruit, and other species found in and around fields of agriculture can all contribute to feeding the population in different areas. Wild species, either as pests and illnesses or as resource competitors, can have a severe effect on production.

Many traditional livestock farmers use multi-breed flocks and herds, and multi-species to preserve high diversity in niches that are on farm site and to guide against economic and climatic challenges (Hoffmann 2003; FAO 2009). Breeds with different species contribute to ecosystem in different ways, such as providing food, fiber, cash income, transportation, draught power, and fertilizer.

In general, the more complicated diverse systems of livelihood are, the more adaptability and resilience required for diverse animal genetic to execute the required ecosystem activities. A variety of adaptation techniques, both behavioral and physiological, can be used to further improve tolerance to abiotic stress (Hall 2004). Bedouin goats, for example, can graze without needing protection because they have a better ability to regulate their body temperature, but other northern breeds lose hunger and bodyweight if the shade is not being given (Mualem et al. 1990).

In aquatic environments, combinations of species boost productivity and output. Small indigenous fish species, such as Amblypharyngodon mola with commercial carp species, can be integrated into polyculture systems to boost fish pond production (Roos et al. 2007).

Furthermore, since those little species fetch high price (Ahmed 2009; Saha 2003), they represent an additional revenue for rural people. Self-recruiting organisms also contribute greatly to the generation of resources of aquatic. In Cambodia and Thailand, for example, three species of fish that are self-recruiting (*Channa striata*, *Clarias batrachus*, and *Anabas testudineus*) accounted for total household capture by weight of more than 40%, (Amilhat 2006). Diversification of fish species and breeds improves resource efficiency and decreases waste in aquaculture.

As a result, in China, four different varieties of carp are regularly maintained in a pond: silver carp filters phytoplankton, grass carp eats microorganisms that live on plants, the well-known omnivorous carp is a bottom feeder, and carp filters bighead, zooplankton (Naylor et al. 2000). The preservation practices of useful wild species, which contribute to ecological processes, such as control of pest, pollination, and enrichment of soil are all benefits of maintaining vegetation that is wild patches in the landscape of farming (Vandermeer et al. 2002). Traditional systems of coffee and cocoa (raised as polycultures with understory and overstory plants) provide adequate habitat for migratory and residing forest birds, which decrease pest insect populations (Robbins et al. 1993). 190 plant species were found on pastures of dairy farms in Costa Rica Montverde area with over 90% of them identified to offer food for animals in the forest. Several other species were useful to people as timber sources (37%), firewood (36%), and fence posts in their local areas (20%).

Good pollinator management strategies can be found on a range of scales, including field, farm, and landscape. Pollinator friendly activities in the field include organic farming, integrated control of pests, set-aside areas, application techniques of sound, and finding another option to agrochemicals. A decrease in herbicides and pesticides used, in some portions of the field, has been shown to assist pollinators in crop fields. Pollination services can be influenced by how farmers organize diverse land uses across their property. Pollinator populations can be boosted by preserving a variety of patterns of cropping on farms, such as mixed cropping combination with cover crops, kitchen gardens, and systems of agroforest, as well as providing bee habitat. At the level of landscape, natural vegetation areas adjacent to farmland are advantageous to crop productivity because they supply floral resources and nesting locations for pollinators.

Preserving crops variety is another well-known aspect of excellent agronomic practice. Crop rotation, intercropping, and cultivating many kinds of a crop were discovered to improve crop yield, nutrient accessibility, pest and disease control, and water management. The influence of regimes based on combining multiple species occupying distinct niches in time and space has been studied in agroecological studies.

Multi-cropping, intercropping, alley farming, rotation, and cover crops are all examples of crop species combinations that improve productivity and yield stability. Other ecosystem benefits of species-rich communities include better water retention at the top soil (Caldeira et al. 2001), better diversity among related species (with pest controlling organisms at the top or beneath the soil surface), and better resource use productivity than communities with fewer species (Loreau et al. 2002).

Sustainable intensification measures regarding precise pairings of species and functional groups, occupying a specific niche delivers certain services, such as nitrogen fertilizer, can enhance this inherent efficiency in resource usage. Crop-rotational practice of cereal and legume was used in an unsuitable environment, like West Africa's dry savannah. It was also used for maize and promiscuous soybean where nitrogen was introduced to destroy many striga hermonthica seeds present in soil. The crop rotation of millet and dual-purpose cowpea permit effective nitrogen supply and uptake without any external supplies. Diverse intraspecies can have direct benefit on cropping systems. Local farmers frequently use genetically heterogeneous traditional varieties to aid recovery from hazardous weather like flooding, droughts, and storms, as well as managing unique added strains, like climate change (PAR 2010) or civil strife (Richards and Ruivenkamp 1997). Landraces have a reduced probability of crop failure under stress than modern types; for example, barley landraces yielded between 25% and 61% more under stress than non-landraces (Ceccarelli 1996). As a result, farmers see landraces and intraspecific variation as an extra tool for assuring stability and productivity in the face of changing weather patterns. Many modern varietal combinations of crops can outperform their monocultures in terms of production: wheat mixtures, for example, have shown to have a yield advantage of 19% over monocultures (Burdon and Jarosz 1990). While scientific data exist for the benefits of spatial and temporal mixes of a wide range of crop species (both in terms of production and disease prevention), evidence from large-scale testing is scarce (Li et al. 2009).

Some benefits of biodiversity and multi-species approaches are as follows:

2.5.1 Improved Soil Fertility

On a landscape scale, the role of soil biodiversity in biochemical and nutrient flow processes is becoming more widely recognized. Plant roots, organic matter, micro- and macrofaunal variety, and soil food webs are extraordinarily complex and ramified. Complex biological interactions and processes with organisms (above ground) are a part of below-ground communities. Management strategies like combinations of crop, tillage, pesticide and fertilizer application, and inputs of organic matter, have a significant impact on the number of species in these communities and their functions. Soil biodiversity is nurtured with considerable care in all management strategies that involve complex, ecologically oriented methodologies. They gain from beneficial cascading effects on the overall system's efficiency and production.

Organic farming is based on the philosophy of "feeding the soil, not the crop." Plant residue decomposition supplies nutrients to soil flora and fauna, which increases the availability of nutrients to plants via solubilization, mineralization, physical transfer (in the case of siderophores and mycorrhizal fungi), and other processes. Mäder et al. (2002) found a 40% increase in biomass and symbioses of mycorrhizal in organically farmed soils, a 130–320% increase in microbial and earthworm decomposition, and a 200% increase in biodiversity and arthropod abundance.

Although organic farming resulted in a 20% fall in production, it also resulted in 30–54% reductions in nutrient inputs and a 97% reduction in pesticide use. Nutrient-use efficiency, phosphorus cycling, soil fertility, and aggregate stability are all improved 10–60% in organic plots. Organic crops respond better to stressful situations than those managed with large inputs. Organic soybeans in the United States yielded 2 t/ha in 1999, despite one of the worst droughts on record, compared to only 1.07 t/ha for conventionally cultivated soybeans (Rodale Institute 1999). Many African countries are adopting the System of Rice Intensification (SRI) because, when compared to standard rice management (SRM), it regularly achieves gains in output while reducing seeds input, agrochemicals, water, labor, and energy. SRI employs management practices of water and crop that promote an anaerobic environment of soil, tillering, root growth, soil biodiversity, and more efficient biological activity of plants and soil, resulting in a greater impact of all nitrogen application levels on yields in SRI fields than in fields of SRM (Li et al. 2009). In 2000, SRI was first introduced in India, and it is now used by 600,000 farmers on approximately one million hectares. In eight countries (Cambodia, Bangladesh, India, Indonesia, Sri Lanka, Nepal, Vietnam, and China), the average increase in income with SRI was roughly 68%, with yield increases of 17–105% and reductions in water requirements of 24–50% (Africare 2010).

Conservation agriculture strives to maximize the soil biodiversity functions by maintaining year-round organic cover, minimizing disturbance of soil and using diversified rotations of crops that include nitrogen-fixing legumes. Rotations help sustain biodiversity above and below ground, provide nitrogen to the soil/plant system, and prevent insect populations from accumulating (Kassam et al. 2009). Conservation agriculture presently covers an estimated 117 million hectares of arable and permanent crops around the world. Rainfed rice yields of 8–9 tons per hectare, substantially above irrigated yields, have been reached in Brazil within 4–5 years of utilizing conservation agricultural practices; maize and soybean yields have grown by around 50% at half the cost of production (Machado and Silva 2001). Even tiny farmers in Paraguay have been able to cultivate crops that were previously deemed to be unsuitable for no-till systems, such as cassava. Planting cassava as part of a conservation agriculture system with cover crops has resulted in yields that are often twice those of conventional farming systems (Derpsch and Friedrich 2009), as well as increased the system's variety. Three decades of success in large-scale conservation agriculture implementation show that a system of agriculture that "imitates" nature and fosters soil biodiversity can be both productive and lucrative. In Brazil, an economic study of conservation agriculture reveals that, aside from direct advantages to farmers (which account for 26% of the total), the main indirect-use gains come from reduced government spending. These are based on the value of reduced native vegetation removal (57% of total), reduced off-farm consequences of soil erosion, lower greenhouse gas emissions, carbon sequestration, and improved aquifer recharge (owing to higher rainfall infiltration) (Landers 2007). Although conservation agriculture is not inherently organic, recent improvements reveal that it has a lot of potential for non-chemical weed and insect control. In trials conducted with farmers in Paraguay (Kliewer et al. 1998) and Brazil (Sorrenson and Montoya 1984), crop rotation and short-term green manure cover crops drastically reduced herbicide use and cost, and it has been suggested that conservation agriculture has great potential for smallholders in Africa given adequate resources and institutional support.

2.5.2 Pest Control

Diverse intraspecies genetic, diverse cropping systems, and landscape heterogeneity boost agroecosystem resilience contribute to more effective pest and disease control and hold great promise for sustainably improving production and productivity. Infection and damage are reduced by growing a variety of species and cultivars with varying resistance qualities (Hajjar et al. 2008). Numerous researches comparing simple and diverse agroecosystems shows that insects are considerably lower in mixed-species plants than in single-species plantings, proving the efficacy of this method. Many interventions aiming at managing or averting pest and disease epidemics by appropriate management of landscape and field-level variety have been created as a result of these study findings, and many of them have been adopted on a broad scale (Gurr et al. 2004).

The emergence of a new race of the virus able to bypass the resistance gene, Yr9, and its migration from East Africa to the Near East, Central, and South Asia, caused global epidemics of wheat yellow rust in the 1980s and 1990s (Singh et al. 2004). In Asia, successful integrated pest management (IPM) programs have demonstrated that protecting arthropod biodiversity by assisting the local understanding of how agroecosystems work is a critical component of effective pest management in rice production. IPM projects in Bangladesh have focused on enhancing natural diversity in rice paddies, including the integration of fish and the use of agro-ecological technologies to restore the natural balance between insects and other wildlife. This method has resulted in higher rice yields while using less pesticide, as well as valuable new food sources. Thousands of farmers have implemented IPM approaches, including initiatives to improve local biodiversity and restore natural pest–predator balance, as part of Indonesia's national IPM program. As a result, from the start of the program in 1986 to 2001, pesticide spending on rice reduced by more than 75% while yields increased by 25%, thanks in part to a favorable governmental climate.

One of the best strategies to achieve pest and disease management results is to diversify the farming landscape by favoring species combinations over monocultures. The shadowing effect of mung beans or sweet potatoes being grown with maize, for example, discourages weed development. Intercropping maize with the fodder legumes Desmodium uncinatum (silver leaf) and D. intortum (green leaf) reduced infestation of the parasitic weed Striga hermonthica by a factor of 40, according to farmer-participated trials in Africa (Pretty 1997). Brachiaria species were also used as a cover crop in bean fields, which reduced Rhizoctonia, Sclerotinia, and Fusarium infections, by 75%. Planting Phaseolus into parched Brachiaria has resulted in farm yields of over 3 t/ha, revolutionizing rainfed and irrigated Phaseolus bean production (corroborated by Kluthcouski et al. 2003). Human management of insect biodiversity by the release of natural predators has had some promising outcomes, particularly for pest control in crops, like cassava. At world market rates, a study of the economic benefits of cassava mealybug treatment over 40 years estimated a cost-benefit ratio of 200 (Zeddies et al. 2001). *Neochetina eichhorniae*, a weevil found in natural vegetation, is effective at controlling water hyacinth (Eichhornia crassipes).

Another effective technique for reducing insect outbreaks is intraspecific variability. Growing a basic variety of rice (Oryza sativa) species across hundreds of fields in China dramatically reduced the development of rice blast, according to Zhu et al. (2000). Blast-susceptible rice types produced in combinations with resistant rice varieties yielded 89% more grain and suffered 94% less blast damage than those grown in monoculture in Yunnan Province, China. The experiment was so successful that by the end of the two-year program, fungicidal sprays were no longer used. This strategy represents a targeted and effective reversal of the monoculture trend. This evidence backs up the idea that intraspecific crop diversification is an ecological approach to disease control that can be extremely effective over broad areas while also contributing to crop production sustainability.

The management of various components of the agroecosystem is linked to disease and pest control in target crops. Through a complex food web that keeps weeds and pests under control through competition, predation, and parasitism, a healthy and diversified soil population leads to productive crops (Susilo et al. 2004). Maize and sorghum injected with arbuscular mycorrhizal fungi and cultivated in Striga infested soil, for example, were successful in reducing Striga hermonthica emergence by 30–50% and biomass by 40–63% in northern Cameroon (Lendzemo et al. 2005). Other research (Marshner 1995) has discovered discrepancies in phosphorus intake and supply among mycorrhizal species, highlighting the importance of preserving diverse soil genetic resources.

2.5.3 Increased Crop and Livestock Production

Crop and livestock production systems have grown increasingly specialized in modern farming (Entz et al. 2005), and large-scale, specialized, energy-intensive farming activities are often separated (Kirschenmann 2007). Recent concerns about agricultural production's environmental quality have rekindled interest in crop–livestock systems, particularly because they allow for higher diversification, nutrient cycling, and energy efficiency (Entz et al. 2005). Mixed systems allow diverse farm businesses to work together; cattle supply draught power and manure, while crop wastes are given to livestock. Farmers with several sources of income (livestock and crops) have more alternatives for coping with crop failures and animal illness epidemics (Carvalho de Faccio et al. 2010).

Crop rotations with a variety of appropriate dual-purpose crops, especially those incorporating a range of appropriate dual-purpose crops, can improve the efficiency of mixed crop–livestock systems. These provide nourishment for humans as well as fodder for animals, resulting in increased farm productivity. Improved dual-purpose sorghum and millet cultivars have allowed smallholders in India to enhance buffalo and cow milk production by up to 50% without compromising grain output from their crops. Brazilian integrated crop–animal zero tillage systems are based on carefully planned crop and livestock combinations, resulting in enhanced yields while halting additional deforestation (Landers 2007).

Monoculture coconut systems were replaced by a diversified system combining tree crops (coconut and fruits), root crops, and herbs with dairy cattle, goats, and poultry in the uplands of Sri Lanka's midlands, with the main purpose of improving farm income. When compared to coconut monoculture, the integrated system was more cost-effective, with dairy production and biogas fulfilling home needs and contributing the most to total revenues. The installation of a mixed pasture based on easy-to-manage *Brachiaria subquadripara* and *Pueraria phaseoloides*, as well as the multi-purpose trees *Gliricidia sepium* and *Leucaena leucocephala*, increased nut and copra yields by 17% and 11%, respectively. The system generated enough fodder to keep animals growing and producing, and the manure considerably enhanced soil fertility, lowering the cost of fertilizing the coconuts by 69%. The three-stratum forage system in Bali incorporates forage crops, shrub legumes, and fodder trees, as well as food crops (maize, soybeans, and cassava) and cattle.

According to a study by Pretty and Hineb (2000), while the method lowered the production of food crops due to cropped area decreases, forage yield grew by 91%, and the composition of livestock feed benefited from a 13% increase in protein content. As a result, steers' live weight increases increased by 56%, while egg production and hatchability increased by 22%. Soil erosion was reduced by 57%, while the organic matter content of the soil rose by 11%. The supply of fuel wood has increased to fulfill 64% of annual needs. A similar project in India involved many farmers who introduced trees, fodder, and livestock into a previously homogeneous cropping system; the positive effects of diversification on soil and water retention turned an unproductive season into a productive one, resulting in a sharp reduction in seasonal out-migration (Pretty and Hineb 2000).

2.5.4 Increased Crop and Fish Production

Rice and fish cultivation have been practiced in various parts of Southeast Asia for over 2000 years. However, due to population pressures and the widespread introduction of high-input monoculture with high-yield rice varieties, as well as the use of pesticides and herbicides that depleted fish species due to their toxicity, the practice was progressively abandoned. Rice–fish culture as a managed farming system saw a resurgence in the 1980s and early 1990s.

Fish culture and rice farming are complementary activities from an IPM standpoint: fish not only play a direct role in pest population regulation but they also provide additional income, raising the economic threshold for chemical pest control of rice pests to a higher level than would be considered critical in rice monocultures. Dhela (*Rohtee cotio*) and Thai sarpunti (*Barbonymus gonionotus*) in Bangladesh are indigenous fish species that respond better to mixed culture than frequently cultivated varieties. Integrated agriculture not only produces a wide range of goods from a single plot of land, but it also boosts rice yields (both grain and straw), especially on poorer soils and unfertilized crops (Dewan et al. 2003).

Since the mid-1980s, the area and production of rice–fish systems in China have increased dramatically: finfish and other aquatic animal production increased from around 81,000 tons in 1985 to 1.16 million tons in 2007, while the area increased from about 650,000 hectares to about 1.55 million hectares. These increases were mostly the outcome of local and national government measures targeted at enhancing the income of rural farmers (De Silva and Davy 2010). In China, rice yields from mixed systems have grown by 10–15%. Increases in net revenue on rice–fish farms are allegedly 7–65% higher than on rice monoculture farms due to pesticide savings and earnings from fish sales (Halwart 1998). The rice crop's diversity is also important in determining the integrated system's efficiency and productivity: using long-stemmed, late-maturing traditional varieties allows for a higher water table and a longer period for fish farming, though modern rice varieties are not a constraint for rice–fish farming. The capacity to blend different types with differing adaptability and productive potential opens up possibilities for increasing variety and contributing to Africa's overall system resilience (Halwart 1998).

2.6 Sustainability of Industrial Applications of Biodiversity Potentials

As discussed in the previous sections, biodiversity is very important to varieties of core industries and indeed has notable benefits as the genetic, physiological, chemical, and metabolic diversity of various species support agriculture, fisheries, forestry, pharmacology, engineering, and technology. Components of biodiversity, which includes vertebrates, invertebrates, plants, and microbes, also provide useful products for food, medicine, research, monitoring, and manufacturing, as well as necessary ecosystem services that are vital to life and are necessary for the continual of life on earth (Beattie and Ehrlich 2014). The use of biodiversity, therefore, should be compliant with sustainable management of natural resources given the huge and vital role it plays in primary industries. In order to use biodiversity in a sustainable manner, care must be taken to ensure that pressure is not exerted on natural resources in such a way that supply for future generation is threatened.

The increasing human population increases the pressure on the ecosystem as we continue to extract more and more resources from the environment (UNEP-CBD 2011). For example, many biodiversity-based products and industries depend on microbial diversity. Microbially produced enzymes find application in the treatment of domestic, agricultural, and industrial wastes, manufacturing of textile, and processing of wood and pulp. Microbes are also being used to generate biogas from waste dumps and landfills. Leaching metals from ores in biological mining is another industrial application of biodiversity that is already a commercial reality. The projected development and expansion of these applications in the future necessitates appropriate and sustainable utilization of these biological resources in order to conserve it (Beattie et al. 2005).

To promote the sustainability of the use of biodiversity, operational guidelines and institutions that support and actively promote a balanced approach to the use of biological resource are necessary. Also, there is a need for accountability and transparency between stakeholders, as well as a strict adherence to policies and standards that ensure the preservation of crops variety, the legal acquisition of genetic resources and information, and the implementation of precise and research-backed techniques that are sustainable and adaptive in nature. Environmentally sustainable sourcing or harvesting of biological resources needed in the industries benefiting from biodiversity is likewise encouraged to promote conservation and ensure sustainability.

2.7 Conclusion

Biodiversity is of great importance to the industrialization of a nation and it is crucial in obtaining raw materials for the production of novel product which are necessary for the well-being of the entire ecosystem. Though some industrial activities are responsible for the declination of biodiversity in Africa, some strategies have been put in place to curtail the negative implications of the industries through the SDGs (Obrecht et al. 2021).

Presently, Africa countries contain the majority of the world biodiversity and there are potentials for its increase through effective utilization and conservation. Biodiversity utilization in African industries has provide diverse solution to some existing problems in the continent especially in the agricultural and food production industries, cosmetic industries, pharmaceutical industries, and other related industries (UNEP-WCMC 2016; Ten Kate and Laird 1999; Beattie and Ehrlich 2004).

There are some other emerging novel products developed by African industries which depend on diversity of bioresources. It is noted that the industrial application of biodiversity has the potential to further develop Africa economy, thereby moving some countries from under developed countries to developed countries (Beattie and Ehrlich 2004).

The industrial applications of biodiversity potentials can be sustained from leading to biodiversity degradation by the integration of sustainable intensification models, collaboration among farmers and conservation ecologists, development of environmental literacy, and improvement of policy planning and actualization. This will preserve the biological resources needed for the welfare of the ecosystem both now and in the future (Emogine et al. 2020).

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Chapter 3
Botanical Gardens: A Reliable Tool for Documenting Sustainability Patterns in Vegetative Species

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Abstract Gardens are mapped out areas where plants like flowers, trees, spices, herbs, fruits, or vegetables are grown and/or cultivated for the impetus of conservation, aesthetics, or scientific studies. The specific role of botanical gardens all over the world is repositories of diverse collections of functional and utilitarian plants in their gardens and seed banks. Botanical gardens help increase public awareness of threats to plant diversity and promote education on biological conservation and preventing biodiversity loss while achieving sustainability and preventing extinction of germane plant life. Over-exploitation of forest resources has affected plant diversity and various species have been forced to go into extermination. Thus, it is imperative to protect and preserve the vegetative species which supports life and the functioning of our ecosystems. Botanical gardens' strength and experience in conservation stem from their in-depth perception and understanding of the tutelage, management, and biology of a wide range of plant species. Ex situ and in situ conservation projects aiming at safeguarding endangered species, rebuilding imperilled populations, and maintaining living plant and seed collections of endangered species are some of the ways of improving the existence of botanical gardens. Improving the existence and impact of botanical gardens is tantamount to sustenance of vegetative species all over the world. The advent of greenhouse system in plant production has stimulated the production of plants, thereby avoiding extinction which may occur in the wild. With these immeasurable benefits, the production is

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affected by cost because plants need to be given full attention in terms of water and nutrient supply for optimal production. The greenhouse system of gardening is a fast-growing system which involves the production in a controlled environment. This measure has generated an increase in production per unit area based on the aim of the farmer and availability all year-round. This book chapter therefore describes the concept of botanical gardens, its economic importance, challenges, and potential strategies to be employed for sustainability.

Keywords Botanical garden · Vegetative species conservation · Controlled system · Greenhouse technology · Plant biodiversity

3.1 Introduction

The loss of plant diversity in the world today is at an unprecedented rate; this is due to various threat factors such as forestry activities, pollution, environmental degradation, land use, globalization, and climate change, which may lead to extinction of plant species and a decrease in services rendered by the ecosystem (Chen and Sun 2018). Plants have the power to enrich and sustain life, but they remain vulnerable to the effects of climate change as well as anthropogenic activities threatening their very existence. At present, the planet faces a potential loss of thousands of threatened species. While our activities continue to degrade and deplete the natural resources that are essential to our survival, we must remember that we derive direct benefits and advantages from these resources, and only sustainable utilization and long-term conservation can ensure that they are preserved for future generations.

The threats of extinction make plant conservation efforts very important in addressing the issue of sustenance of vegetative species. Promoting education and awareness of these threats is paramount in combating them. Development has led to increased fragmentation of natural habitats and significant increase in extinction rates. Over-exploitation of forest resources, in particular, has affected plant diversity and various species have been forced to go into extinction. It is imperative to preserve and protect vegetative species which bring life and support the functioning of our ecosystems and botanical gardens play an important role in the conservation of diverse plants species. There is a need to devote more resources and effort to the conservation of threatened species around the world while striking a balance between tropical and temperate plants. Botanical gardens are places where plant species are studied and conserved; they play an important role in meeting human needs which are enormous. In science, botanical gardens are useful tools in propagation, taxonomy, seed science, genetics, biotechnology, education, ecology, etc. (Donaldson 2009). They can also serve as a measure for biosecurity because they contain diverse native and exotic plant species (Wondafrash et al. 2019). In the world today, there are over 2500 botanical gardens (Golding et al. 2010) which house over six million plants and represent about 80,000 taxa which is equivalent to one quarter of vascular plants identified in the world today (O'Donnell and Sharrock 2017). It was reported that the Global Strategy for Plant Conservation (GSPC) have conserved about 70% of threatened plants in botanical gardens (Huang 2018). There is still a dire need to conserve plant species most especially the ones in the wild. Gardens can preserve plant species for human consumption, use, and well-being and this function is very important in the increasing climatic change scenario which is becoming more severe (Dunn 2017; Ren and Duan 2017).

Climate change has caused a rapid increase in species extinction and, given the present trends, this situation is projected to get worse (Urban 2015). In 2002, United Nations Convention (UNC) on Biological Diversity (CBD) adopted a GSPC aimed at slowing the rate of plants extinctions by 2010. This decrease in extinction rate was proposed to be achieved through a strategy of five objectives. One of the targets was to have a working rundown of all established plant species to achieve the objective of understanding plant diversity through observation and documentation. This would serve as a key step in assessing the conservation status of the said plant species as such as a vital instrument in guiding conservation actions. Other series of action-oriented agreements reached by the GSPC to initiate urgent intervention and effective management of the extinction crisis include securing ecological regions through effective management and restoration, protecting plant genetic diversity, conserving threatened plant species in situ, ensuring plants in ex situ collections are available when needed for recovery and restoration programmes, and also preserving associated indigenous knowledge and local innovations while at conservation efforts. This chapter discusses extensively the concept of botanical gardens, and their role in conserving biodiversity of vegetative species.

3.2 History of Botanical Gardens

The concept of gardening majorly focuses on conservation, but there are few reports on the species diversity of botanical gardens. It is important to relate the living collections of species richness pattern with the world's botanical gardens in the natural environment. This can be made possible by funding studies relating to botanical gardens so as to provide a plant database for future studies and monitoring of environmental factors (Sun 2016). Researchers on garden horticulture should stimulate collaboration with others in the field of systematics, genetics, and environmental studies so as to debunk the reports on the neglect of research in these field despite its positive contribution to the environment (Blackmore et al. 2011).

The universal need of man across the globe which is drugs and spices has been reported to be the basis of botanical gardens, with the need of plants as spices in the tropics and as drugs in Europe necessitated the establishment of botanical gardens in these regions. The history can be traced to the Aristotle's Garden at Athens (Greene 1909), but evidences of garden formations were reported in Egypt, Assyria, China, and Mexico which cultivated plants in their gardens for economic or aesthetic purposes. The earliest garden was the Royal Garden of Thotmes III in year 1000 B.C. and was planned by the head gardener Nekht who was attached to the Temple of Karnak (Holmes 1906). The Chinese may be attributed as the real founders of gardens and the plants grown at that time were for economical and medicinal values. These plants were tested by the Father of Medicine and Husbandry, the semi-mythical Emperor Shen Nung of the twenty-eighth century B.C., and reported the plants cure diseases. The interest in study and learning about plants increased from the fourteenth and fifteenth centuries, their uses, and information about plants increased. The botanical garden at Edinburgh has evolved and presently is the sixth and only garden left in the Scottish capital despite three gardens being identified in the eighteenth century.

Botanical gardens with known established date are up to a total of 1594, among which 54% were confirmed during 1951 and 2001. The progressive report for creating emerging botanical gardens in various parts of the world shows no declining signs till date. For the last 50 years, botanical gardens have emerged in almost all regions across the world, most especially in the topics. For a mention, in Brazil, out of 29 botanical gardens known in the region, only two are investigated to be established earlier than 1900, but at least 14 gardens have been established since 1990. There are still comparably few botanical gardens around the world, like the Middle East, China, and Asia, among others in the late 1990s, while various new botanical gardens and projects were initiated, and existing ones rehabilitated.

3.3 Biological Diversity of Plants

The diversity of plants species around the world is a topic of interest for many plants' specialists and scientists as biodiversity, in itself, is the fundamental basis for the sustainability of mankind (Chen et al. 2017) Biodiversity, which derives from the words 'biological' and 'diversity', consists of three major aspects, including diversity of genes, species, and ecosystems. It encompasses 'the assortment of living things found at all sizes of natural association, going from qualities to species to biological systems' (eAtlas.com). Genetic change and evolutionary processes are among the factors responsible for an increase in biodiversity while a reduction in diversity is usually caused by habitat fragmentation and destruction, as well as various climatic impacts on the environment. The level of biodiversity existing on the planet earth helps ecosystems achieve stability and presents an important influence on the resilience of ecosystems to certain disturbances. Plants create the habitat for many ecosystems and at the same time play an important role in the stabilization of the soil system while inhibiting erosion.

Plants make up a huge part of global biodiversity and serve to provide the major nutrient sources to food webs as well as provide shelters to animals. The network of operations within a functioning ecosystem is such that when a plant species is lost, either due to over-collection of that species or its outright destruction and phasing out, a destabilization, however, slightly occurs in the ecosystems. Other species, plants, and animals alike rely on the lost species for any kind of relationship or interaction, which may negatively affect them. These negative impacts may come in the form of loss of food source or shelter. Also, the loss of a species may mean the loss of a natural resource needed for medicine, fuel, or food. Biodiversity loss is, therefore, a major threat not only to the planet but its inhabitants as well.

Consequently, it is important to carry out plant conservation activities to continue to enjoy the benefits and functions of existing biodiversity. Intentional preservation of diversity, as well as sustainable use of plant resources, is crucial for preventing biodiversity loss.

3.4 Conservation of Biodiversity in Botanical Gardens

The aim of conservation is to promote the management, preservation, and restoration of biological diversity. Since plants are vital to life, plant conservation is a key aspect of biological conservation as it aims to conserve whole ecosystems and associated habitats in the actual sense. Plant conservation activities require the cooperation of everyone to ensure the preservation of native plants communities and habitats around the world.

Conservation is a major activity in both the educational and research programmes of botanic garden. The various measures for conservation of plant diversity include internal and external conservation, direct ecological intervention, reinforcement and reintroduction, and assisted migration (Wyse Jackson and Kennedy 2009). In the saving of biodiversity, botanical gardens play an important role and have great potentials for doing more for the future of biodiversity, especially that of plants (Heywood 2011). Botanical gardens engage in the study and conservation of several vegetative species both ex situ and in situ.

3.4.1 In Situ/Internal Conservation

Botanical gardens are largely recognized for the role they play in ex situ conservation of plants, but their in situ conservation activities which are imperative are often overlooked (Chen et al. 2009; Mammides et al. 2016). In situ conservation is the keeping of plants in their natural habitat for the purpose of protecting and studying them. In situ conservation areas include areas where plants are monitored, preserved, and managed in their native setting and these commonly include botanical gardens. Botanical gardens in the tropical environment is meant to have a positive role to play in situ conservation. This can be achieved through the direct promotion of initiatives such as the reintroduction of valuable native species, habitat restoration, 'assisted migration' of species that are vulnerable to climate change, as well as a creative collaboration with both governmental and non-governmental agencies, and the local people or communities. (Chen et al. 2009).

3.4.2 Ex Situ Conservation

Another method for preserving vegetative species is the protection and management of biological diversity outside of their native or natural habitats. This is referred to as ex situ conservation. Ex situ conservation efforts are usually aimed at protecting endangered plant or animal species by removing part of the population from the pressurized habitat to locate them in another area that could be under the care of people or in a wild setting. A setting under the management of humans is typically preferred for the conservation of threatened species. Storing or growing different plant species away from their native habitat is a way of protecting plants for the future, especially when their original habitat is endangered. Up to 30% of the world's plant species are comfiture outside of their original ecosystem in botanical gardens around the world (Mounce et al. 2017). It is therefore indisputable that botanical gardens serve a key function in the preservation and management of endangered species. Although vegetative or seed propagation is oftentimes easy and cheap, management of ex situ plants is more expensive than in situ.

3.5 Role of Botanical Gardens in Sustainability of Vegetative Species

Botanical gardens typically consist of a fairly wide variety of plant species that are identified and labelled with their local and scientific names, and occasionally, their taxonomy and unique characteristics. There are different types of botanical gardens, each with different plant varieties, such as trees, shrubs, flowering plants, and even herbs. Many of the varieties contained in botanical gardens are from specific parts of the world. Some plants may be tropical while others are temperate. Greenhouse technology may be employed for the preservation of species less suited for an environment in an ex situ conservation programme. When a species is at risk of been endangered in the wild, the ex situ method of conservation becomes a viable means of ensuring its survival.

Mounce et al. (2017) concluded that botanical gardens conserve plant diversity ex situ and can prevent extinction through integrated conservation action. In their research, they enumerated how diversity is conserved in botanical gardens across the world. According to them, 105,634 plant species are managed in botanical gardens. This amounts to about 30% of all studied plant species. Over 41% of known threatened species are also said to be conserved. However, the botanical gardens under their study were disproportionately temperate, leaving about 76% of species of tropical origin absent from their collection. Due to phylogenetic bias, there exists a disparity between the percentage of vascular genera and non-vascular genera that is conserved ex situ. Botanical gardens, however, continue to respond to the threat of species extinction even though a little capacity of them is devoted to threatened species.

3.5.1 Ecological Restoration

A good percentage of plants conserved ex situ are to be made available for species restoration and rehabilitation as well as research endeavours. Researchers can collect rare plants in botanical gardens to investigate the methods of plant conversation in natural habitats. Also, the exploration of plants aimed at recognition of threats and timely intervention efforts for species in danger of extinction is another related role of botanical gardens. Ecological restoration focuses on ensuring the resilience of native plant species and diversity in restored or protected areas, and on the establishment of reserves.

3.5.2 Botanical Gardens' Role in Urban Greening

The complications of conservation and development are twisted. Inferably, in tackling one, the other should also be considered. The challenge of poor environmental quality is an issue with many developing countries while some city areas in developed countries are not left out too. The Greening projects aimed at improving the outlook of neighbourhoods have been conducted by functioning botanical gardens. For instance, in Russia, some botanical gardens have focused mainly on developing new strains of plants that can withstand harsh climate condition. In the same vein, New York Botanical Garden also laboured to transform derelict lots into a safe abode by working with individuals and community groups in Bronx (Keller 1996). One of the important roles of botanical gardens in plant conservation is the cultivation and horticulture aspects, while they also maintain plant genetic diversity ex situ. Botanical gardens, therefore, remains a powerful resource for plant conservation programmes.

3.5.3 Role of Botanical Gardens in Scientific Research

The scientific contribution of botanical gardens in terms of research in plant science and horticulture remains one of the major advantage botanical gardens present. The living collections of plants in situ and ex situ conservation method endeavours not only help preserve genetic diversity but also support several activities in research and development. There are questions about biological diversity and a wealth of information to be garnered on the genetic level through works in scientific research. Resilience and adaptability of plants, resistance to pests, and diseases are examples of knowledge that can be sourced on the level of genetic diversity. Scientific research helps us understand biodiversity on both ecosystem and genetic levels to improve our interpretation of the diversity of nature. Botanical gardens are used to preserve seeds or germplasms of plants for easy access for upcoming research, utilization, and or propagation. This process which involves careful seed collection and storage is known as seed banking and is a method of ex situ conservation that helps protect a species of plant and minimize its risk of extinction.

Through research and scientific experiments, botanical gardens can be a platform for the generation of plants that can be of environmental benefit or economic importance to the society. Botanical garden researchers, using their knowledge of plants characteristics, can also invest their expertise to improve upon the existing approaches to maintain and preserve endangered species, and to investigate alternative methods of plant conservation in their natural environment.

According to Donaldson (2009), global change in research depends on the opportunities botanic gardens brings due to the gathering of living collections of species involved. It is also believed that it has a role in bridging the gap between conservation of biological diversity and the benefits from the ecosystem services. Botanic gardens and scientific institutions should, therefore, be strengthened to support more research and development activities and to ensure that the preservation of genetic diversity is at the maximum level possible and endangered vegetative species are well conserved. For the overall well-being and sustainability of vegetative species on a healthy planet, scientific contribution to botanical gardens should be intensified and strengthened for better conservation of biological diversity.

3.5.4 Recreation and Well-Being of Humans

Contemporary policies for conservation, such as the Convention on Biological Diversity (CBD) and the GSPC, judge it important that human needs be taken into account in conservation (Glowka et al. 1994). Botanical gardens are a popular place for visitors. Per annum, hundreds of millions of people visit the over 2000 botanical gardens holding about 80,000 plant species in their living collection (Wyse Jackson 2001). Botanical gardens remains a strong force of attraction throughout the world to date as they provide a wonderful visual representation of the beauty of nature coupled with immense value for plants. The role botanical gardens serve in terms of recreation cannot also be underemphasized. They not only conserve and promote indigenous plant knowledge but are appreciated for their aesthetic beauty and offer a range of other social benefits. Plants are key to the well-being of man and his environment as they are responsible for the release of oxygen into the atmosphere, and the absorption of atmospheric carbon dioxide during the photosynthesis process. They also serve as a source of food, spices, and medicine. It is from plants we derive ornamentals and herbs, as well as cash crops, and fruits. Man can live in health, well-being, and prosperity due to the existence of vegetation.

The extensive resources and huge expertise available at botanical gardens see to the ability of these gardens to contribute to human well-being. Usually, the stores of knowledge accrued from years of plant collection, taxonomy research, and seed banking afford the opportunity to develop useful plant medicine as well as to conduct researches into specific properties and uses of plants and their various parts. The Botanical and Experimental Garden of Radboud University, the Netherlands, investigated the taxonomy, morphology, nutritional qualities, and alkaloid properties of African Solanum which are commonly consumed as leafy vegetables and herbs by African consumers to provide a definite and comprehensive 'safe to eat' guide. Also, Kisantu Botanic Garden in the Democratic Republic of Congo conducted experiments on a particular fruit, 'mangosteen', with the sole aim of discovering how to extend its shelf life to reach a larger market (Kibungu Kemelo 2004).

Many botanic gardens are engaged in the cultivation and evaluation of traditional medicinal plants to establish a system of medicine that is sustainable and meets local needs. Improvement in both health and nutrition through home gardening endeavours can also be observed in local communities that have been educated and empowered in the creation of home gardens and the use of novel plants. Hence, botanical gardens contribute significantly to human well-being especially by promoting access to food and medicinal plants for proper nutrition and health care. There have also been claims of gardens playing a role in the development and hosting of horticultural therapy techniques for the treatment of mental health problems which, according to the World Health Organization, is universally widespread. Botanical gardens and the conservation of biological diversity, thus, can be linked with improvements in the well-being of humans.

3.5.5 Botanical Gardens and Biosecurity

Globally, plant health is affected as a result of invasive pests and pathogens which can cause significant loss on ecological and economic damage (Lovett et al. 2016). In the Unites States alone, these invasive pests were reported to cause damage up to 39 billion dollars per year (Pratt et al. 2017) and these pests have increased over the last decades in many countries (Wingfield et al. 2015; Hurley et al. 2016). These increases have been attributed to trade, travels and the movement of live plants form one location to another (Santini et al. 2013). Measures of quarantine have been posed so as to reduce the spread, but the lack of knowledge on novel pests and pressures from predation and parasitism can make the natural environment complex. To this end, information on the invasive pests is unknown to science because their identification and mode of action are new to science, prior to their occurrence in the new environment.

The major target of botanical gardens and biosecurity is the issue of pest detection and management. Wondafrash et al. (2019) identified various hazards as well as opportunities presented by gardens as bridgeheads for invasions, sentinel sites for pest detection, and eradication for research, and for various meaningful engagements regarding biosecurity issues.

3.5.6 Gardens as Bridgeheads for Invasions of Pests

From time immemorial, botanical gardens have historically been identified as areas for conduits in the introduction of plants (Hulme 2011). It is evident that despite the role of conservation played by gardens, it poses high risk if introduction of pests (Liebhold et al. 2012). Therefore, the gardens can be pictured as a pathway of introducing pests and the activities in the gardens can establish their spread to the surrounding environment. For instance, the invasion of the root rot fungus (*Armillaria mellea)* in South Africa as reported by Coetzee et al. (2001, 2003). It was initially detected in two locations: Company's Garden and Kirstenbosch National Botanical Garden and now it was reported by Coetzee et al. (2018) that the pest was found in the natural vegetation surrounding the Table Mountain National Park which is a UNESCO world heritage site. With the pests already established at the Kirstenbosch Garden in South Africa, plants were donated to London which resulted in an accidental introduction of the five sap-sucking hemipteran pests (Salisbury et al. 2011). These were resolved by quarantine measures and there is dare need for this activity coupled with repeated inspections.

3.5.7 Gardens as Sentinel Sites for Detection and Elimination of Pests

Emerging research into sentinel plants has enabled emerging pest risks to be detected and identified. Projects, such as the European Horizon 2020 Holistic Management of Emerging Forest Pests and Diseases and the IPSN, are basically into sentinel plant research in the world today (Hulbert et al. 2019). A report showed that 67 pest species were detected in South Africa alone from different gardens from 1996 to 2019 (Tchotet Tchoumi et al. 2019). Recently, Mansfield et al. (2019) reported several novel pest–host associations between bacteria, fungi, insects, and nematodes from sentinel plants and botanical gardens. When these detection and identification of pests are prompt, eradication is much easier, thereby reducing all forms of risks to the natural environment, vegetation, and agricultural production systems (Kenis et al. 2019). Eradication of established pathogens in the natural environment is very difficult, but there have been reports of successful eradication from controlled environments (Paap et al. 2020); therefore, early detection and identification of pest is easier to achieve in botanical gardens when compared with the natural environment.

3.5.8 Determination of Pest–Host Range

A variety of plants in gardens are useful in determination of pest–host ranges and can infer information on the future threats of such hosts on plant health (Scott-Brown et al. 2018). In the case of presence of exotic plants, it can provide information on the possible threats, thereby stimulating regulations and possible quarantine measures against pests (Groenteman et al. 2015). Such studies were conducted on *Euwallacea fornicates* in the Los Angeles Arboretum in California (Eskalen et al. 2013) and it reported the potential of beetles and its fungal symbiont to establish in diverse plant communities in the United States and beyond. This method has been introduced in South Africa. Studies were also conducted on *Xylella fastidiosa* which dwells in the xylem and causes different diseases in plants.

3.5.9 Public Awareness and Education

To enable people to improve their lives through environmental education, the expertise of botanical gardens cannot be brushed aside (Willison 2006). An example of the role botanical gardens play in public awareness can be found in Uganda. Using various methods of communication to transfer knowledge and skills, the Botanic Garden at Makere University educated groups of women and children on the usefulness and cultivation of certain medicinal plant species (C. Kiwuka, survey response).

It is crucial to promote the importance of plant conservation to the public and botanical gardens help in this regard. They increase public understanding and awareness of threats to plant diversity as well as promote education on biological conservation and how this helps prevent biodiversity loss, achieve sustainability, and prevent the extinction of key plant life.

Botanical gardens are sometimes involved in local conservation efforts through education, training, and capacity building. This helps in the sourcing, documentation, and preservation of local and indigenous knowledge on plant conservation. When botanical gardens, in turn, disseminate to the public both the cultural knowledge garnered on local levels and the scientific knowledge from research on plants, the required public awareness and education on plant conservation can be effectively achieved.

3.6 Highlights of Existing and Functioning Botanical Gardens

Botanical gardens are being managed by different organizations and administrations. They are managed either by the state or by regional or local authorities. The universities and other research institutes own over 30% of the world's botanic gardens while a relatively small proportion are private owned.

Recently, for botanical gardens to improve functionality, operations should be guided to achieve more financial and independence in administration via independent fund-raising efforts. The various categories of botanical gardens are presented in Table 3.1.

3.6.1 Regional Distribution of Botanical Gardens

In Western Europe, France, Germany, Italy, and the UK have the greatest number of botanical gardens while only Greece has a relatively small number of botanical gardens which are mostly minute institutions/organizations. The largest number of botanical gardens in the East and Central Europe are found in the Czech Republic and Poland (Table 3.2). Majority of the botanical gardens are located in Australia and New Zealand while relatively few are in the Pacific Ocean Islands. The categories of the global botanical gardens were also stated by Wyse Jackson and Sutherland (2000). Similarly, some countries do not possess botanical gardens, for example, The Cook Islands, Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caledonia, Palau, Pitcairn, French, Islands, Saipan and Tinian, Tonga, U.-S. Pacific Trust Territories, Tuvalu, and Vanuatu. The countries in the South-West Asia and Middle East have smaller of botanical gardens, though there are no botanical gardens in Afghanistan, Bahrain, Jordan, Lebanon, Qatar, Syria, and Yemen.

3.6.2 Report on Distribution of Botanic Garden Worldwide

The world according to BGCI database (2000) stated that a total of 2178 botanical gardens are known to be existing and distributed around the world. The highest (878) been recorded from Europe while the least is from Africa. However, some regions do not have botanic gardens. Africa has 127 botanical gardens with the highest (60) from the West, Central, and East Africa which was closely followed by Southern Africa (38) and North Africa (20) while Indian Ocean Islands have the least (9). In America, a total of 617 botanical gardens are recorded with the least (38) from the Caribbean Islands, and the highest 355 from North America while others 122 from South America and 102 from North America. In Asia, the East and

Table 3.1 Categories of botanical garden

Type	Activities/purpose
Classic multi-purpose gardens	For improving training in horticulture and horticultural related studies. It also helps in research particularly ones associated with botany, taxonomy. For effective result, herbaria and relevant laboratories should be associated with. It also serves as a means of educating the public and as amenity for the populace
Gardens of ornamental plants	These are mainly used for penning down different plant collections; it also plays important role in research, educating the populace, or conserving the species to avoid extinction
Gardens meant to value history	They are established to improve the teaching of medical related courses; some were established for religious purposes which focus majorly on the gathering and production of medicinal and herbs plants, also to assist in increasing the awareness of the public on the cultivated plant species
Gardens solely for conservation	This is established for developing the major need of the community which are solely plant species conservation. Some communities possess natural vegetation in addition to their natural environment. Also, this garden type conserves indigenous garden plants, cultivated only from within and outside their region and overall flora. Most conservation gardens are useful tool in training and educating the public
Gardens meant for both botany and zoology	This is established to collect plants which are being evaluated, experimented, tested, and developed to provide habitats for the displayed and available fauna. In addition, botany gardens provide interpretation of these habitats for public consumption which is also an important element in biological conservation and observation
Gardens created in the university	As the name implies, it is mainly for teaching and research; other functions may include recreation, improve well-being of the university family and environs
Gardens for the purpose of Agriculture, botany, and for keeping germplasm	It functions as a plant collection outside the ecosystem. It has high economic value prospective for conserving, exploration, plant pedigree, and improvement and agriculture. Most of them are preliminary experimental stations which are associated with Institutes of agriculture or forestry while teaming with other synonymous laboratory in plant improvement and seed testing which may not open for public consumption
Gardens located on Alpine or mountain	They are mostly found in regions with mountains in Europe and other Tropical countries. They are designed particularly for the production of mountainous and alpine flora, and or in the case of tropical

(continued)

Table 3.1 (continued)

Type	Activities/purpose
	countries, for the cultivation and reproduction of sub-tropical or temperate flora. Some gardens located on alpine and mountains are secondary gardens
Gardens for keeping indigenous and wild species	This type of garden is regarded as a vegetative area, natural or semi- natural, which is enclosed and well managed. Most of this type of garden are created to play the role of conserving species and for educating the public especially in areas where a specific native and indigenous plants are grown and known
Gardens for horticultural purpose	They are private owned and managed by horticultural societies and organizations, thus available and accessible to the general populace. They operate majorly to invite and improve the growth and development of horticulture through the training of professional gardeners and plant breeders and conserving different garden plant varieties and species
Thematic gardens	These gardens focus majorly on cultivating small range of morphologically comparable or similar plants and plants grown to illustrate a particular purpose mostly in support of education, science, research, conservation, and exhibition. These include orchids, rose plants, Rhododendron, bamboo, and succulent gardens or gardens established on such themes as ethnobotany, medicine, bonsai, topiary, butterfly gardens, carnivorous plants, and aquatics
Gardens for the community	These are generally small gardens owned by the community with little or no resources, which is created and developed for, and by, a local community to fulfil its special purpose and vision which may be either be recreation, education, conservation, training, and for the growth of medicinal and other economic plants

Southeast Asia has 220 botanical gardens; the Southern Asia has 143 while the Midian East and South West Asia has only 40. The region of Australasia and Oceania has just 153 botanical gardens. The Western Europe has 583 followed by Russia and the C.I.S. with 170 botanical gardens while Central and Eastern Europe has 125 making close to a total of 878 botanical gardens in Europe.

3.6.3 World Best Botanical Gardens

The most massive botanical garden around the globe is Kew Royal Garden in London. It is an international garden with research focus and educational institute mindset. The garden employs more than 1100 employees with a fascinating and

Table 3.2 Regions in the world with existing and functioning botanical gardens

Countries	Botanical gardens
West, Central, and East Africa	Nigeria has the highest number (16) of botanical garden in this region, followed by 9 in Kenya although most major countries have one or more. Countries like Guinea, Burkina Faso, Equatorial Guinea, Guinea-Bissau, Sao Tome, Congo, and Principe have no botanical gardens
Southern Africa and the Southern Atlantic Islands	South Africa possesses the highest number of botanical gardens in this region. Recently, new botanical gardens have been established and extended to several countries. Ascension Island and South Georgia have no botanical gardens
Southern Asia	Every country in the Southern part of Asia has a botanical gardens, although the largest achievement and establishment are in India. Recently, Bhutan has her pioneer botanic garden established
The Caribbean Islands	The highest figure of botanical gardens is in Cuba. Many of the newly established and developed institutions focused majorly on conservation and increasing knowledge of biological diversity. Major island countries have at least one botanical garden, though some may generally be either old and historical gardens or relatively recently established. There are no botanical gardens recorded in the following countries: Haiti, St Lucia, and the Turks and Caicos
South America	Argentina, Brazil, and Colombia have almost all the botanical gardens in this region. However, many of these gardens have just been established particularly in Brazil and Colombia
East and Southeast Asia	Most of the botanical gardens in these regions are located in China where there are over 100 with Japan having more than 50. There are no known botanical gardens in Brunei Darussalam, Cambodia, and the Lao People's Democratic Republic
Central and North America	A majority of botanic gardens in these regions exist in the United States, Mexico, and Canada. All Central American countries have at least one botanical garden.
Indian Ocean Islands	Botanical gardens exist in 4 territories of the Indian Ocean Island and countries like the Seychelles, Mauritius (where the oldest tropical botanical garden in the world exists), Réunion, and Madagascar. There is no botanical gardens in the British Indian Ocean Territory, the Maldives, Comoros, Mayotte, or Rodrigues
North Africa	This region has few botanical gardens which are scattered throughout the area, other than in Central African Republic, Chad, Djibouti, Eritrea, Mali, Mauritania, Niger, and Somalia where none is established. There are developments and expansion in countries like Morocco and Tunisia

beautiful environment (Table 3.3). There are other large botanical gardens available all over the world and India. Although Kew Royal garden is the largest botanical garden, there are many other interesting botanical gardens as well in the world and must be visited, with details stated in Table 3.3.

Table 3.3 List of the world best botanical gardens in the world

S/N	Botanical garden	Year established	Acre	Location
1	Kew Royal	1840	320acre	London, UK
2	Longwood Gardens		1000 m^2	Philadelphia, USA
3	Jardin Botanique Montreal	1931		Canada
4	Hawaii Tropical	1984	17acre	USA
5	Orto botanico di padova	1542	22,000 m^2	Italy
6	Botanischer Garten	1809	18acre	Munich
7	Kirstenbosch Botanical		89acre	South Africa
8	Singapore Botanical	1859	183acre	Singapore
9	Sydney Royal Botanical	1816		Australia
10	New York Botanical		37acre	United Kingdom

Table 3.4 Botanical gardens in Africa

S/N	Botanical garden	Location
1	Kirstenbosch National	Kirstenbosch, eastern Cape Town
2	Mauritius National	Pamplemousse, Mauritius
3	Jardin Majorelle	Marrakech, Morocco
4	Aburi	Accra, Ghana
5	Sarius Palmetum	Abuja, Nigeria
6	Nairobi	Nairobi, Kenya
7	Jardim Tunduru	Maputo, Mozambique
8	Entebbe	Lake Victoria in Entebbe, Kampala.
9	Seychelles National	Outskirts of Victoria on Mont Fleuri
10	Aswan	Egypt

3.6.4 Exquisite Botanical Gardens in Africa

Gardens are haven for various flora and fauna diversities offering conservation of these species with educational and recreational functions. Listed below are some exquisite gardens in Africa as described by Africa.com (2019) (Table 3.4):

- Kirstenbosch National Botanical Garden
- Jardin Majorelle Botanical Garden
- Mauritius National Botanical Garden
- Seychelles National Botanical Gardens
- Aswan Botanical Garden
- Entebbe Botanical Garden
- Aburi Botanical Garden
- Jardim Tunduru Botanical Garden
- Sarius Palmetum Botanical Garden
- Nairobi Botanical Garden

3.6.5 *Description of the Listed Botanical Gardens*

Kirstenbosch National Botanical Garden It was established in 1913 to preserve flora diversity in Kirstenbosch, Eastern Cape Town's Table Mountain. It is the home of the country's national flower, the Protea, and others, like Fynbos, Erica, and Restios and houses over 125 bird species, insects, and amphibians.

Jardin Majorelle It is located in Marrakech, Morocco in 1886 by Jacques Majorelle who was a French painter and purchased in 1980 by two French designer partners: Yves Saint Laurent and Pierre Berge. It houses about 30 species of cactus family, bamboos, and variety of bird species, such as sparrows and turtledoves. The garden has a monument erected in 2008 and a Berber Museum opened in 2011 which contains the historical background of the Berber tribe.

Mauritius National Botanical Garden It is located in Pamplemousses, Mauritius and formally known as Sir Seewoosagur Botanical Garden. It is the most visited on island and was initially the private garden of the French governor almost 300 years ago but was launched as the country's botanical garden. It houses over 600 species of plants, talipot palm trees, jackfruit tree, and Indian almond tree.

Seychelles National Botanical Gardens It is located outskirts of Victoria on Mont Fleuri and houses diverse flora and fauna; Koko Maron which is used to make brooms and ropes by natives; and Coco Der Mer which is the largest nut in the plant kingdom. The garden has a signature feature of brightly coloured orchid house with variety of orchids and native orchids.

Aswan Botanical Garden This is a world class garden located in the heart of Egypt on an island in River Nile as Aswan, similarly known as the Kitchener's Island or El Nabatat Island and was owned previously by Lord Kitchener in 1800s. It leisure spot and area for botanical research is located in Egypt. It contains rare and exotic species of plants and wildlife.

Entebbe Botanical Garden It is located along the shores of Lake Victoria in Entebbe, Kampala. It contains a large extent of different birds like eagle owls and weavers and wildlife birds, like the yellow-bellied duck and grey-headed gull. Apart from these, it houses a small rainforest which contains medicinal plants, tall trees, and a thick forest of bamboo.

Aburi Botanical Garden It is listed among the most beautiful gardens of tourist attraction outside Accra coastal plain, Ghana. The garden encourages cocoa production by supplying seedlings and scientific information to the southerners, Ghana. It houses several flora species for conservation, like the Ficus tree and medicinal plants. There are diverse birds and butterfly species for nature lovers.

Sarius Palmetum Botanical Garden It is located in Abuja, Nigeria, and houses over 1000 different plant species and 450 palm species. It houses several flora species, Nigeria's oil and coconut palm, golden and royal palms, and endangered plants, like pepper fruit, sea grapes, and cherry. The garden was created with the aim to conserve Nigerian indigenous plants by a plant lover called Aisha Mohammed.

Jardim Tunduru This is a beautiful garden located in Maputo which is the heart of Mozambique's capital. It was rehabilitated and reopened in 2015 with addition of greenhouse, fences, public benches, and improved irrigation and sanitation systems. It houses a rich collection of flowers, trees, and shrubs such as magnolia and Palmae plants. It also houses birds, butterflies, and colony of bats which utilizes the trees as haven.

Nairobi Botanical Garden This is a beautiful garden in Nairobi Museum and ideal for picnics and relaxation in Kenya. It is the home of 600 indigenous and 100 exotic species of plants for research, education, and conservation. It also displays the herb garden which contains the indigenous medicinal plants, the papyrus plants, water lilies, and other aquatic plants.

3.6.6 Categories of Worldwide Botanical Garden Ex Situ Collections

The highlights below are a broad category representing the worldwide collection of ex situ botanical garden.

- *Limited collections*
  - Rock garden plants and Alpines
  - Herb/spice plants species
  - Bonsai
  - Bulbs
  - Carnivorous plants species
  - Medicinal/herb plants
  - Ornamental plants
  - Scanty and endangered plants
  - Temperate region fruits
  - Temperate region herbaceous (perennials)
  - Temperate region (trees, shrubs, and climbers)
  - Tropical region fruit trees
  - Tropical region timber trees
  - Tropical region flowering and ornamental plants
  - Wild crop species
  - Xerophytes species
- *Taxonomic collections*
  - Woody plants
  - Aroids

  - Bromeliads
  - Cacti
  - Conifers
  - Crassulaceae
  - Cycads
  - Euphorbiaceous
  - Ferns
  - Ficus
  - Grass
  - Bamboos
  - Legumes
  - Orchids
  - Palms
  - Rhododendrons

- *Collections based on geographical location*

  - Temperate indigenous plants in North America, Europe, and Asia
  - Temperate Woody indigenous plants in Australia, New Zealand, and South America
  - Plants of the Mediterranean regions of Europe, Southern Africa, South America, and Australia. Island plants
  - Collections from tropical continental South America, Southeast Asia and Africa and other countries with few numbers of botanic gardens.

3.7 Herbaria

A herbarium is a collection of non-living specimens of plant for scientific study. It is usually dried and mounted on a plain sheet of paper. Mostly, existing botanical gardens across the globe either contain and or are closely collaborating with a herbaria. Many harbour important, different, and indispensable scientific resources documenting the world's plant species diversity (BGCI database 2000). Historically, various original collections on which plant identity are based and enveloped in herbaria other than the natural habitat of the concerned species. For the sake methodology of science, strategy has to be established or planned to evaluate the need for herbaria, which is to allow accessibility to their plant collections. A point to note is the fact that most of species preserved in botanical gardens herbarium are vascular plants, few important specimens of non-vascular plants, like the bryophytes; several botanical gardens also preserve microorganisms. The major botanical garden herbaria are listed in Table 3.5.

Table 3.5 Herbaria in major botanical garden

Botanical garden	Location	Specimens (aprox.)
Museum National d'Histoire Naturelle	Paris, France	8,000,000
The Royal	Kew, U.K.	7,000,000
Conservatoire et Jardin Botaniques	Geneva, Switzerland	6,000,000
New York Garden	U.S.A.	5,600,000
Komarov Botanical Institute	St Petersburg, Russia	5,000,000
Missouri Garden	St Louis, U.S.A.	3,500,000
University, Jena	Germany	2,800,000
Helsinki, University	Finland	2,720,000
The Berlin Dahlem	Berlin	2,000,000
University, Uppsala	Sweden	2,000,000
Kebun Raya Bogor	Indonesia	2,000,000
Beijing Garden	China	2,400,000
University, Copenhagen	Denmark	2,500,000
Institute of Botany	Pruhonice, Czech Republic	2,000,000
Royal Garden	Edinburgh, U.K.	2,000,000
National Garden	Belgium	2,000,000
University of Tokyo	Japan	1,500,000
Indian Garden	Calcutta, India	1,500,000
Goteborg Garden	Sweden	1,350,000
University of Wien	Vienna, Austria	1,300,000
University of Oslo	Norway	1,300,000
Pretoria National	South Africa	1,200,000
Melbourne Garden	Australia	1,170,000
Sydney Garden	Australia	1,000,000

3.8 Major Challenges Facing Botanical Garden Existence in Africa

Mostly public and private botanical gardens, the major challenges reported have been the increased rate of using threatened and or wild species due to insufficient resources and opportunity for acquisition of species seeds (Bischoff et al. 2008; Brancalion et al. 2011). Others are insufficient knowledge of threatened species, lack of efficient propagation, and planting methods (Volis 2016). To resolve the challenge, seed availability must increase (Jalonen et al. 2017; Silva et al. 2016); a comprehensive list of existing species must be created to know which variety of species are available, necessary, and appropriate for their nursery site. Furthermore, other strategies include as follows:

- Seed sharing programme participation between private and public seed collectors, community-based, and local seed exchange programmes have been declared to increase restoration of biological diversity other than relying on any one strategy alone Brancalion et al. (2011).

- Seed obtaining support empowering nurseries to convey more species in satisfactory amounts closely.
- Increased information on compromised species so rebuilding professionals can settle on informed choices on which species they can certainly add without discouraging the situation rates.
- Increasing open doors for Ns and RPs to make partner networks where information, seeds, and scene level plans can be divided among entertainers.
- Use of long haul between situ and semi in situ protection systems, which all the while gives long haul conservation of hereditary variety and increment seed creation of target species. With an equilibrium of reasonable contemplations, it is feasible for reclamation plantings in the Araucaria timberland locale to be species rich, addressing an expanded number of useful gatherings and focused on the protection of the under-privileged plant species at the verge of extinction.

3.9 Way Forward on Improving the Botanical Garden Existence in Africa

Botanical gardens are important for the preservation and conservation of plant species like trees, shrubs, and flowers. Plants are important tools in promoting good health and social well-being among the people. They help achieve this by eliminating air contamination, decreasing pressure, empowering actual work, and advancing social ties within a community. It was reported that school kids with perspectives on trees are bound to dominate. Trees advance a solid economy and can give various assets to individuals. To reduce temperature, trees can be utilized. They also serve as habitat and food sources for animals.

The strength and expertise that botanic gardens bring to conservation are based on their detailed knowledge and understanding of the care, management, and biology of a diversity of plant species. Some of the ways of improving the existence of botanical gardens in Africa include the following:

Increased conservation: Botanical gardens are concerned with both in situ and ex situ conservation of plant species. Conservation can be done by both in situ and ex situ conservations.

In situ conservation: This is the conservation of biological components by enhancing their growth and survival in their home environment. This simply denotes that the growth and development of the trees are promoted in their locality where they normally occur in. This conservation type is concerned with the preservation of the ecosystem and the environment. This method has the added benefit of assisting in the continuing processes of evolution and adaptation within their habitats. Natural disasters such as drought, floods, and forest fires cause the species to adapt, and this strategy is highly cheap and convenient.

Ex situ conservation: According to the convention of Biological Diversity, it is the conservation of biological components outside their natural habitat. This means the storage, propagation, and cultivation of plant or tree species outside of the locality they are primarily found. This kind of conservation has both positive and negative implications on the genetic composition of such plant species. The main purpose of a botanical garden is to facilitate ex situ conservation.

The techniques employed by botanical gardens for ex situ conservation of plant species are as follows:

Cryopreservation: This is done by storing the pollen, seed, or embryo under liquid nitrogen. Liquid nitrogen, a coolant produced from the fractional distillation of air, is made up of nitrogen in a liquid state. This method allows for almost endless storage of material without deterioration over a far longer time span.

Tissue cultivation: This is the cultivation of seeds or their propagative parts in test tubes, Petri, or culture dishes in a temperature- and light-controlled environment that promotes cell growth.

Field gene bank: A large-scale open-air planting used to preserve the genetic variety of wild, agricultural, or forestry plants. Field gene banks typically conserve species that are difficult or impossible to conserve in seed banks. Other ex situ procedures can also be employed to cultivate and select progeny of species maintained in field gene banks.

Ecosystem restoration: According to the United Nations Environment Programme (UNEP 2019), ecosystem restoration is 'a process of reversing the degradation of ecosystems, such as landscapes, lakes, and oceans to regain their ecological functionality; in other words, to improve the productivity and capacity of ecosystems to meet the particular need of society. This can be done by allowing the natural regeneration of over-exploited ecosystems or by planting trees and other plants'. Facilitating natural succession is an important part of ecosystem restoration. Human activities and obstructions frequently obstruct this process, necessitating solutions, such as removing exotic plants, minimizing soil erosion, and reinstalling native species to kick-start it. Ecosystem restoration aims to contribute to biodiversity conservation and sustainable use while also providing social, economic, and environmental benefits, with healthy and connected ecosystems helping to improve food and water security, people's livelihoods, and climate change mitigation and adaptation.

Maintenance of soil biodiversity: Soil biodiversity comprises the living components in the soil, like bacteria, fungi, termites, and nematodes. Soil biodiversity maintenance is important because the soil serves as the buffer for pests and diseases control, soil water, and structure determination as well as the availability of nutrients for the plants. Some of the methods of improving soil biodiversity are through the following:

Mulching: This is done by using materials, like polythene or grasses, to cover the soil surfaces. This reduces the rate of evaporation, thereby maintaining the soil water level. It also improves the availability of mineral nutrients in the soil and maintains soil temperature. This will increase the chances of survival of the different organisms residing in the soil.

Composting: A mixture of organic wastes, with or without soil, that has been allowed to decompose is used as an artificial manure to fertilize or enhance land.

Composting is an aerobic process (Schwedt 2001). Composting helps with fertilizing the crops, acting as a soil conditioner, increasing the humus content of the soil, and introducing helpful microbial colonies that help decrease the presence of diseases causing organisms in the soil.

Bulking soils from different places: Topsoil from an area with the desired biodiversity can be mixed together with the original soil of the place to introduce new organisms to the area.

Increased collaboration with other experts, like taxonomists, breeders, and horticulturists: There is a need for all hands to be on deck in the improvement of the botanical gardens all over. There is an urgent need to protect tropical forests, particularly lowland forests, in extensive nature reserves throughout all tropical countries, free of economic exploitation, such as logging, mining, hunting, and other activities. This can be achieved when all the stakeholders involved come together to promote botanical gardens.

Botanical gardens are key sources of plant ecology data, counting phenological signs of environmental change, plant physiology and plant development procedures, and plant–creature connections, as well as filling in as ordered and methodical study sites. All these are prerequisites needed for scientific research on health, pharmacology, as well as agriculture. The benefits associated with the development of botanic gardens to scientific research across all fields of work cannot be trifled with.

3.10 Greenhouse System of Gardening

With the ever increasing need to prevent the extinction of biological species especially in botanical gardens. Thus, there is increasing pressure on land especially for agricultural/food production/research/gardening especially in developing countries. On this note, there is need to adopt the new technology and innovation greenhouse brings that requires a little space with optimum result as reported by Timothy (2016). A greenhouse is a structure with controlled environment in which plants are raised and or grown for commercial and research. It can also serve as a means of keeping living plants to prevent extinction due to prevailing climate change among other challenges of sustaining biodiversity. Greenhouse structures are made from different covering (roof and wall) materials (glass or plastic) which are durable and lasts for up to 15 years. On an acre of land, close to 8 greenhouses can be erected depending on the intended use (Timothy 2016). The science behind the greenhouse technology lies between the fact that

1. The structure collects light and converts it to heat.
2. The greenhouse stores thermal energy and releases that energy properly.
3. It helps moderate temperature and produce a controlled environment for plants to grow and thrive optimally.
4. It also offers protection from wind, rain, snow, and other weather elements.

5. Finally engaging the greenhouse as a garden for conservation of biological species keeps the species from pests, animals and theft.

Greenhouse structures and practices are found in prestigious and magnificent botanical gardens and or gardens all over the world. Most of these gardens prefer the use of glass conservatories which serves dual purpose of practical/research and aesthetic/beauty. Conservatory and greenhouse are mostly interchanged, but specifically simple structures that functions mainly as a place for growing delicate or fragile plants and fruit trees.

On the other hand, conservatory doubles the activity of forms and functions. In conservatories, the plants are tendered intensively and shielded and equally camped in a bright glass structure; it can also serve the purpose of entertainment, refreshment, and/or relaxation.

The conservatory building is active all year-round with the advantage of producing refuge for outdoor plants and trees during the winter season, by providing adequate warmth and optimum access to sunlight. In the nineteenth century, greenhouse and/or conservatories structures are made from modern but energy efficient materials in which the present ones were used as background knowledge in establishing the trending gorgeous ones around the world, some of which are listed according to Leung (2016) as:

- The Curitiba Botanical Gardens, Curitiba, Brazil
- The Adelaide Botanical Garden, Adelaide, Australia
- The Brisbane Botanic Gardens Mount Coo-tha, Australia
- Gardens by the Bay, Singapore
- Botanique, Belgium, Brussels
- Belfast botanical garden, Ireland
- Botanical garden, Copenhagen, Denmark
- Goldengate Park, San Francisco
- Allen Garden, Toronto
- Muttart Greenhouse, Edmonton

3.11 Conclusion

The global diversity is incomplete without diversity in botanic plants which encompasses a huge part of the total diversity. Plants are a great source of highly nutritious food and doubles as abode for animals both large and small. Without adequate filing and recording of existing plant species, there will not be any way to trace the species which may be lost via over collection, destruction, climate change, and phasing out, among others. Humans are not left out in the plant species loss game as it means that a loss could lead to reduction in natural resources needed for medicine, energy, and food.

Efforts towards education are significant for botanical gardens to promote and implement various activities in plant conservation as communicating the importance or significance of conservation is paramount for gaining the cooperation required to make considerable progress in achieving the goals of conservation. Availability of educational resources is one of the ways to educate the public and promote awareness on biodiversity and plant conservation.

In this vein, biodiversity loss is a major challenge for the ecosystem, planet, and its inhabitants. To avert the consequences, it is important to establish and evaluate existing plant conservation resources and structures to save the biological community and also to enjoy the benefits and functions of her existence. There has to be an intentional approach in the preservation of biological diversity coupled with sustainable use of plant resources. To prevent the influence of climate change, greenhouse conservatories are suggested; for phasing out species, updated recording is advised while the proper monitoring and administrative role must be independently controlled to facilitate growth and development of existing and upcoming botanical gardens.

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Chapter 4
Food Security: A Pathway Towards Improved Nutrition and Biodiversity Conservation

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Abstract Food is required by all living things without which life processes will be on halt. Food security defined by the United Nations' Committee on World Food Security is a condition in which people have access to adequate, safe, and nutritious food at all times that meet their dietary needs for a healthy life. The importance of biodiversity in the conservation of African foods for the sustenance of healthy and nutritious diets cannot be overemphasized. It is crucial for improving food security, conservation, livelihood, human well-being, and ecosystem services in Africa, and can be said to be a basis the Sustainable Development Goals (SDGs) 1 and 2. However, there has been a steady decline in species biodiversity for food and agriculture at the level of genetic composition, species, and ecosystem levels resulting in deteriorating diet quality and subsequently increase in the risk of malnutrition. The natural resources which may serve as for food include diverse vegetation, various species of sea life, including fishes, crabs, prawns, and shrimps, as well as animals. All of these have been depended on by mankind since time immemorial. Some African countries have been using some biodiversity friendly approaches, yet their usage needs to be amplified to increase the potentials of food security and biodiversity across Africa. These approaches can increase the plant and animal sources by increasing their ability and ensures sustained production for the long-term survival

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of mankind. However, the biodiversity that underpins much of modern agriculture is fast disappearing as our reliance on plants and animal species has led to increased biodiversity loss which puts food security livelihoods and health at risk. In this chapter, some biodiversity friendly approach as it enhances food security in Africa is expounded. Biodiversity conservation strategies practised in Africa, plant and animal sources of biodiversity, and the application of biodiversity friendly approaches to food production are also discussed. Likewise, the peculiarity of Africa potentials towards the biodiversity of food and animals is well captured in this chapter.

Keywords Agriculture · Conservation strategies · Food security · Sustainable Development Goals · West Africa

4.1 Introduction

4.1.1 Food Security and Biodiversity

The world is faced with a great challenge in terms of the urgency of providing and securing food for the ever-increasing human population. The sense of urgency is quite essential in estimating the current biodiversity loss because the loss is accelerating. In 2002, a commitment was made by 182 countries in the World Food Summit to reduce to half a total of 425 million people who are malnourished and prices of food items have hiked and reduced the purchasing power of individuals (Roesel 2019). The decline in biodiversity in the areas of agriculture and food security is a global phenomenon and it poses a great risk to global food security by making agricultural crops vulnerable to pests, diseases, and climate change. To this end, more sustainable production systems to conserve and sustain biodiversity are needed, such as the genetic digitalization of information needs to be addressed.

It has been estimated that environmental changes have been caused by human-induced changes to the environment and over one million species of plants and animals are threatened with extinction (IPBES 2019). Biodiversity loss is very alarming, and humans depend on them for food and activities such as forestry, fisheries, and livestock are one of the major causes of biodiversity loss because they rely on complex web of living organisms (Iyiola et al. 2020). Once it is lost, food and agriculture biodiversity cannot be recovered (FAO 2019a). Plant species which contain over 6000 different species contribute 66% of total crop production; the contributing crops are nine, namely wheat, rice, sugarcane, potato, sugar beet, cassava, oil palm, soybean, and wheat. Livestock contributes 97% of world meat production and consists of products like chicken, pig, sheep, cattle, turkey, goat, and buffalo (FAO 2019a).

As reported by IUCN (2021), valuable wildlife plant and animal species in the natural ecosystems are decreasing with about 20% of species which are principal sources of food to humans are threatened, about a third of fish stocks in the ocean are overfished, and a third of fresh water fish species are threatened. Species of invertebrates and microorganisms are not left out; they principally function in keeping soil fertile, pollination, and purification of water and air and fight pests and diseases of crops and animals. Examples of such are the birds, bats, earthworms, bacteria, and fungi and have been reported to decline, thereby reducing agricultural production, although their potentials have not been explored in detail. There is therefore a dare need for increased knowledge on food and agriculture ecosystems and the role of biodiversity in food production; this will enable conservation and management of biodiversity which functions principally in all food systems (IPBES 2019).

The rise of biodiversity has incited extensive discussion and misconception among general society, strategy creators, and surprisingly the specialists. However, much has been distributed regarding the matter starting around 1986 at the National Forum on Biodiversity, and till date has turned into a more alluring point for scientists in the course of the last decade. The crucial part of the asset of nature "biodiversity" has provided many human needs and insures against environmental disasters. Unfortunately, the environmental change, air contamination, increase in innovation and industrial activities, advancement of farming, and changing human ideology towards species, biological systems, and scenes are some issues on biodiversity. There is need to gather updated information on the definition of biodiversity, the importance, major elements, and various diversity conservation strategies. Biodiversity is intrinsically valuable and necessary for human's emotional, psychological, and spiritual well-being. There is a significant purpose for diversity to be properly conserved and sustainably utilized; otherwise its loss would have residual effects on the goods and ecosystem services on which all living organisms depend on. Therefore, the authors of this chapter have gathered information on the definitions, significance, components, and ideas of biodiversity.

4.1.2 What Is Biodiversity?

Biodiversity involves different living organisms and incorporates different species in diverse environments and biological cycles. Their preservation is dictated by human activities around the environment. Biological diversity was defined at the United Nations Conference on Environment and Development (UNCED), as the change among living organisms from all sources such as environmental, oceanic, biological systems, and the environment to which they belong. Nonetheless, researchers are yet to have a holistic definition of biodiversity. It is described that biodiversity as the change of environments and its parts expressed as alpha, beta, and gamma variety. Alpha, beta, and gamma variety implies the variety inside living spaces (nearby scale), among territories and in scene scale. In many investigations of biodiversity, alpha and beta variety have been reported. Then again, scientists arranged biodiversity in three significant levels and furthermore allude to the interrelatedness of qualities, species, and biological systems and their connections with the climate. For the most part, three degrees of biodiversity are identified and talked about which are hereditary, species, and environment variety.

4.1.2.1 Variations in Genetic Structure

Genetic diversity simply refer to all the differences in genes that may be present in living organisms (plants, fungi, animals, and microorganisms) which allows them to adapt with environmental changes over a period of time. It occurs within a species (inter-species) as well as between species (intra-species).

4.1.2.2 Variations in Species

Diversity of species can be described as the diversity of intra- and inter-meaning a particular number of species and/or among diverse species of a particular variation that uses three components of the community structure which are richness, evenness, and abundance of species.

4.1.2.3 Variations Among the Ecosystem

This is described as in different homes, ecological activities, and biological communities, as well as variation that may occur within an individual ecosystem. However, differences in the genetic structure and species diversity usually apply to intra-species differences and inter-species disputes, respectively.

Biodiversity means diverse things to different category of ecology tiers:

- To a taxonomist it is defined as a list of species or taxa.
- A geneticist/breeder described allelic diversity to be the active expression of a particular variety.
- While plant sociologist viewed diversity as record, distribution, and types of vegetation.

The role of diversity is significant in providing ecosystem services. Furthermore, ecologists assume there is a positive relationship between biodiversity and sustainability when comparing the functions. Recently, while highlighting ecosystem's ability to provide multiple services and functions (ecosystem multi-functionality) and diverse aspects of biodiversity (such as taxonomic, phylogenetic, and functional), some researchers have been addressing several questions that require more extensive research.

4.1.3 Importance of Biodiversity

Diversity attracts diversity. Few consider that it is solely human responsibility to watch out for the rest of the world's living organisms (Aigberua et al. 2021; Richard et al. 2021a). There are different clusters of living beings, which permits different creatures to explore the provided assets. For example, trees give territory and supplements to birds, bugs, different plants and creatures, organisms, and microorganisms. Biological resources provide food, shelter, warmth, and medicine directly for humans as shown in Fig. 4.1.

- Foods are species that are pursued, fished, and assembled, just as those developed for agribusiness, ranger service, and hydroponics (Iyiola and Asiedu 2020).
- Shelter and warmth are wood and other woodland items and strands, like fleece and cotton.
- Prescriptions are both conventional drugs and those blended from organic assets and cycles (Richard et al. 2021b).

By implication, biodiversity additionally supplies administrations to people which are unnoticed and simply neglected. These reaches from drinkable water, undiluted air, and rich soils. The deficiency of populaces, species, or gatherings of species from an environment can raise a strange circumstance which disturbs these biological administrations. The World's biodiversity contributes straightforwardly and by implication to the efficiency of the normal and horticultural frameworks. For example, creepy crawlies, bats, birds, and different creatures fill in as pollinators; parasites and hunters can go about as normal vermin controls while different life forms are answerable for reusing natural materials and keeping up with the usefulness of soil (Izah and Aigberua 2020).

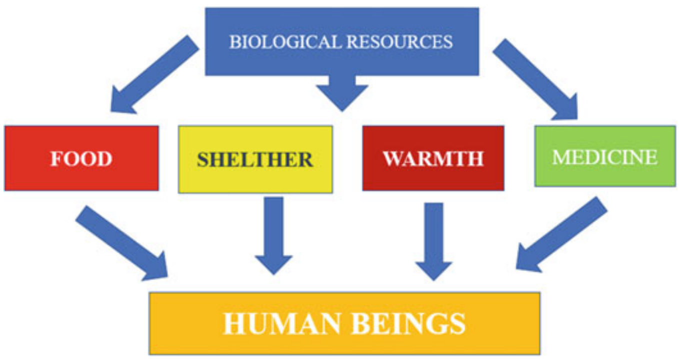

Fig. 4.1 Components of biological resources

4.1.4 Challenges of Biodiversity

Africa is immensely rich in biological differences; a quarter of the global diversity is accrued to the living organisms in Africa which supports the earth largest intact of large mammals which roam in the country. Human activity has been tagged as the major factor leading to significant loss of biodiversity (Seiyaboh and Izah 2020). This has migrated to be a significant issue for the common man, scientists, and policy makers. Species are going into extinction at a fast rate as a result of the following:

- Loss of habitat
- Destruction of habitat
- Disrupted composition of the ecosystem
- The introduction of exotic species
- Change in climatic condition
- Over-exploitation
- Pollution and contamination orchestrated by man

It was reported that scientists have observed a high decline in biodiversity globally, which has been severe over six decades. There have been several factors leading to the reduction in the existence of certain plants and species ranging from change in climate, pollution of the air and land, change in the usage of land, rapid advances in technology and industry, development in the practices of agriculture, changes in urban cities, and inconsistent attitude of humans towards species biodiversity, environment, and landscapes. Generally, natural resources have recently become a topic of attraction and interest for researchers. The rate of species loss differs in different ecosystems. There is a geometric increase in the risk in solving food insecurity through agricultural expansion. The risk of food insecurity may cause the loss or extinction of biological variations (biodiversity), and through the destruction of habitats that are critical and requires dire need for conservation (Izah 2018a, b).

4.1.5 Prescribed Solution to Biodiversity Loss

It is currently and generally accepted that biodiversity has long ways past the assorted number of species in at least one explicit locale. The preservation technique of biodiversity cannot be founded exclusively on the number of species in single or more biological systems. Therefore, consideration of the best protective measures goes towards a different disciplinary method by creating scientific–political partnership to enhance positive result (Izah and Seiyaboh 2018a, b). The management and conservation strategies must be developed and improved around the world to inscribe the issues to biological diversity caused by habitat degradation, disruption of habitat, and over-exploitation of the environment. Biodiversity is a minute and significant element of life on earth. Despite the volume, the gigantic diversification and complex nature of the relationship between species keep our ecosystems functioning and our economies very productive.

The dramatic change in the activity and attitude of humans is putting the plant and animal species at a higher risk of going into extinction. Only the highly adaptive species have occupied the empty and void ecological niches due to their high tolerance to stressful conditions. On this note, assessments of the biological diversity using different scales and prediction of its ranking under different strategies in the nearest future provide the foundation for various administrative solution in conserving the natural habitat. There should be a purposeful consideration of presenting different standards to shield the fragile points and/or review the former diversity indicator, so with proper classification of hints and guide on the awareness of their sturdiness and loss of energy. Substantially, the results of these indices can be sorted, operated, and surveyed successfully. However, their use can justify the reduction of factors such as change in land use, human activities like bush burning, hunting, and change in climate (Izah et al. 2018).

For effectiveness and result, these measures require pivot from regions, nations, and international law, policy, and regulations. As an idea, biodiversity protects the working and supportability of biological systems and environments administrations against anthropogenic changes and degradation (Seiyaboh et al. 2018a, b). The issues from biodiversity loss can affect future life choices. While the condition of biodiversity on planet is more terrible than recently suspected, numerous biodiversity appraisals have not been able to communicate the enduring effect of sudden land changes. Most secured regions and biodiversity areas of interest on the planet do not have a particular administration plan. All in all, there are no normal public making arrangements for secured regions, in which this off-base technique should be changed. Researchers desire to assist state run administrations with acquiring a harmony between financial turn of events and biodiversity preservation by laying out the administrations that nature can accommodate individuals and attempting to evaluate biodiversity with suitable and effective lists, just as recognizing what is missing with diminished biodiversity (Kigigha et al. 2018a, b).

4.1.6 Advances in Biodiversity Research

Information on biodiversity has expanded over the most recent 10 years, as has the acknowledgment that something should be done to neutralize the deficiency of species, populaces, and environments. There is still a lot to be found out with regard to biodiversity and its relationship to the working of our reality, so logical examination and discussion proceed. Furthermore, results are being applied to endeavours to preserve biodiversity now.

Ecologists conduct research to understand biodiversity better, measure the loss, develop strategies for conservation, and utilize the proposed strategy for better result (Fig. 4.2). More result is sought on existing species, their location/ecology, and their

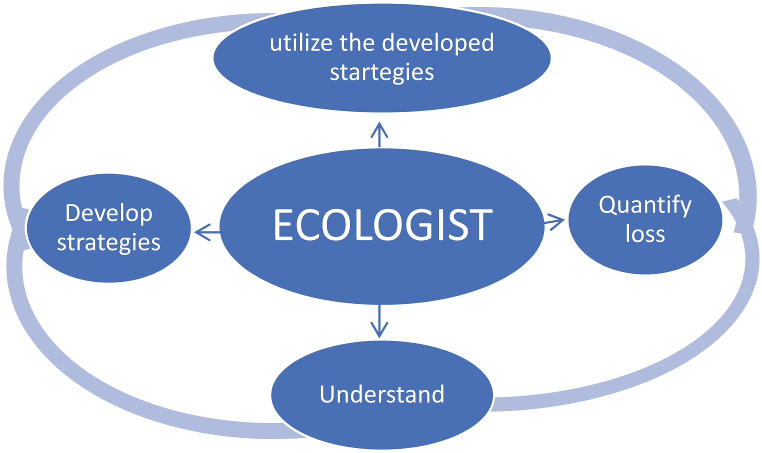

Fig. 4.2 Focus of ecologist in biodiversity research

relationship (Aigberua et al. 2018). For intervention the following questions must be asked and must focus on inventorying and monitoring biodiversity based on:

- Abundance and functions of species
- Interactions among species
- The significance of biodiversity in maintaining or enhancing the quality of human life (Fig. 4.3)

While the unanswered questions are as follows:

- How fast is biodiversity lost?
- Which location losses more?
- What are the causes of migration or extinction of specie from a particular location?
- What are the secondary impacts of those losses stated?
- What management interventions will produce the best result in preventing the loss of biodiversity?

4.2 Global Food Security

Food and agricultural biodiversity involve the domestication of plants and animals in systems such as crop, livestock, forest, and aquaculture, and harvested for food (FAO 2019c). These processes are adapted globally with management systems based on the peculiarity of the environment. But the world is suffering today because countries do not have the sufficient ability to generate food for the populace and this is peculiar to developing and under developing countries of the world. Food production in the world today comprises systems from traditional/conventional

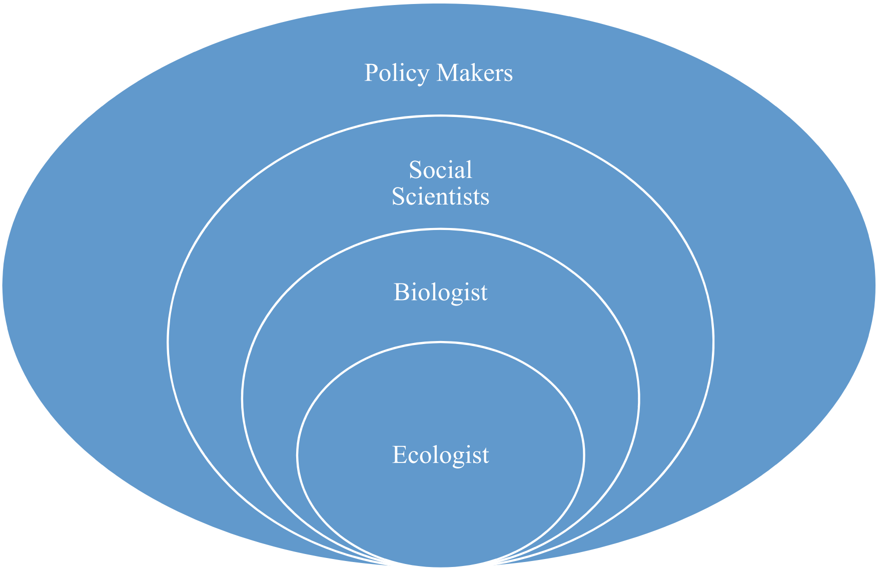

Fig. 4.3 Inter-disciplines harnessing together to improve biodiversity

agricultural systems to high industrialized input systems which generate high production (Izah et al. 2017a, b).

Generally, an assessment of methods of production using alternative techniques of agriculture by small farms may be almost four times energy efficient than large farms that employ conventional use of technology. The high use of synthetic chemicals, use of fuel for farm machines, use of pumped water, and other external inputs are factors that infer the low energy efficiency by conventional systems (Heller and Keoleian 2000).

4.2.1 Food Security and Sustainable Development Goals

The year 2030 Agenda for SDG 15 elaborates on the protection, restoration, and promotion of sustainable activities in terrestrial ecosystems, how to manage forests in a sustainable manner, fight desertification, and reduce the degradation of land and biodiversity loss (Aigberua et al. 2017; Kigigha et al. 2017) The Agenda also recognized the extent of global biodiversity loss, how much the environment has been degraded, and all the stress the negative impacts have imposed on the environment in terms of provision of water, food, health, and food security worldwide. In lieu of this, a strategic plan for biodiversity was proposed from 2011 to 2020 which was adopted at the tenth Conference of Parties.

4.2.2 Agriculture and Biodiversity Loss

Agriculture is the largest challenge to biodiversity loss and affects it directly by destroying the natural habitat for food production and the intensification effects and greenhouse gases generation from fossils (Izah and Aigberua 2017). Agriculture occupies about 40% of the land surface in the world today and 12% of the global land area is occupied by the protected wildlife areas. It was estimated that 12% out of 12,000 animal species live outside protected areas and 43% of invertebrates and terrestrial plants live in gap areas. It is quite important to integrate management for general agriculture so as to ensure a conservative approach (Bruns 2017). Over intensification of agricultural area can affect the natural ecosystem by reducing its capability to support various life forms, thereby increasing desert surfaces.

4.3 Plant and Animal Sources of Food

4.3.1 Food of Plant Origin

Food from plant sources plays an important role in diverse diets around the world. It is crucial for basic human health and nutrition. Foods of plant origin are generally classified into fruits, grains, legumes, vegetables, nuts, and seeds. Foods such as bread, pasta, cereals, as well as fruit purées and jams, are considered plant-based foods as they are processed from plant-sourced products. Other edible ingredients derived from plants include oils from vegetables, sugars from sugar cane crops, culinary herbs, and spices. Many plant-based foods may be consumed raw while, the grainy ones usually have to undergo some form of processing to make them safe and edible (Izah and Aigberua 2017).

4.3.1.1 Cultivation

The series of activities revolving around growing and caring for plants is referred to as cultivation. Since time immemorial, mankind has relied on this process to provide cultivation of food from plant sources that take various forms. The following are the common types of cultivation that exist: shifting cultivation, subsistence farming, intensive farming, extensive farming, commercial farming, and dry land farming. In the shifting cultivation system of farming, plots of land are cultivated temporarily after which they are abandoned and left to revert to their natural vegetation, while another plot is being cultivated. Subsistence farming is a type of farming aimed at self-sufficiency. Those engaged in subsistence farming are focused on cultivating enough crops to feed themselves and their immediate families.

Commercial agriculture on the other hand is farming done on a large expanse of land and with the use of mechanized equipment. It is usually for profit. Intensive farming is another method of plant cultivation that is characterized by high inputs in form of capital, fertilizers, pesticides, and labour. In this kind of farming, there are higher crop yields per unit land area but the environment risks being damaged as a result of the activities involved in this type of framing (Iyiola et al. 2019). The alternative to intensive farming is extensive farming. This type of farming utilizes small inputs relative to the land area being farmed; hence, the environment is shielded from damage. Monoculture is another common method of cultivation which is the practice of growing a single plant, or livestock species in a field or farming system at a time, while crop rotation aims to cultivate different crops to improve soil structure and fertility. All these types of cultivation methods are employed in various parts of the world and food supply comes from these practices (Izah et al. 2017a, b).

4.3.2 Nutritive Values and Contribution to Well-Being

In many parts of the world, traditionally consumed plants possess great nutritive value. Fruits and vegetables are generally the richest sources of multiple nutrients among plant-based foods. Edible leaves, flowers, and stems of plants can usually be consumed raw or cooked to provide nutrients. Grain products which consist of legumes, cereals, and nuts are also foods known for their high carbohydrate, protein, and lipid contents, respectively. Rich in fibre, plant-based foods are also known for their macro- and micronutrient content. The macro-ingredients include proteins, carbohydrates, and lipids, while micronutrients consist of minerals, vitamins, and trace elements. Many of these plant foods also possess phytonutrients, e.g., polyphenols and carotenoids. Phytonutrients, otherwise known as phytochemicals, are complex compounds that plants synthesize and accumulate and which are capable of promoting health or preventing diseases.

The health benefits derived from plant-based fruit are undeniably great. From time immemorial, fruits, nuts/seeds, vegetables, grains, and products derived from plants have been known to good sources of nutrients and energy. Fibre, minerals, and vitamins that are needed for optimum health can be found in plant-sourced foods. Studies have reported that the increased intake of plant foods can drastically reduce incidences of chronic diseases and metabolic symptoms. Also, asides from the health benefits derived from them, plant foods find usefulness as functional ingredients in food applications such as antioxidants, antimicrobials, natural colorants, and improving sensory and textural properties (Yasmina and Michael 2019). Foods of plant origin continue to be a topic of interest and intensive research to investigate and ascertain their potentials for health and well-being. The potential of many wild or cultivated macrofungi is not clearly understood; however, they are still wildly consumed for medicinal purposes (Karun et al. 2016). Liu et al. (2021) examined the phytochemical profile as well as the antioxidant, anti-Alzheimer's disease, antidiabetic, antibacterial, cytotoxic, and hepatoprotective activities of

Elsholtzia rugulosa and reported that this species of the Labiatae family has a long history of use as a herbal tea and local medicine in China. The study investigated the total phytochemical composition, and multiple biological functions of this plant to fill the information gap about its biological activities. The study found that *E. rugulosa* exhibited strong antioxidant, hepatoprotective, cytotoxic, and acetylcholinesterase (AChE) and α-glucosidase inhibitory activities and has an antidiabetic potential and anti-Alzheimer's disease drugs (Liu et al. 2021).

Piperine is another plant source food whose weight loss effects have gained considerable attention (Wang et al. 2021). *Opuntia ficus-indica* extracts have shown promise in diminishing the growth of colorectal adenocarcinoma cells in humans and a xenografted-immunosuppressed mice model. The study demonstrated the chemo-preventive effects of *Opuntia ficus-indica* extract and its purified compound Isorhamnetin-3-*O*-Glucosyl-Rhamnoside, revealing their potential as an alternative in the treatment of colorectal cancer (Antunes-Ricardo et al. 2021). The fruit peels of *Passiflora edulis* (Passifloraceae) (yellow passion fruit) are considered a rich source in bioactive compounds with a lot of beneficial health properties. A study carried out to evaluate the effects of *P. edulis* fruit peel extracts in type 1 diabetics model and the potential vasorelaxant effect revealed that *P. edulis* fruit peel extracts is a good source of valuable bioactive raw material for production of nutraceuticals or pharmaceutical products (Cabral et al. 2021).

Another beneficial plant food source is the leaves of mulberry. They are rich in phenolic compounds and exhibits antioxidant activity. Two mulberry species *Morus alba* L. and *Morus nigra* L. were characterized and evaluated in terms of their phenolic composition and antioxidant activity and the findings suggest the crucial role of phenolic compounds as antioxidant agents and demonstrate that leaves of both mulberry species can be used in the food sector as a valuable source of phenolic compounds with bioactive potential (Polumackanycz et al. 2021). Given its excellent nutritional properties (proteins, phenolics, flavonoids), the morphological parts of *Amaranthus viridis,* which includes its leaves, inflorescence, seeds, roots, and stem, can be a potential source of protein, fibre, minerals, and antioxidant compounds (Silva et al. 2021). Other beneficial plant foods are *Mentha longifolia* which can alleviate exogenous serotonin-induced diabetic hypoglycaemia and relieves renal toxicity (Ali et al. 2021). Raspberry is a source of dietary fibre and phenolic compounds, which when metabolized by the gut microbiota results in the production of short-chain fatty acids (SCFAs) and phenolic catabolites and affects the microbial activity depending on the bodyweight condition (Núñez-Gómez et al. 2021), and turmeric has antioxidant potential (Gonzales et al. 2021).

The need to boost the immune system naturally has generated interest in consuming healthy foods. Vegetables that is rich in compounds which are bioactive compounds, and can be called "superfoods" that promotes overall health and improve immunity. Green leafy vegetables remain an excellent source of fibres, proteins, vitamins (niacin, ascorbic acid, choline and alpha-tocopherol), carotenoids, minerals (calcium, iron, and phosphorus), and polyphenols (Opazo-Navarrete et al. 2021; Izah et al. 2016a, b).

4.3.3 Socio-Economic Benefits of Foods of Plant Origin

Several economic benefits can be derived from plants foods. The Bambara nut is one such high-value crop that can be used effectively in several food applications. It is a good protein source, fats, carbohydrates, and other minerals. It is rich in calcium, iron, potassium, and fibre (Murevanhema and Jideani 2012) and possesses the potential to replace wheat in the making of bread, pasta, and other confectionaries (Multari et al. 2015). Bambara groundnut seeds can be eaten in several ways. Immature seeds could be eaten fresh, grilled, or boiled, while mature seeds are usually boiled, roasted, or pounded into flour to make traditional dishes (Mayes et al. 2019). In some areas of Africa, Bambara groundnuts have increasing market value. They are roasted and consumed as a salted snack, and the seeds can be processed and canned too. However, there is less promotion of products from Bambara in the local or international markets and advocacy of new products are needed that can present nutritional and culinary advantages which are inherent (Izah et al. 2015; Hillocks et al. 2012).

Legumes also play significant roles by delivering various multiple services and provide high-quality food and feed for humans. Legumes are competitive because they have diverse socio-economic and environmental benefits. They can be used to increase the yield of crops and reduce external input and used in modern inter-cropping systems. They can fix nitrogen in the atmosphere, release organic matter in the soil, and stimulate nutrient circulation in the soil (Stagnari et al. 2017).

Non-Wood Forest Product (NWFP) has the potentials to contribute to socio-economic uses because they function and contribute indirectly to food security. They can contribute up to 40–50% of cash income to rural dwellers (FAO 2020). Examples are the use of bush mango for ogbono seed in Nigeria, oil palm, bread fruit, wild spinach, oil bean, bitter cola, etc., and their products command high price during trade. NWFP can contribute to food security by consumption and selling of the resources.

4.3.4 Plant-Based Food and the Environment

There are numerous underutilized legume crops although nutritionally important because of their rich nutritional profile, adaptability to adapt to adverse conditions of the environment, and ability to grow in soils that are deficient in nutrients, which are highly advantageous for sustainable cultivation. The Marama bean (*Tylosema esculentum*) and Bambara groundnut (*Vigna subterranea*) are two crops of this kind. Given their nutritive value and high tolerance to low water as compared to commercially available legume crops like soybean and cowpea, these crops (Marama and Bambara) have the potential to sustainably produce food and feed resources in the future. However, despite their huge potential for sustainable production, the Marama bean (*T. esculentum*) is still to be cultivated domestically, while the Bambara groundnut is cultivated majorly by small landholders as a subsistence crop. Other legume crops with great potentials but underutilized include pigeon pea, yam bean, and lablab. These crops are highly rich in proteins and can support future global protein demand by biodiversity and can partially or completely substitute animal proteins in the human diet. To make the best of their potential as environmentally friendly and adaptive cash crops, "intensification in researches in agronomy, genetics, and food research is essential to move these underutilized crops out of obscurity".

4.4 Foods of Animal Origin

In many countries in the world, foods from animal sources are major contributors of nutrients in the food supply chain. Animal Source Foods (ASF) include food items from an animal source such as eggs, meat, fish, milk, cheese, honey, and yogurt (Murphy and Allen 2003). Among these foods, those derived from the muscle of animal or meat are good examples of food and products that are dense in nutrients and naturally nutrient rich (Lofgren 2013). Meat is a valuable product from livestock and is composed of diverse protein and amino acids, fats, minerals, fatty acids, vitamins, and other bioactive components. The importance of meat is derived from its high protein quality and bioavailable minerals and vitamins which are of high concentration (FAO 2019a).

4.4.1 Breeding, Processing, and Preservation

While milk, eggs, and dairy products are animal source food, muscle foods which include veal, beef, poultry, lamb, pork, and processed products derived from them are major foods in the food chain (Lofgren 2013). The breeding, processing, and preservation of muscled animal source food involve a long process that starts with the rearing of livestock and ends in slaughter and meat harvest. Since the production, and preparation, of food of animal origin has been the concern for public health (Hilbert et al. 2014), the principles of meat hygiene are usually employed to safeguard public health. This is especially important as a primarily local food-borne disease can easily become a global issue because food-borne pathogens spread more readily because of increased trade in livestock worldwide and the food products derived from them (Hilbert et al. 2014).

Hilbert et al. (2013) identified *Campylobacter* sp. and *Salmonella* sp. as the major pathogenic bacteria which commonly associated with poultry meat. The intestines of otherwise healthy animals can harbour these pathogens which then spread to the carcass surface during slaughter. It is possible for seafood and fresh fish to be contaminated with various pathogens resulting from poor sanitation during handling and processing. Examples of the pathogens are *Vibrio cholera, Escherichia coli,* *Listeria, Salmonella* sp., etc. The safest measure is to purchase foods of animal origin from places that are reliable and it is important for authorized and qualified veterinarian to inspect such animal products.

Food safety issues, however, do not end at the handling or processing stage but continue till the consumption stage. The application of clean and hygienic practices can help maintain the safety and quality of foods that are of animal origin and reduce microbial and chemical hazards in the production of foods. The temperature of cooking, for example, affects both the taste and safety of food. Cooking meat at increased temperatures makes it safe to eat; hence, safe cooking temperatures at the core of meats must be attained during preparation. To achieve adequate safety of food before consumption, it is essential to have an understanding and implementation of safe handling, storage, and cooking practices for foods of animal origin (Attrey 2017).

4.4.2 Nutritive Values of Foods of Animal Origin

Animal source food reinforces and contributes to food and nutrition security by providing both calories and nutrients needed for the proper functioning of the human body (Roesel 2019). The nutritional merit of ASF is one of the most difficult and least accounted values of livestock (Turk 2014). Extensive and comprehensive nutrient databases for meat and meat products however exist and one of the most comprehensive listings of nutritive values of all meat, poultry, and other meat products is a database developed and maintained by the United States Department of Agriculture. This extensive database of complete nutrient profiles for more than 700 beef, 200 pork, 195 lambs, 85 veal, 140 poultry, and 130 turkey products is available for reference for particular products of interest (Lofgren 2013).

Globally, animal source food (including fish) provides approximately 17% of the energy needed by humans and over 35% of the required dietary protein. In developing counties where the diet of children, especially in the rural areas, is primarily plant-based and nutrient-deficient, essential minerals and vitamins such as vitamin B, riboflavin, vitamin A, vitamin E, iron, zinc, calcium, and vitamin D can be derived from foods of animal source. Although the above-mentioned nutrients are not unique to animal sources and can be derived from non-animal sources (Vesanto et al. 2016), animal proteins are more digestible (about 20–30%) than plant protein forms (96–98% vs. 65–70%) and their minerals and vitamins are in higher and in more bioavailable levels than the plant protein forms. Vitamin A, which is an important micronutrient for development of children, is present in the animal source force (Murphy and Allen 2003). There are six micronutrients commonly found in foods of animal origin: calcium, zinc, iron, vitamin A, vitamin B2, and vitamin B12. These play a critical role in the growth and development of young children. Inadequate intake or poor absorption of these micronutrients is linked to stunted growth, irreversible cognitive impairment, anaemia, night blindness, neuromuscular deficits, mental disorders, and death (Black 2003; Murphy and Allen 2003).

4.4.3 Socio-economic Benefits of Foods of Animal Origin

Livestock has a critical value for its role in poverty alleviation, conflict mitigation, prevention, and resolution (Turk 2014). Small ruminants are even more important in terms of providing economic stabilization to vulnerable households in rural economies. Sheep and goats are used to substitute the nutritional deficits in cropping seasons (Al-Khalidi et al. 2013; Turk 2014). The traditional livestock system of production in Ghana contributes to the well-being of households domiciled on the farms. Income is generated from the sale of small ruminants such as goats and sheep and is sources of non-pecuniary benefits as insurance, manure production, farm diversification, and savings. These ruminants can also be sources of physical cash for the sustenance of the financial needs of the farmers (Adams et al. 2021; Weyori et al. 2018; Bettencourt et al. 2015).

There is a certain social value attached to animals in some societies. Status in the community is often based on the number of animals an individual or a household owns. In some cultures, in place of dowry payment in marriage, cattle, sheep, and goats are given (Turk 2014). Livestock can be a valuable means of promoting gender equity by identifying and supporting women's roles in livestock rearing. Women are often owners, processors, and users of livestock products. This strengthens their decision-making power and capabilities and is key to elevating social and economic empowerment.

4.4.4 Foods from Animal Sources and the Environment

Livestock plays a major role in the rural livelihoods and the economies of developing countries, and the impact of animal production on the environment is very significant (Herrero et al. 2012). Due to population growth, urbanization, and increasing income, there is an increase in demand for animal products (FAO 2019a, b, c; Davis et al. 2016). According to a study conducted by United Nations in 2006, the livestock industry discharges more greenhouse gases which causes climate change, as measured in CO_2 equivalent, than transportation. The sector is becoming one of the top contributors to environmental problems on both regional and global levels. Smarter methods of production are urgently needed to preserve the environment (FAO 2006). Plant-sourced foods are typically considered better for the environment, although the meat production, and other animal source products such as eggs if done in an industrial, highly efficient manner, may still be environmentally friendly. For example, raising goats for meat and milk has been favoured by certain environmental activists, such as Mahatma Gandhi (Gandhi 2008).

With increased demand for meat and dairy products every year, problems of degradation of land, climate change, water and air pollution, water shortage, and biodiversity loss associated with meeting these needs require proper attention. As a result of the threats, animal sources of foods pose to sustainability, their environmental footprint, and negative impacts on the health. The planetary diet of the EAT-Lancet commission, which consists of 37 world-leading scientists from 16 countries from various scientific disciplines, has advised substantial reductions in consumption of foods from animal origin (Willet et al. 2019). This was argued that the experience of marginalized women and children in low- and middle-income countries whose diets regularly lack the necessary nutrients was not duly considered as animal source food offers the best source of nutrient-rich food for young children, as earlier expounded in the previous section. As livestock sector continues to impact already scarce water resources, contributing to water pollution from animal wastes and chemicals in fertilizers and pesticides used to spray feed crops, positive environmental values are urgently needed to preserve the environment.

4.5 Food Security and Biodiversity Conservation

Biodiversity contributes significantly to food production and it is indispensable to food security, sustainable development, and the supply of many vital ecosystem services (FAO 2019b). Reconciling food security and biodiversity greatly derive from taking into consideration the prominent role biodiversity plays in building resilience into production systems (Kolawole and Iyiola 2018). To generate insights on the food–biodiversity nexus remains a key challenge in the twenty-first century, especially with the reality of perpetual hunger and biodiversity loss existing side by side. As such, papers have begun to address the connection between food security and biodiversity conservation.

Agriculture which includes crop production, livestock rearing, forestry, and aquaculture makes livelihoods more resilient to shocks and stresses (FAO 2019b), yet there is a legitimate concern about the negative impacts of agriculture on biodiversity. While many components of biodiversity are declining on genetic, species, and ecosystems levels, there are opportunities for sustainable biodiversity management for food and agriculture. Improvement in the use efficiencies of water nutrients and production processes could increase food production while reducing negative impacts on the environment per unit of production. Other biodiversity friendly practices include nutrient cycling, water cycling, proper and efficient use of fertilizers, improving water storage by planting vegetative cover, and enabling the condition of the soil for storing soil carbon (Mortimore et al. 2009). One of the ecosystem services provided by the biodiversity is provisioning of food. As biodiversity declines, food security is threatened. A decrease in biodiversity adversely impacts opportunities for ensuring increased options for human nutrition and improvement of livelihoods. This is so because the dependence on these biodiversity for protein source will reduce as their abundance is reduced. Biodiversity is closely linked to food production, income, and the environment; hence, it is critical to safeguard the potential diversity of nature that plays a major role in food security and agricultural process that is sustainable (Sundar 2011).

4.6 Measures to Fight Against Biodiversity Loss

4.6.1 Farming Sustainability

The threats on biodiversity are divided into two: the direct and indirect threats. The indirect threats are pressures, such as climate change, urbanization, population growth, and market trades on biodiversity. The direct threats are human actions, such as deforestation, overfishing, indiscriminate use of agro-chemicals, and intensity in production systems, land and water use management, and ecosystem degradation on biodiversity. To fight biodiversity loss, food and agriculture requires sustainable management, use, and conservation in activities. This implies that the production systems should be friendlier to biodiversity, which will favour more crops and livestock species. Natural habitats can also be maintained for sustainable production, soil management, and reduction in the usage of agro-chemicals (Pilling et al. 2020).

In the world today, the custodians of biodiversity are the forest dwellers, farmers, livestock keepers, and fisher folks, which comprises 84% of all farms in the world but manage only 12% of agricultural lands (Lowder et al. 2021). These custodians are small holders of less than 2 hectares of land use and have higher yields and house larger species of biodiversity on the average than larger farms (Ricciardi et al. 2021). Sustainable food production systems can be promoted by improving agricultural practices which are based on local knowledge. New technologies and management practices such as smart farming and mechanized farming systems which can result in increased biodiversity conservation are a call for action to agricultural producers, scientists, and stake holders in the agricultural sector. These improved methods are not one way; it may range from agro-ecology to precision farming. The use of these principles is relatively a function of the scale of farming; industries that produce in large quantities for commercial supplies will function based on its target and market audience and requirements.

4.6.2 Recognition of Biodiversity

It is important for countries to better recognize the significance and values of biodiversity conservation. The only permanent intergovernmental body that addresses the biological diversity for food production and agricultural practices is the Food and Agricultural Organization's (FAO) Commission on Genetic Resources for Food and Agriculture. This commission is in charge of policy development and negotiation for member states of about 178 countries and the European Union (Ricciardi et al. 2021). They mandate sustainability, use, and conservation of genetic resources and share benefit for food production and agricultural activities. Technical guidelines and policies have been adopted as well as the development of global plan of action on gene preservation. Currently, a policy response is being developed towards the State of the World on Biodiversity for Food and Agriculture (FAO 2019b). There is dire need to further improve sustainability of genetic resources and strengthen policy makers, consumers, and civil societies across the environmental sectors that are into food and agriculture. Recognition of biodiversity can also be improved by creating awareness on the ecosystem services by biodiversity consumers, civil societies, educational institutions, etc. This can go a long way in complementing the dictates by FAO.

4.7 Biodiversity Friendly Approaches to Food Production and Economic Implications

The sustenance and conservation of the ecosystem cannot be possible without considering the sustainability of food and agricultural biodiversity which calls for the integration of genetic resources, species, and ecosystems.

4.7.1 Biodiversity Friendly Approaches to Food Production

Some environmental friendly approaches have been strategically adopted by different countries in Africa to sustain biodiversity to food production. Some of these approaches are as follows:

- The management of landscape
- The application ecosystem approach to fisheries management
- Restoration of the environment
- Diversification
- Creation of gardens in the home
- Agroforestry practices
- Processes of polyculture or aquaponics
- Organic processes in agriculture
- Sustainable management of the soil
- Management of microorganisms
- Conservative agriculture which may occur on-site, e.g., protected areas, on farm management or off-site, e.g., gene banks, zoos, culture collections, botanic gardens
- Enrichment planting
- Integrated plant nutrient management
- Reduced-impact logging
- Pollination management
- Integrated pest management domestication
- Base broadening

4.7.2 Conservation Agriculture

This is a strategic approach for sustaining agricultural production for both on-site and off-site. The on-site approach of this system encourages diversification of plant species, maintains top soil, and minimizes soil disturbance (no tillage). This is with the aim to guide against soil erosion and degradation, to improve soil nutrient and biodiversity, and to preserve natural biological processes above and beneath the top soil which aid in moisture and nutrient use efficiency while optimizing the farm yields. The off-site approach deals with gene banks, zoological gardens, culture collections, and botanic gardens. Gene Bank is a manmade bio-repository that preserves the genetic resources of organisms in an ecosystem under a simulated ecological environment for a long period of time till subsequent sustainable utilization (Nair et al. 2017). Zoological garden refers to a facility constructed for animals to care for them, and bred them for conservation purpose. A continuous existence of a standard zoological garden that takes care of the physical health, long life, and reproduction of animals has a great influence on the conservation of animals, education, and economy of a nation.

4.7.3 Organic Agriculture

This involves the use of cultural and biological approaches to control weeds and pests, to increase plants biodiversity, and to preserve, replenish, and stabilize soil fertility for optimal production of farm crops. This practice promotes healthy and nutritional agricultural products that are free from harmful component both to human and environment. These principles guide every process stage of agricultural product from the production, processing, delivery, storage, and to the consumption without the application of additives. The present method of agricultural system which intensively depends on the use of artificial efforts is largely responsible for the world's food and crop production (Crowder and Illan 2021). This method has, however, greatly led to the dilapidation of the ecosystem through climatic change (Crowder and Illan 2021). Organic agriculture has been found as a suitable alternative to the conventional system of agriculture due to the natural use of biomaterials in farming (Barbieri et al. 2021).

The use of organic agriculture has shown to be highly profitable, increased biodiversity, improved soil health, decreased the use of pesticide, produce healthy food crops, and positively impact the economy (Barbieri et al. 2021). Saffeullah et al. (2021) stated that about 160 countries are presently practicing organic agriculture and it is expanding to more countries. Worldwide, 0.99% of the agricultural system practised constitutes organic agriculture with 40% of the organic agricultural land (17.3 million hectares) practised in the Oceania region, 27% (11.6 million hectares) practised in Europe, 15% (6.8 million hectares) practised in Latin America, 8% (3.6 million hectares) practised in Asia, 7% (3.7 million hectares) practised in North

America, and only 3% (1.3 million hectares) of the world's organic agriculture practised in Africa.

4.7.4 Integrated Pest Management

This is a systematic eco-friendly approach whereby biological, cultural, and chemical practices are used in controlling and managing infestation of pests in the production of agricultural produce. This method thrives by the study and use of existing widespread information on the life cycles of pest and its interactions with the ecosystem for a lasting prevention. The Bio-integral Resource Center in Berkeley, California developed five phases of operation for this approach to be successful, considering the pest control processes and pesticide use strictly in each phase of the process line. These five phases are as follows:

- There must be a proper identification of the targeted pest as most of the suspected pests are actually not pest but contributor and benefactor to the ecosystem.
- After a pest has been identified, its number and activities have to be monitored to check its potential threat to the ecosystem.
- The intolerable level of the pest activities has to be set so as know when there is a need for the application of pest control. This intolerable level is determined by the economic effect, health implication, and legislative effect of the pest activities which can be determined using different sophisticated models.
- Treatment options should be explored before embarking on treatment. Prevention of the use of pesticide is of major priority in the treatment option next to cultural method or sanitation, then physical or mechanical, then biological, and finally the chemical application of pesticide. If all other options have been exhausted and there is an absolute need for the application of pesticide, pesticide that focuses on the pest alone and has no negative effect on living organism in the ecosystem should be considered.
- Since this type of approach is a continuous process, the effect of the treatment should be monitored afterwards to keep the number of the pest and its activities under a tolerable level.

The cultural or mechanical approach involves the manipulation of the soil and crop environment to discourage pest activities without the application of chemical. Biological approach involves the introduction of parasitic insects that are not harmful to the ecosystem to control the destructive pest by killing them or disrupting their breeding cycle. Chemical approach involves the application of pesticide directly to pest in a quantity that controls pest activities and not harmful to the ecosystem. Chemical approach is used when other methods are not adequate to protect agricultural production.

4.7.5 Agroforestry

This is a farm management system whereby farm crops and trees are cultivated together at the same time. It involves integrating forestry with farming systems to build a suitable environment and generate good economy. This is with the intention to diversify land use by imitating the natural ecosystem, thereby enhancing and sustaining the farming system by increasing biodiversity, and reducing erosion and carbon production. Langford (2014) carried out research on maize production in Zambia integrating forestry with the maize farming. The result from the research showed that maize yields of 4.0 tonnes per hectare was obtained compared to an average maize yield of 1.1 tonnes per hectare in Zimbabwe (Bayala et al. 2010).

4.7.6 Landscape Management

This is a systematic approach which involves the management of landscapes by regulating land's spatial structures and its dynamics for economic development and ecological value. This approach controls unhealthy plants that compete with the soil nutrients, water, and soil light needed for growth by the landscape plant. To achieve sustainable landscape management, there is a need to integrate landscape governance with different contributing factors to landscape ecology (kozar et al. 2014). In Central Africa, Walters et al. (2021) have used landscape management approach as one of the strategies in alleviating poverty and maintaining forest biodiversity. The two main participatory landscape management approaches explored for this are as follows:

- Incorporation of inter-disciplinary researchers into the Sangha Tri-National (Cameroon, Central African Republic, and the Republic of Congo) landscape to apply trans-disciplinary knowledge to landscape conservation.
- Landscape zoning where inter-disciplinary researchers mapped out Bateke-Lefini (between Gabon and Republic of Congo) landscape local land and its resources.

4.7.7 Sustainable Soil Management

This approach generally involves the practical preservation of soil health and natural fertility by preventing degradation through erosion, thereby reducing the need for fertilizer, pesticide, and herbicide. This approach aims at decreasing erosion on soil; improving the organic matter content in the soil; encouraging a balance and cycle in soil nutrient; averting, reducing, and mitigating soil salinization and alkalinity; preventing contamination of soil through pest infestation; minimizing soil acidity; preserving and enhancing biodiversity of the soil; minimizing soil sealing; averting and mitigating soil compaction; and improving water management of the soil (FAO 2021).

4.7.8 Integrated Plant Nutrient Management

This is a cost-effective management approach which involves the optimization of the physical, chemical, biological, and hydrological properties of the soil for sustainable improvement of farm productivities while minimizing land degradation. This is carried out by the integration of organic and inorganic sources of plant nutrients to increase the soil nutrient to required level, thereby increasing crop yields. The use of all these approaches is increasingly recognized yet its coverage has not been adequate enough. And if the trends in the biodiversity declination continue without proper means to secure it, the available ecosystem services may become costlier or even cease to be available for future generations. Based on the steady population increase, industrialization, persistence malnourishment, and the danger of biodiversity loss due to the agricultural system that are in vogue in Africa, the aims of biodiversity conservation and food security appear unachievable. There is an urgent need for biodiversity conservation as the present rate of biodiversity loss ranged between 700 times the natural rate and 10,000 times the natural rate (Chappell and Lavalle 2011). There is still possible rapid declination in biodiversity as there is 1–10% of the African's species predicted lost in the coming years.

4.8 Food Security and Biodiversity Loss

The declination in African's biodiversity and food insecurity cannot be viewed or addressed separately as they are related in several ways. Food security can be viewed from four different perspectives which are food availability, access to the available food, optimal use of the accessed food, and the stability or sustainability of the food supply through biodiversity. The availability of food in the ecosystem depends on the quantity and the quality of wide diversity of food produced and distributed to meet the nutritional requirement of the ecosystem (Iyiola and Iyantan 2021). Many constituting factors of biodiversity greatly contribute in determining the food produced and food distributed within an ecosystem. For several years, genetic improvement has aided the production of food to a great level in meeting up with the consistent population increase worldwide.

Nevertheless, the practice of intensive selection of few species and breeds has resulted into declination of genetic biodiversity which may lead to a risk in future food security. Accessibility to the available food in an ecosystem depends on the certainty of the food distribution, availability, and affordability in the ecosystem. The physical, social, and economic constrains to the purchase of food by the poorest and most marginalized people in the community needs to be addressed for easy accessibility of food when the need arises. Food biodiversity through subsequent food production, storage, and processing by the community can improve their economic value and improve their accessibility to food. Optimal utilization of the accessed food mainly deals with the methods used in the combination and processing of food products to provide nutritious diets in the ecosystem. The nutritional content in food differs across plant and animal species, across varieties and breeds within species, across processing factors, and other services provided by biodiversity. For instance, some people purify the water they use for domestic purpose through material obtained in their immediate ecosystem. Some also depends on animal dung for fuel or bio-manure for farmland cultivation (FAO 2020).

The fourth perspective has to do with the stability or sustainability of the food supply through biodiversity. It refers to the continuous availability, accessibility, and optimal utilization of food. This can majorly be achieved through biodiversity. The seasonal supply of different varieties of food under different conditions in an ecosystem enhances its sustainability. Some food crops exhibit adaptive genes to harsh environmental conditions around them and some can easily cope with outbreak of pest or diseases. Biodiversity conservation helps in the continuous supply of food in the future regardless of the challenges faced by the ecosystem.

4.8.1 Economic Implications on Biodiversity

Biodiversity supplies conserve a wide range of food variety which provides genes for the development of local species by increasing crop yield and building immunity to pest and diseases, thereby improving the economy of the community. Human livelihood depends greatly on biodiversity as it provides many benefits to the sustenance of the ecosystem:

- Ecosystem services, e.g., optimal usage and protection of water resources in the ecosystem, soil formation and conservation, soil nutrient preservation and recycling, stability of the micro and macroclimate, and conservation of ecosystems.
- Biological services, e.g., the sustenance of food security, medical innovations, industrial raw materials supplies, ornamental plants production, and species and gene diversity.
- Social benefits, e.g., research and educational benefits, tourism and recreational benefits, and cultural values.

4.9 Conclusion

Human activities such as speedy increase in world population, industrialization, and increase in land use have been the major cause of biodiversity loss. Issues such as the changes species and ecosystem services are observed to affect both plant and animal origin of food sources. Biological resources provide food, shelter, warmth, and medicine to humans and their presence in the natural environment cannot be neglected. They can function in diverse ecosystem services and must be protected. They are affected by destruction in habitat, alteration in composition of ecosystem, and the introduction of exotic species. The implication of biodiversity loss is severe just as the benefit of biodiversity is numerous. If biodiversity degradation persists, it has a tendency to affect the local and the world economy resulting in a continuous decline in the ecosystem services and other benefits derives from biodiversity. It must be noted that biodiversity degradation will consciously affect not only human but also the entire ecosystem.

Presently, researches have been geared towards sustainable diversity which incorporates an inter-disciplinary action involving the policy makers, social scientists, ecologists, and biologists. With the aim of improvement in biodiversity, several questions and issues are being faced on how and when biodiversity is lost and the interventions that may produce the best result for their optimal presence. Various plant- and animal-based foods have been discovered to contain various essential nutrients needed by the body and friendly approaches must be applied to preserve them, such as diversification, organic processes, landscape management, and soil management. In continuation, friendly approaches to food production and conservation strategies must be ensured for sustained food production.

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Chapter 5
Benefits and Threats of Biodiversity Conservation in Stubbs Creek Forest Reserve, Nigeria

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Abstract The Stubbs Creek Forest Reserve (SCFR), which was officially established in 1930, is a biodiversity hotspot containing various ecosystem types, including freshwater, mangrove swamps and beach ridges, which formed a habitat to a variety of flora, fauna and microbes. Biodiversity of the reserve had sustained local communities in the area for decades, especially for the provision of food and edible fruits, water, timber and non-timber forest products, fuelwood, building materials, fibre, medicinal herbs and spices. The reserve is currently being threatened by several factors. Exotic nipa palm that was introduced into the area in the 1900s is fast displacing indigenous mangrove vegetation, not just in the forest reserve alone but in the entire Nigerian coastline. Oil exploration, which started in the area in the 1950s, opened up the area for human encroachment, farming, wood logging, waste disposal and palm wine tapping which is now threatening the survival of the forest reserve. Except urgent steps are taken to control unstainable resource exploitation in the forest reserve, the biodiversity of the area could be destroyed beyond remedy within few years.

Keywords Anthropogenic Impacts · Beach Ridge · Ethnobiology · Freshwater Swamps · Legal Framework · Mangrove · Nipa Palm · Oil Exploration · Resource Exploitation

5.1 Introduction

Biological diversity, i.e. biodiversity for short, represents the variability of lifeforms on earth, including plants, animals and microorganisms and their habitats. Biodiversity is often considered at three levels, including species diversity, genetic diversity and ecosystem or landscape diversity. Biodiversity is very important to mankind in several ways. In fact, human survival on earth is linked to the presence of healthy

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biodiversity. Humans are aerobic organisms, the air we breathe is often purified by plants. While human activities are generating excess carbon dioxide, which is linked to climate change, plants take carbon dioxide from the air and convert them to biomass and food. The reproduction of plants is influenced by insects. Some insects, wildlife and even humans depend on certain microbes in their gut to function optimally. Wild animals disperse plants seeds. Human diet is exclusively obtained from biological sources, both domesticated and wild. Therefore, without biodiversity, man could starve to death. Plants also depend on insects for pollination and on microbes for nutrient recycling. But for the biodegradation actions of microbes, waste would have choked up the earth. Plants are major contributors to the hydrosphere, water resources are typically stored or processed in various ecological landscapes, such as rivers, underground aquifers and seas. The interdependence among species and their ecosystems cannot be overemphasized.

The services provided by biodiversity are sometimes classified into four, namely, regulatory, provisioning, supporting and cultural services. Ecosystem support services of biodiversity include soil fertilization and nutrient recycling, erosion control and plant pollination. Some of the regulatory services of biodiversity include air quality regulation, water and soil quality regulation, pest and disease regulation. Cultural services of biodiversity include cultural heritage, aesthetics and recreational services. The provisional services of biodiversity are many, including the provision of food, feeds, fibre, spices, fruits, biomass fuel, furniture, beverages, medicines, clothes and raw materials. The human exploitation of these resources has led to the decline of biodiversity, which is now threatening human survival on earth. Many human activities threaten biodiversity, including urbanization, industrialization, unsustainable resource exploitation, farming and use of agrochemicals, bush burning and overfishing.

Environmental conservation is the practice of preserving the natural ecosystem from over-exploitation. The establishment of forest reserves, botanical gardens, game reserves and wildlife parks are among strategies for the conservation of biodiversity. Forest reserves are forested lands where wildlife hunting and commercial harvesting of wood products are excluded in order to conserve biodiversity. Imasuen et al. (2013) listed some of the importance of protected areas, including conservation of species and genetic diversity, supply of raw materials to sustain indigenous people, education and research. The SCFR is one of the 22 protected areas in the Niger Delta. It was the largest forest reserve not just in Akwa Ibom State but entire Eastern Nigeria. The original size of the reserve (310.80 km^2) has reduced significantly due to anthropogenic activities (Udoma-Michaels et al. 2019), hence the need for urgent intervention.

5.2 History, Legal Status and Administrative Framework of SCFR

The SCFR was established prior to the independence of Nigeria by Order 45 of 1930 under the then British Colonial Government, which was subsequently amended by Orders 16, 17 and 28 of 1941, Eastern Region Law of Nigeria (ERLN) 236 of 1955 and ERLN 56 of 1962. The establishment of the forest reserve was published in the defunct Eastern Region Gazette No. 52 of October 18, 1955. Legally, the reserve belongs to Nigeria under the management of Akwa Ibom State (Baker 2003; Essien and Udoh 2015). SCFR is the only gazetted forest reserve in Akwa Ibom State and covers an approximate area of 310.78 km^2. Subsequently, proposals, that were developed for the establishment of a wildlife sanctuary of 21,000 ha called Stubbs Creek Game Reserve (SCGR), did not come to fruition (Gadsby 1989; Oates et al. 2004).

The establishment and sustenance of forest reserves as a strategy for biodiversity conservation is supported by several legal frameworks, both local and international. The Convention of Biological Diversity (CBD) (Brazil, 1992) formed the legal basis for the conservation, sustainable use and equitable sharing of biodiversity resources. The World Heritage Convention (1972) made provision for the protection of world cultural and natural heritage, including habitats of threatened plants and animals, and areas with scientific, conservation or aesthetic value, such as mangroves. The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES 1975) restricts and regulates the trade of endangered species. The Nigerian Endangered Species Act 11 (1985) and Protection of Endangered Species in International Trade Regulations (S. I. No 16, 2011) were promulgated in pursuance of CITES. These regulations made provisions for the conservation, management and protection of some endangered wildlife species in Nigeria. The Ramsar Convention (Iran 1971) made provisions for the conservation of wetlands and sustainable use of wetland resources, including mangrove and freshwater swamps. The Convention on Migratory Species (Bonn 1979) made provisions for the conservation of migratory species throughout their range, including birds, terrestrial and marine organisms. In furtherance to the Ramsar Convention, the Nigerian Wetlands, River Banks and Lake Shores Protection Regulations (S. 1. 26, 2009) was enacted, which seek the conservation and wise use wetland. This regulation seeks to support the sustainable use of wetlands for ecological and tourism purposes and the protection of wildlife, including plants and animals.

There are several other international environmental legislations and conventions that Nigeria is signatory or party to that are applicable to SCFR:

- Convention of the Intergovernmental Maritime Consultative Organization (1948).
- Convention for the Prevention of Pollution of the Sea by Oil (1954).
- Convention on fishing and conservation of living Resources of the High Sea (1958).

- Convention on the High Seas (1958).
- Convention on the Territorial Sea and Contiguous Zone (1958).
- Convention on the Continental Shelf (1958).
- African Convention on the Conservation of Nature and Nature Resources (1968).
- Convention on Civil Liability for Oil Pollution Damage (1969).
- Convention on the Prevention of Marine Pollution of Dumping of Wastes and other Matter (1972).
- Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Regions (1982).
- Basle Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1989).
- Convention on Oil Pollution Preparedness, Response, and Co-operation (1990).
- United Nations Framework Convention on Climate Change (1992).

The Federal Environmental Protection Agency (FEPA) Act (Chapter 131, Laws of the Federation, 1990) established the FEPA, which was later upgraded to the Federal Ministry of Environment (FMENV). The Act tasked the FMENV with the responsibility of protection of the country's environment from degradation, while promoting natural resources conservation. The FMENV has developed several environmental policy guidelines on water quality, effluent limitation, air emissions, soil pollution and hazardous waste management. The Environmental Impact Assessment (EIA) Act (No 86, 1992) specifies that EIA is mandatory for project development especially for activities that are likely to impact the natural environment negatively. They subsequently developed the procedural guidelines for carrying out EIA. The procedural guideline and EIA Act listed project activities requiring mandatory EIA, including agriculture and fisheries, forestry, airport and ports, drainage and irrigation, land reclamation, housing, infrastructure, mining and quarries, petroleum, power generation and transmission, railway and other forms of transportation, and waste disposal. The procedural guideline directed that projects located in environmentally sensitive areas such as freshwater swamp, mangrove and other wetlands, conservation and protected area, and areas harbouring threatened and protected species, will require mandatory EIA. In 1995, the FMENV developed sectoral guidelines for carrying out EIA in different sectors. The FMENV EIA guidelines for oil and gas projects presented the guidelines and coverage for carrying out EIA relating to the oil industry.

Notwithstanding the role of FMENV in overseeing environmental and conservation issues in the country, the Akwa Ibom State Ministry of Environment and Mineral Resources oversees environmental and conservation issues at the state level. The Akwa Ibom State Environmental Protection and Waste Management Agency Edit (CAP 47, 2000) established the Akwa Ibom State Environmental Protection and Waste Management Agency, which is vested with the responsibility of environmental protection and wastes disposal. However, Local Government Areas (LGAs) are tasked with the statutory mandate for municipal waste management and environmental sanitation. At the community level, there are ways of conserving biodiversity that is linked to cultures and traditions. For instance, some wildlife and plant species, habitats such as water bodies and evil forests are considered as sacred grooves and are restricted from exploitation. Some sacred grooves do not allow non-indigenous person access, while others may allow access and/or exploitation at designated periods.

The National Environmental (Coastal and Marine Area Protection) Regulations (2011) seek to protect coastal areas from industrial activities, oil exploration and was management. The regulation specifies limits for effluent discharge including ballast water. The Wild Animals Preservation Act (1916) appears to be among the earliest laws aimed at the conservation of wildlife and their habitat in Nigeria. The National Parks Decree (No 36, 1991) upgraded to National Parks Act (1999) made provisions for the establishment of national parks for the protection and conservation of wildlife and vegetation. The decree restricts economic activities including fishing, hunting, wood logging and the setting of fires in and around established parks.

Nigeria has promulgated land and forestry laws, which are key to environmental conservation. For instance, the land use act (1978) vested the rights to land in the state government on behalf of the people. Hence, state governors sign and approve land certificate of occupancy. Forestry Act (1958) made provisions for the establishment of forest reserves or state forests. The Act declare that any land within 1·5 km of any forest reserve is also considered as protected forest. The Act seeks to protect forest resources from human exploitation. The Act provides sanctions for encroachment into forest reserves. The Forestry Act (1958) was amended and upgraded as Forestry Law CAP 51 (1998), and it presented the legal framework for the establishment of forest reserves. The law made provisions for the management, protection and utilization of forest reserves in the country. The law prohibits the destruction of timber and non-timber forest products in gazetted forest reserves. The National Conservation Strategy (1998) presented the conservation strategy of natural resources in Nigeria, including vegetation, wildlife and fisheries. Nigeria has other legislations pertaining to the conservation of biodiversity, but the challenge is enforcement:

- National Inland Waterways Authority (Act No 131997).
- Control of Bush/Forest Fire and Open Burning Regulations (S.I. No 15, 2011).
- Federal Ministry of Agriculture, Water Resources and Rural Development, agricultural policy for Nigeria (1988).
- Harmful Wastes (Special Criminal Provisions etc.) Act (1988).
- The Department of Petroleum Resources (DPR) enacted several regulations protecting the environment from oil and gas exploration activities.

Notwithstanding the many regulations and regulators at various levels, environmental law enforcement is weak in the country, hence unable to protect the SCFR.

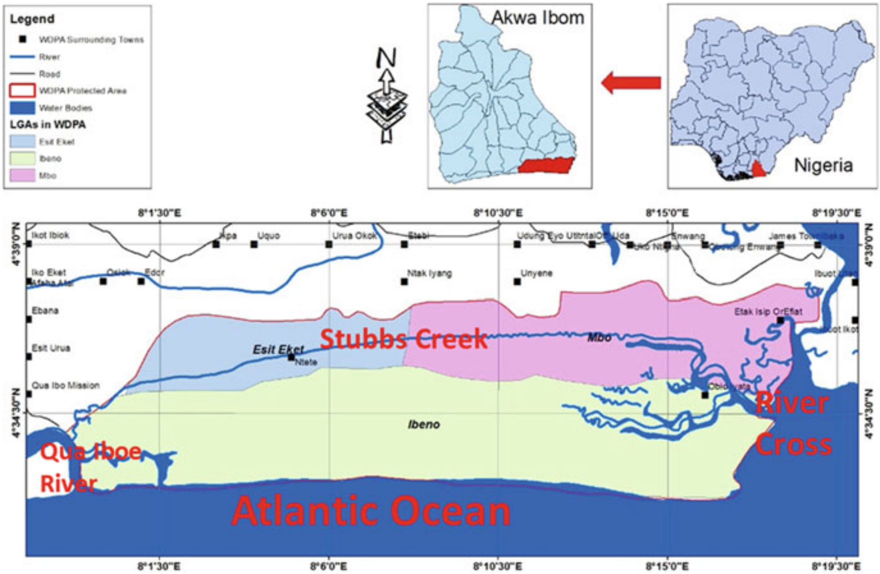

Fig. 5.1 Map of SCFR

5.3 Description of SCFR

Politically, the SCFRs are located in Esit Eket, Mbo and Ibeno LGAs of Akwa Ibom State (Fig. 5.1). However, a tiny strip of the forest reserve at the northwest edge fell in Eket LGA; hence, this LGA is often excluded in literature as one of the hosts LGA. Climatically, temperatures in the forest reserve range from 25 °C to 30.5 °C. The area experiences high rainfalls ranging from 1700 to 4700 mm annually, with relative humidity ranging from 60% to 95% with the highest values occurring during the raining reason in July and the lowest during the dry season in January (Werre 2001; Baker 2003; Jacob et al. 2015; Udoma-Michaels et al. 2019). The heavy rainfall and wetland hydrology of the reserve support the ever-green luxuriant vegetation all year round.

The SCFR is located approximately in latitude 04°32″–04°49″ N and longitude 08°00″–09°10″ E and occupies the land, swamp and beach ridges between the river mouths of the Qua (Kwa) Iboe and Cross. Hence, the area is surrounded by water bodies, including Qua Iboe River in the west, the Atlantic Ocean in the south and Cross River in the east. Located in the northern half of the reserve almost parallel to the Atlantic Ocean are two major creeks approximately 30–50 m wide, Stubbs and Widenham (Wydenham), which run in the east–west direction. From the centre of the reserve, Widenham Creek flows eastward into the Cross River, the Stubbs Creek flows westward into the Qua Ibo River, while Douglas Creek, which occurs south of the Stubbs–Widenham Creeks, also flows into the Qua Iboe River. There is no major river system on the northern border (Gadsby 1989; Baker 2003; Akpan-Ebe 2005).

Table 5.1 Species biodiversity SCFR

Features	Types (no. of species)	Examples
Vegetation	Freshwater (200)	*Alchornea cordifolia*, *Alstonia boonei*, *Anthocleista vogelii*, *Gmelina arborea*, *Costus afer*, *Elaeis guineensis*, *Raphia* spp.; *Rauvolfia vomitoria*, *Musanga cecropioides*, *Albizia* spp.
	Transition (2)	*Dalbergia ecastaphyllum*, *Pandanus candelabrum*
	Mangrove (5)	*Rhizophora racemosa*, *Rhizophora mangle*, *Avicennia africana*, *Nypa fruticans*, *Acrostichum aureum*
	Macrophytes (20)	*Nymphaea lotus*, *Nymphaea maculata*, *Azolla africana*, *Salvinia nymphellula*, *Sacciolepis africana*, *Ludwigia abyssinica*, *L. decurrens*, *L. octovalvis*, *Aeschynomene indica*, *Acroceras zizanioides*, *Lasiosperma senegalense*, *Nephrolepis biserrata*, *Dryopteris filix-mas*
	Beach ridge (2)	*Ipomoea, Paspalum*
Wildlife	Mammals (100)	Cercopithecus *sclateri*, *Cercopithecus mona*, *Cercopithecus nictitans*, *Cercocebus torquatus*, *Procolobus verus*, *Perodicticus potto*, *Arctocebus Calabarensis*, *Galagoides demidoff*, *Galagoides alleni*, *Euoticus elegantutus*, *Cephalophus Maxwelli*, *Tragelaphus spekii*, *Potamochoerus porcus*, *Hyemoschus aquaticus*, *Uromanis tetradactyla*, *Phataginus tricuspis*, *Atilax paludinosus*, *Herpestes ichneumon*, *Anoyx capensis*, *Lutra maculicollis*, *Civettictis civetta*, *Nandinia binotata*, *Genetta tigrina*, *Funisciurus Pyrrhopus*, *Heliosciurus rufobrachium*, *Anomalurus derbianus*, *Anomalurus Beecroft*, *Thryonomys swinderianus*, *Atherurus africanus*, *Lemniscomys striatus*, *Rattus rattus*, *Cricetomys emini*, *Hypsignathus monstrosus*, *Rousettus aegyptiacus*
	Birds (200)	*Gypohierax angolensis*, *Milvus migrans*, *Ardea cinereal*, *Scopus umbrette*, *Ceryle rudis*, *Corvus albus*, *Motacilla aguimp*
	Reptiles (50)	*Calabaria reinhardtii*, *Python sebae*, *Python regius*, *Gastropyxis smaragdina*, *Boaedon lineatus*, *Psammophis phillipsi*, *Dasypeltis fasciata*, *Grayia smythii*, *Dendroaspis viridis*, *Naja melanoleuca*, *Naja nigricollis*, *Bitis gabonica*, *Osteolaemus tetraspis*, *Crocodylus niloticus*, *Varanus niloticus*, *Mabuya blandingi*, *Mochlus fernandi*, *Agama agama*, *Chamaeleo gracilis*, *Hemidactylus brookiangulatus*, *Pelusios niger*, *Pelusios castaneus*, *Kinixys erosa*, *Cyclanorbis* sp.
	Amphibians (10)	*Bufo maculatus*, *Bufo regularis*, *Hoplobatrachus occipitalis*, *Hylarana galamensis*, *Ptychadena mascariensis*, *Ptychadena bibroni*, *Afrixalus congicus*, *Afrixalus dorsalis*, *Xenopus tropicalis*
	Insects (1000s)	*Aedes* sp., *Anopheles* sp., *Culex* sp., *Palpopleura lucia*, *Ceriagrion glabrum*, *Pseudagrion kersteni*, *Chalcostephia flavifrons*, *Locusta migratoria*, *Zonocerus variegatus*, *Periplaneta Americana*, *Musca domestica*

(continued)

Table 5.1 (continued)

Features	Types (no. of species)	Examples
Fish	Fin fish (200)	*Tilapia zillii*, *Tilapia marinade*, *Ilisha africana*, *Chrysichthys nigrodigitatus, Ethmalosa fimbriata*, *Clarias gariepinus*¸ *Mugil curema*
	Shell fish mudskippers and crabs (10)	*Macrobrachium felicinum*, *M. vollenhoveni*, *Callinectes amnicola*, *Desmocaris trispinosa*, *D. bislineata*, *Periophthalmus barbarus*, *Cardisoma armatum*, *Ocypode* sp.
Others	Phytoplankton (200)	*Coscinodiscus lacustris*, *Diatoma elongatus*, *Fragilaria capucina*, *Chlamydomonas gracile*, *Euastrum elegans*, *Scenedesmus quadricauda*, *Spirogyra spiralis*, *Ulothrix* sp., *Volvox aureus*, *Euglena gracilis*, *Dactylococcopsis irregularis*, *Oscillatoria tenuis*
	Zooplanktons (100)	*Squatinella rostrum*, *Oikopleura* sp., *Sagitta elegans*, *Nereis diversicolor*, *Acartia tonsa*, *Diaptomus oregonensis*, *Oncaea venusta*, *Paracalanus pygmaeus*, *Pseudocalanus elongatus*, *Upogebia nauplii*
	Benthic invertebrates (100)	*Nereis diversicolor*, *Palaemon serratus*, *Tympanotonus fuscatus*, *Donax oweni*, *Donax* sp., *Dosinia exoleta*, *Pecten* sp., *Dentalium entails*, *Cucumaria lacteal*, *Anguilla* sp.
	Microorganisms (10^6–10^9 cfu/unit media)	*Aspergillus fumigatus*, *Saccharomyces cerevisiae*, *Rhizobium* sp., *Nitrosomonas* sp., *Nitrobacter* sp., *Bacillus* sp., *Clostridium* sp., *Staphylococcus aureus*, *Streptococcus faecalis*, *Micrococcus varians*, *Candida* sp., *Penicillium* sp., *Proteus* sp., *Desulfovibrio* sp., *Acidithiobacillus* sp., *Schizosaccharomyces pombe*, *Salmonella* sp., *Candida* sp., *Klebsiella* sp., *Pseudomonas aeruginosa*, *Escherichia coli*, *Vibrio* sp.

[a]The table is an original work that was compiled from several literature sources and field observations

5.4 Biodiversity of SCFR

The biodiversity of the SCFR is presented in Table 5.1. This list, which is by no means exhaustive, is a pointer to the highly diverse nature of the reserve. There are diverse landscapes and water types in the area habited by different plant species which forms diverse habitats for diverse fauna, including freshwater swamp forests, brackish and mangrove swamps, freshwater–mangrove transition, beach ridge and marine ecosystems. The core of the forest reserve is a predominantly a freshwater ecosystem, which is among the most productive ecosystems in the world. Some authors (Gadsby 1989; Baker 2003; Ofem and Inyang 2019) have reported that the high biodiversity of the forest reserve is mostly attributed to the extensive freshwater swamps. Many important plant species are found in this landscape, including *Alchornea cordifolia*; *Alstonia boonei*; *Anthocleista vogelii*; *Gmelina arborea*; *Costus afer*; *Elaeis guineensis*; *Raphia* spp.; *Rauvolfia vomitoria*; *Musanga* *cecropioides* and *Albizia* spp. This landscape is predominantly driven by rain-fed freshwater hydrology. Aquatic macrophytes dominated the several seasonal swamps in the freshwater zone, which served as a breeding ground and refugia for aquatic organisms, including fish, insects especially mosquitoes, amphibians and planktons. Aquatic macrophyte species in the forest reserve include *Nymphaea lotus*, *Azolla africana*, *Salvinia nymphellula*, *Ludwigia abyssinica*, *Acroceras zizanioides*, *Lasiosperma (Cyrtosperma) senegalense*, *Nephrolepis biserrata Dryopteris filix-mas*. The freshwater ecosystem tippers seamlessly into the transition ecosystem, which is the interface between the freshwater and coastal mangrove ecosystems. The transition ecosystem is dominated by specialized species, such as *Dalbergia ecastaphyllum*, *Pandanus candelabrum* and *Terminalia catappa*. Mangrove vegetation is mostly restricted to the Cross River Estuary, i.e. at the eastern flank of the reserve and to a lesser extent at the mouth of the Qua Iboe River. Both the Cross River Estuary and Qua Iboe River are tidal because they are connected to the Atlantic Ocean, providing access to the forest reserve via marine route. The mangrove swamp forest consisting mostly of indigenous species, including *Rhizophora racemosa* and *Rh. mangle*, *Avicennia africana,* the mangrove fern *Acrostichum aureum* and the invasive nipa palm *Nypa fruticans* that is fast outcompeting other species. The beach ridges which occupies the sand bars and barrier islands are dominated by strand vegetation, including *Ipomoea* and *Paspalum* species.

The wildlife fauna of the forest reserve is quite diverse comprising mammals, avian species, reptiles, amphibians, fishes and insects. The mammals of the forest reserve comprise primates, rodents, bats, carnivores, etc. Monkey appears to dominate the primates of the area, with the Mona Monkey (*Cercopithecus mona*) most frequently sighted primate even in large population. Other monkeys reported in the study area include red capped Mangabey (*Cercocebus torquatus*), Sclater's monkey (*Cercopithecus sclateri*), Putty-nosed monkey (*Cercopithecus nictitans*) and Olive Colobus monkey (*Procolobus verus*). Some authors (Gadsby 1989; Baker 2003; Oates et al. 2004) reported massive disturbance of the forest reserve; notwithstanding, four species of monkey, *C. torquatus*, *C. mona*, *C. nictitans*, and *C. sclateri*, are still sighted in the relatively intact section of the reserve. It should be noted that the Sclater's guenon, which was classified as endangered, is endemic to South-east part of Nigeria. Chimpanzee (*Pan troglodytes*) that used to be present in the forest reserve is now considered locally extinct.

Prosimians were also sighted in the forest reserve, including Calabar Angwantibo (*Arctocebus calabarensis*), Bosman's Potto (*Perodicticus potto*), dwarf galago (*Galagoides demidoff*), Allen's squirrel galago (*Galagoides alleni*) and Needle-clawed galago (*Euoticus elegantulus*). These are all nocturnal species, highly solitary and secretive in behaviour.

Some mammals are particularly restricted to the raffia palm swamp and coastal areas such as African clawless otter (*Anoyx capensis*) and speckle otter (*Lutra maculicollis*), water chevrotain (*Hyemoschus aquaticus*), sitatunga (*Tragelaphus spekii*), blotched genet (*Genetta tigrina*) and African civet (*Civettictis civetta*). Some mammals sighted in farmlands and bush fallows include cane rat (*Thryonomys swinderianus*), Emin's giant rat (*Cricetomys emini*), brush-tailed porcupine

(*Atherurus africanus*), Kusimanse mongoose *(Crossarchus obscurus*), Egyptian mongoose *(Herpestes ichneumon)*, red-legged sun squirrel (*Heliosciurus rufobrachium*) and black house rat (*Rattus rattus*), which are found in households.

Over 200 species of birds are found in the forest reserve, including *Gypohierax angolensis*, *Milvus migrans*, *Ardea cinereal*, *Scopus umbrette*, *Ceryle rudis*, *Corvus albus and Motacilla aguimp*. Different types of reptiles are sighted in the forest reserve, including lizards, snakes and turtles. Agama lizard *(Agama agama)* and grey skink *(Mabuya blandingi affinis)* are the most abundant reptiles, sighted in the different vegetation types. In the raffia forest, dwarf crocodile *(Osteolaemus tetraspis),* monitor lizards, *(Varanus niloticus),* Smyth's water snake *(Grayia smythii)* and rock python *(Python sebae)* are the dominant reptiles, followed by West African black forest turtle *(Pelusios niger)* and West African mud turtle *(Pelusios castaneus).* The Nile crocodile *(Crocodylus nilotius)* is also found in the reserve. Various snake species are also encountered including Black Cobra *(Naja melanoleuca),* spitting cobra *(Naja nigricollis),* Gabon viper *(Bitis gabonica) and Calabar ground Python (Calabaria reinhardtii).* Umoren et al. (2020) listed amphibians in the reserve, including *Ptychadena*, *Xenopus laevis*, *Bufo regularis and Chiromantis rufescens.*

Over 200 different fish species are found migrating between the forest reserve and the continental shelf, including *Tilapia zillii*, *Tilapia marinade*, *Ilisha africana*, *Chrysichthys nigrodigitatus, Ethmalosa fimbriata*, *Clarias gariepinus and Mugil curema*. The non-fin fishes observed include *Macrobrachium felicinum*, *M. vollenhoveni*, *Callinectes amnicola*, *Desmocaris trispinosa*, *D. bislineata* and land and sand crabs *Cardisoma armatum* and *Ocypode* sp., respectively. The mangrove swamp provides breeding and spawning ground for fishes. Both aquatic and terrestrial invertebrates inhabit the forest reserve. Table 5.1 also lists some of the species of phytoplankton, zooplanktons, benthic invertebrates and microbes found in the area. Microbial species listed were identified through cultural methods, which clearly is an underestimate of the total species in the area because it is unable to assess the non-culturable species, and therefore not able to detect up to 10% of the microbes in the ecosystem.

Not much research work has been done on the insects of SCFR. Several insects are found in the reserve with butterflies of different species dominating. Other insects include damselfly, dragonfly, bee fly, weaver ants, driver ants, locusts and grasshoppers. Kemabonta et al. (2019) recently studied the abundance and distribution of Odonates, i.e. dragonflies and damselflies.

Some insects that are a nuisance to mankind particularly disease vectors are also found in the area, including mosquitoes (Anopheles, Culex, Aedes), Tsetse fly (*Glossina* sp.) and sand flies (*Phlebotomus* spp.). Itina et al. (2014) studied the Culicidae insects of Akwa Ibom state. This is a family of insects associated with several diseases including malaria, yellow fever, zika fever and West Nile fever. Ogbemudia et al. (2013) identified several insect species responsible for necrotic leaf spots and other pathological conditions of plants in SCFR.

5.5 Benefits of SCFR and Its Biodiversity

The forest reserve recycles nutrients, protects the watersheds and coastline and provides barrier against harmful natural phenomena such as erosion and flooding, which is increasing owing to global climate change. The SCFR being the foremost biodiversity hotspots within the Gulf of Guinea (Udoma-Michaels et al. 2019) is exploited first for food, meat and water, which sustains the local communities. Wild animals (bushmeat) and fishes are hunted as sources of animal proteins, while wild fruits and tubers are harvested for food. Non-timber forest products such as fruits, spices, seeds and snails are also sourced from the forest. Subsistence farming soon followed, where parts of the forest reserve were cleared for the planting of cassava and vegetables. Later, agricultural activities increased with the planting of plantain and oil palm plantations.

Beyond food, a forest provides diverse array of other products, including timber and other building materials, herbal medicines and spices, fibres and gum, and ornaments (Table 5.2). The forest protects the soil, climate and water resources and preserves the genetic pool of the fauna and flora species of the area, thus preventing them from extinction (Essien and Udoh 2015). Olajide and Udofia (2008) estimated the density (number/ha) of some economic flora found in SCFR, including *Thaumatococcus danielli* 308, *Gnetum africanum* 33, *Calamus deeratus* 2325, *Piper guineensis* 6, *Mitragyna ciliata* 11, *Tetrapleura tetraptera* 7, *Elaeis guineensis* 8 and *Raphia* spp. 333 among others. Local communities depend on the forest reserve for basic utilities, including water, fuelwood and waste disposal. Udoma-Michaels et al. (2019) recently enumerated the benefits derivable from the forests, which include provision of food (80%), medicines (98%), tourism (94%), source of income (76%), and fuelwood and timber (30%) among others (98%).

Mangroves are sensitive and unique ecosystems occupying the intertidal zones between land–sea and freshwater–saltwater interface. However, they are quite tolerant to fluctuating salinity, sulphate and oxygen levels and tidal inundation, but are quite sensitive even to minor topographic and hydrological changes. Mangrove forests provide several economic and ecosystem services, including sequestration of carbon and heavy metal in sediments, breeding and spawning grounds for fish, coastal protection, aesthetic values and sources of biomaterials such as biomass fuel, poles, medicinal herbs and spices.

5.6 Threats to the Biodiversity of SCFR

The SCFR, which is the largest remaining intact forest in Akwa Ibom state (Udo et al. 1997), is under threat due to uncontrolled exploitation. The biodiversity of the forest reserve is being threatened, involving virtually all lifeforms, including vegetation, mammals, birds, reptiles, amphibians, fishes, insects and microorganisms. Threats occur from multiple sources such as urbanization/community encroachment,

Table 5.2 Ethnobotany of some plant species in SCFR

Taxa	Local name (Ibibio/ Annang)	Common names	Family	Uses
Alchornea cordifolia		Christmas tree	Euphorbiaceae	Medicinal plant for treatment of malaria and other infections. Animal feeds
Allanblackia floribunda	Udia ebiong			Timber
Alstonia boonei			Apocynaceae	Medicinal plant. Bark used for the treatment of fever, asthma
Alstonia congensis	Ukpo edep	Stool wood	Apocynaceae	Timber
Anchomanes difformis			Araceae	Medicinal plant and fruit crop. Stem juice for treatment of eye sores
Ancistrophyllum secundiflorum			Palmae	Stick used for furniture and craft making, leaves as roofing materials
Anthocleista vogelii planch			Loganiaceae	Latex used for medicine
Artemisia annua	Unani		Asteraceae	Medicinal plant, anti-malaria
Asystasia gangetica			Acanthaceae	Food use
Balanites aegyptiaca			*Zygophyllaceae*	Medicinal plant for snake bite, jaundice, yellow fever, cough and syphilis and wound dressing
Bombax buonopozense	Ukim	Red silk cotton tree	Malvaceae	Timber
Calamus deeratus			Palmae	Stick for furniture making; leaves as roofing materials
Calopogonium mucunoides			*Fabaceae*	Animal feeds
Carica papaya			Caricaceae	Fruit crop and medicinal plant
Carpolobia alba			*Polygalaceae*	Used as broom
Cassytha filiformis			Lauraceae	Medicinal plant used for treatment of ringworm, diarrhoea, infertility
Cleome rutidosperma			*Capparaceae*	Medicinal plant used for eye treatment

(continued)

Table 5.2 (continued)

Taxa	Local name (Ibibio/ Annang)	Common names	Family	Uses
Cocos nucifera	Isip-Mbakara		*Arecaceae*	Fruit crop, medicinal plant
Coelocaryon preussii	Uno idim	Man Carabot	*Myristicaceae*	Timber
Colocasia esculentum		Cocoyam	Araceae	Food crop
Coula edulis	Ekom	African walnut	Olacaceae	Timber
Cyperus rotundus		Nut grass, purple nut, sedge or purple nutsedge	*Cyperaceae*	Medicinal plant used for the treatment of diarrhoea, infertility, diabetes, inflamma-tion, malaria and stomach pains
Cyrtosperma senegalense			Araceae	Medicinal and pack-aging material. Leave used for food wrap-ping, rhizome used for the treatment of gonorrhoeae, diarrhoea
Dacryodes edulis	Eben ekpo	Wild pear tree	Burseraceae	Food, fruit, timber
Dialium guineense			*Fabaceae or Leguminosae*	Medicinal. Leaves and fruits used to the treatment of fever, diarrhoea. Roots boost libido, twigs used for cleaning teeth (chewing stick)
Dioscorea dumetorum		Yam	Dioscoreaceae	Food crop
Diplazium sammatii			*Athyriaceae*	Medicinal. Leaves used for treatment of asthma
Distemonanthus benthamianus	Eto afia	Ayan	*Fabaceae*	Timber
Drypetes floribunda			Euphorbiaceae	Stem as fuel wood
Elaeis guineensis	Eyop	Oil palm	Arecaceae	Diverse uses. Fruits used for production of palm oil and palm kernel oil, sap for palm wine and other alcoholic beverages. Biomass used for making soap, leaves for broom and thatch roof, stem as poles

(continued)

Table 5.2 (continued)

Taxa	Local name (Ibibio/ Annang)	Common names	Family	Uses
Emilia sonchifolia			Asteraceae	Food and medicinal. Leaves and stem eaten as vegetables, leaf used for treatment tonsillitis, halt bleeding
Epiphyllum ackermannii	Utip	Leaf cactus, orchid cactus	Cactaceae	Timber
Erythrophleum suaveolens	Barando/ badondo	Sasswood, ordeal tree	Fabaceae	Timber
Fagara macrophylla	Nket	African satinwood	Rutaceae	Timber
Ficus spp.			Moraceae	Animal feed
Gambeya albidum	Udara		Sapotaceae	Edible fruit and trunk for timber
Garcinia kola	Efiad		Clusiaceae or Guttiferae	Entertainment and cough treatment
Gnetum africanum	Afang		Gnetaceae	Food crop. Leaves used for soup making
Gongronema latifolium			Apocynaceae	Food, medicinal. Leafy vegetable
Gossweilerodendron balsamiferum	Agba	Achi gum	Leguminosae	Timber
Ipomoea alba			Convolvulaceae	Food and feed. Leafy vegetable
Ipomoea involucrate			Convolvulaceae	Medicinal. Leaves used for treatment of jaundice
Irvingia gabonensis	Uyo-Ikot	Ogono	Irvingiaceae	Food crop. Edible fruits and seed used for soup making
Khaya grandifoliola		African mahogany	Meliaceae	Timber
Laportea aestuans			Urticaceae	Medicinal. Leaf juice for the treatment of malaria
Lasianthera africana	Editan		Icacinaceae	Food (edible vegetable), medicinal
Lovoa trichilioides	Sida	African walnut	Meliaceae	Timber
Luffa cylindrica			*Cucurbitaceae*	Ornamental. Artworks, hat, sponge and fibre for making oil filters

(continued)

Table 5.2 (continued)

Taxa	Local name (Ibibio/ Annang)	Common names	Family	Uses
Manihot esculenta Krantz		Cassava	Euphorbiaceae	Food crop. Biomass energy feedstock
Milicia excelsa	Iroko		Moraceae	Timber
Mitragyna stipulosa (Mitragyna ciliata)	Owen	Abura	Euphorbiaceae	Timber
Musa paradisiaca L.		Banana	Musaceae	Fruit crop
Musa sapientum L		Plantain	Musaceae	Food crop
Musanga cecropioides			Cecropiaceae	Medicinal. Stem bark used for malaria treatment
Nauclea diderrichii		Opepe	Rubiaceae	Timber
Nypa fruticans		Nipa palm	Arecaceae	Ornamental, thatch, biomaterial
Pachystela brevipes	Akwa		Sapotaceae	Timber
Pachypodanthium staudtii	Ntokon eto		Annonaceae	Timber
Papaver somniferum	Maprounnea		Papaveraceae	Medicinal. Hypertension treatment
Pentaclethra macrophylla		African oil bean	Fabaceae	Timber, medicinal plant
Phyllanthus amarus Schum. and Thonn.			Euphorbiaceae	Medicinal. Leave extracts have microbial properties.
Piper guineensis			Piperaceae	Medicinal, leafy vegetable
Portulaca oleracea	Mfep ekpu	Common purslane	Portulacaceae	Timber
Pteridium aquilinum		Bracken fern	*Dennstaedtiaceae*	Poison antidote
Pterocarpus erinaceus	Ukpa	African rosewood	*Fabaceae or Leguminosae*	Timber
Pycnanthus angolensis	Abakang	False walnut	*Myristicaceae*	Timber
Randia longiflora			*Rubiaceae*	Stem used as chewing stick
Raphia sp	Ukod	Raffia palm	Arecaceae	Biomass energy feedstock, leaves used as broom, roofing material, sap used for wine and alcohol production, stem used as poles and furniture
Rhizophora racemosa		Tall red mangrove	Rhizophoraceae	Medicinal, ecologic

(continued)

Table 5.2 (continued)

Taxa	Local name (Ibibio/ Annang)	Common names	Family	Uses
Saccharum officinarum		Sugarcane	Poaceae	Beverage, bioenergy feedstock
Selaginella myosurus			Sellaginellaceae	Biomaterial used for filtering
Senna occidentalis			Leguminosae	Medicinal. Leaves used for the treatment of worm, abscesses and inflammation
Solenostemon monostachyus			*Labiatae*	Medicinal. Used for the treatment of dizziness and measles
Spondias mombin	Nsukakara	Cashew	Anacardiaceae	Edible fruit
Staudtia stipitata	Iyip okoyo	Niove, M'bonda	Myristicaceae	Timber
Taxus brevifolia	Ayurveda		Taxaceae	Medicinal. Treatment of cancer
Terminalia superba	Eeka ubok abasi	Afara, Limba	Combretaceae	Timber
Tetrapleura tetraptera	Uyayak		Fabaceae or Leguminosae	Food (spice) and medicinal fruit
Thaumatococcus daniellii			Marantaceae	Biomaterial. Alternative packing, sweetener
Urena lobata			Athyriaceae	Biomaterial. Fibre used as rope

infrastructural development, industrialization especially oil exploration and attendant environmental pollution (soil, air, water), unsustainable exploitation, farming, bush burning, agrochemicals, solid waste disposal, open defecation, sand mining and filling, domestic effluents) and alien invasive species. The exploitation of the forest reserve results in the destruction of habitats through farming and logging, fragmentation of the forest by linear structures, including roads and pipelines, and creating access for hunting, wood logging and farming.

Several authors have also reported large-scale disturbance of the forest reserve arising from multiple human activities, including farming, illegal wood logging, unregulated hunting, petroleum exploration, overfishing, bush burning, alien invasive species and sand mining (Popoola et al. 2004; Udoma-Michaels et al. 2019; Umoren et al. 2020). Udoma-Michaels et al. (2019) listed the factors responsible for the reduction in the size of forests, including encroachment for settlement (82%), overgrazing (58%), bush burning (2%) and others (20%), like farming activities, oil exploration, wood logging and fishing activities. Numbere (2019) linked anthropogenic activities particularly oil and gas exploration, deforestation, urbanization and

Table 5.3 Threats to SCFR biodiversity

Threats	Relative impacts	References
Nipa palm invasion	Major	Numbere (2019), Nwobi et al. (2020), Baker (2003)
Oil and gas exploration	Major	Baker (2003), Numbere (2019), Udoma-Michaels et al. (2019)
Human settlement/ urbanization	Major	Udoma-Michaels et al. (2019), Ndoho et al. (2009)
Poor waste management	Major	Numbere (2019), Essien and Udoh (2015)
Infrastructural development	Major	Udoma-Michaels et al. (2019)
Farming and land use change	Major	Udoma-Michaels et al. (2019), Ndoho et al. (2009), Effiong (2011), Essien and Udoh (2015), Amubode (1992), Akpan-Ebe (2005)
Fishing activities	Medium	Udofia and Udo (2005), Essien and Udoh (2015)
Lumbering and fuel wood harvesting	Major	Baker (2003), Udoma-Michaels et al. (2019), Ndoho et al. (2009)
Wildlife hunting	Major	Baker (2003), Akpan-Ebe (2001), Oates (1986)
Palm wine tapping	Medium	Baker (2003), Essien and Udoh (2015)
Over-exploitation of non-timber forest products	Medium	Ofem and Inyang (2019), Udoma-Michaels et al. (2019), Udofia and Udo (2005)
Other activities (bush burning, flooding)	Minor	Ndoho et al. (2009)

poor waste management to the displacement of native mangrove species by invasive nipa palms. The disturbance of mangrove ecosystems can facilitate the invasion, colonization, expansion and successful establishment of nipa palm.

The effects of human activities on the reserve is now manifesting as reduced fish catches and declining agricultural productivity, while sighting of wildlife is becoming rare. Essien and Udoh (2015) listed some of the consequences of impacts on SCFR, including the loss of genetic base, species loss, deforestation, siltation of streams and increased vulnerability of the state to natural disasters.

Based on our studies and literature, the major threats to SCFR are presented in Table 5.3.

5.6.1 *Exotic Nipa Palm Invasion*

The earliest and perhaps the most devastating impact on the biodiversity of the Forest Reserve started in the 1900s when Nipa palm (*Nypa fruiticans*) was introduced into the area, even before the establishment of the forest reserve in 1930. Nipa palm is not native to Nigeria, but was imported from Singapore into Calabar in 1906. It was planted along the Oron beach at the north-eastern flank of the SCFR in the Cross River estuary in 1912.The twin aims of introducing the palm into the area was to control coastal erosion from the Atlantic ocean and coastal beautification. The

Fig. 5.2 Expanding nipa palms

palm soon proliferated rapidly and spreads along Nigeria's coastline with the greatest impacts in coastal Akwa Ibom State, including the SCFR (Fig. 5.2). The palm displaced native mangrove species and colonized the entire coastal LGA of Akwa Ibom State particularly Oron, Mbo, Okobo, Ibeno, Uko, Ikot Abasi, Udung and Eastern Obolo, the nearly 1000 km Nigeria coastline and coastlines of other African countries. Nwobi et al. (2020) showed that nipa palm is fast replacing native mangroves across the entire Nigerian coastline, while Baker (2003) noticed that the palm now dominated the eastern portion of SCFR that was previously occupied by mangroves. Ogbemudia et al. (2013) did a study on the health of the vegetation of the lower reaches of the SCFR and found 13 plants belonging to 11 families in the area with nipa palm dominating with 98% frequency, followed by *Acrostichum aureum* and *Avicennia africana* with 50% frequencies. Nipa palm infestation has decreased the productivity of the estuarine ecosystem, particularly the fisheries. The traditional role of mangroves as breeding and spawning sites for coastal fisheries became threatened by nipa palm. Numbere (2019) listed some of the negative impacts of nipa palm, including clogging and blockage of drainage channels, stagnation of fast-moving rivers and streams resulting in siltation, and obstruction to marine transportation.

Nipa palm possesses several characteristics that made it more resilient than native mangrove species. Its seeds are buoyant and highly resistant. They possess underground stems with rhizomes. They are adapted to muddy soils along rivers and estuaries, even though they can tolerate infrequent tidal inundation and inland waters. Udofia and Udo (2005) reported the colonizing characteristic of the palm. Nipa palm reduces the firmness of the soil by its prostrate underground stem, thus predisposing the soil to coastal erosion that is currently being witnessed. Numbere (2019) reported factors that have made nipa palm outcompete mangroves in the Niger Delta, which include the development of a superior root system for anchorage and intensive nutrient uptake, fast and high productivity, and hard and buoyant seeds, which facilitated their widespread dispersal. They appear to strive better in a polluted or disturbed environment, including oil-, effluent- and solid waste-polluted areas, areas with modified topography, and hydrology arising from dredging and sand filling activities. Nipa palms seemed to have fully acclimatized to the environmental conditions in the Niger Delta and appeared to have altered the soil and possibly water qualities of the Niger Delta and through allelopathy resulting in the decline and displacement of native mangrove species. Numbere (2019) observed that in mixed forests, nipa palm seemed to produce more seeds than mangrove plants.

Udofia and Udo (2005) reported some of the many uses of nipa palm among Asian countries, including the production of sugar, palm wine, alcohol, vinegar, tea, thatching material, broom, fodder, ornamentals, baskets, mats, fish traps and cigarette wrappers. About 3tonnes/ha of sugar can be produced from the palm. But unfortunately, these benefits were not realized in Nigeria, where the palm has been put into a few uses, including roofing sheets, production of broom and making of crafts such as hats and bags. Perhaps owing to the intensity of the utilization of the palm, it has been ranked as endangered in some Asian countries like Singapore, whereas in Nigeria, it has gone out of control and has become a nuisance threatening the entire mangrove ecosystem and fisheries of the Atlantic Coast of Africa. Some authors have reported the rapid spread of nipa palm (Udofia and Udo 2005; Numbere 2019; Nwobi et al. 2020). Within 100 years of the first introduction, the palm has become the most dominant plant species in the Atlantic coast of Africa. Some of the problems attributed to Nipa palm in Nigeria include obstruction to marine transportation, rapid siltation requiring frequent maintenance dredging and displacement of native mangrove species especially *Rhizophora* spp. and *Avicennia africana*. Their rapid displacement of native mangrove species has been considered as being catastrophic to the ecosystem of the SCFR and the entire African coastline, thus displacing the ecological benefits of mangrove species in the control of coastal erosion, breeding and spawning grounds for fish, attachment surfaces for oysters and clams. Other products derived from native mangrove species such as medicinal extracts, fuelwood and poles are also lost. The decrease in the fisheries of the African coastline is partly attributed to nipa palm expansion.

Nipa palm is underutilized in Nigeria. Increased utilization of the palm has been considered as a way of controlling its expansion. The palm can also be considered as a biomaterial, especially for wine, biofuel and sugar production. The sap from the palm can be used for wine, sugar and biofuel production, and oils extracted from the seeds can be used for the production of biodiesel. The fruits can be used as biomass fuel for direct cooking. The fruits, fibrous roots, and stem can be used for the production fibres.

Using remote sensing technology, Nwobi et al. (2020) estimated the area occupied by nipa palm and mangrove forests in the Niger Delta in 2007 and 2017. They found that the area occupied by mangroves and freshwater forests decreased by 12% each, while nipa palm increased by nearly 700%, built-up areas by 50% and agricultural land by 11% within a decade. They also found that nipa palm is migrating inland as well even into freshwater zones occupied by raffia palm. At the Cross Rivers estuary, mangrove declined by 8%, while nipa palm increased by 335%. Higher values were recorded across the entire Niger Delta where mangrove decreased by 14% and nipa palm increased by over 1200%. This rapid expansion of nipa palm is one of the greatest threats to the biodiversity of the SCFR and the entire Niger Delta.

5.6.2 Oil and Gas Exploration

Oil and gas exploration activities (Table 5.4) appear to be the second most important threat to the SCFR. Petroleum exploration commenced in the area in the 1950s, when two multinational oil companies, i.e. the Shell Petroleum Development Company Nigeria Ltd. (SPDC) and Mobil Producing Nigeria Unlimited (now ExxonMobil), moved into the area. Both companies have now divested from the area.

SPDC was given two oil concession areas and sank several oil wells leading to the discovery of the Uquo field in 1958, Qua Iboe field in 1960, Stubb Creek field in 1971 and Tom Shot Bank in 1980 (Table 5.2). None of these fields was developed, but abandoned. These fields were later farmed out to marginal field operators in 2003, who subsequently developed and operated them. Hence, three marginal field now operate around the forest reserves, namely Stubb Creek Marginal Field, Uquo Marginal Field and Qua Iboe Field Marginal Field, while Tom Shot Bank is yet to commence operations. Eze et al. (2017) reviewed the emergence of marginal field operations in Nigeria and their contributions to the nation's economy. In 1991, part of the forest reserve was allocated to SPDC for the construction of the proposed Qua Refinery, which did not commence eventually (Popoola et al. 2004). SPDC also constructed a tarred road and bridge over Widenham Creek that runs from the main Esit Eket road through Esek Unyenge and Urua Inyang into the forest reserve (Coad n.d.; Baker 2003).

ExxonMobil commenced operations in the area in 1961. Though a major oil producing company, its fields are located offshore, but sited a terminal at the southwest edge of the forest reserve. Between 1970 and 1997, the company acquired over 400 hectares of the SCFR for the construction of the Qua Iboe Terminal (QIT), which Baker (2003) considered as having a little direct impact on the reserve because the company's wells and other production facilities are located offshore. But they, however, mentioned that rights of ways (ROW) created by the oil industry roads and pipeline opened up previously inaccessible areas and indirectly facilitated human use and exploitation of the reserve via hunting, farming, settlements and logging. It was

Table 5.4 Oil and gas exploration activities within and around SCFR

Facility (operator)	Location relative to SCFR	History, activities, facilities and footprints	Type of facility
Qua Iboe Terminal, QIT (Exxon Mobil, currently under divestment finalization)	Southwest edge of SCFR. Offshore wells and onshore terminal	Entered Nigeria in 1955, but started operations in 1961. Access roads and bridges. 400 ha land take. Operate over 90 offshore platforms comprising of about 300 producing wells at a capacity of over 550 bopd of crude oil, condensate and NGL. 18,000-tonne gas compression facilities platform	Crude oil terminal containing tankfarm, pipelines, but oil fields located offshore
Qua Iboe Marginal Field (Network Exploration and Production Nigeria Ltd., NEPN)	Southwest edge of SCFR. Located in Qua Iboe River about 2 km west of QIT. OML 13. Onshore	The field discovered by SPDC in 1960, appraised in 1971 and abandoned until Feb 2003 when it was farmed out to NEPN. Size 14 sq.km. 5 wells have been drilled; Qua Iboe-1 (1960), Qua Iboe-2, Qua Iboe-3, Qua Iboe-4 and Qua Iboe-3ST1 (side track). 10,000 bopd Qua Iboe flowstation commissioned in 2014	Oil field containing oil wells and production facilities, pipelines and flowlines
Uquo Marginal field (Frontier Oil Limited)	Northwest edge of SCFR. OML 13	The field was discovered by SPDC in 1958 and remained undeveloped until it was farmed out in 2003. It exports her crude oil via QIT. 2 MMscf/d CPF supply gas to Ibom IPP, Calabar IPP and Alaoji IPP, UniCem cement plant etc. Drilling campaigns; Uquo-1 (1958), Uquo −2 (1971), Uquo-3 (1972), Uquo-4 (1972), Uquo-5 and Uquo-6 (2008). Work-	Oil field containing oil wells and production facilities, manifold, pipelines, flowlines and CPF

(continued)

Table 5.4 (continued)

Facility (operator)	Location relative to SCFR	History, activities, facilities and footprints	Type of facility
		over and completion of Uquo-2 and − 3 wells (October 2009–February 2010). 3D seismic survey of 133 sq. km acquired in 2006–2007 1000bopd CPF send crude oil to QIT	
Stubb Creek marginal field (universal energy resources ltd)	Middle of SCFR. OML14	Field was discovered in 1970/1971 by SPDC. Explored and abandoned until 2003 when it was farmed out to UERL. The reserve contains 19 million barrels of oil and 700 bcf of gas. Field size 42 km^2. 9 wells drilled. Seismic lines acquired 46.2 km 2D (1960s, 1970s) and 42.3 km^2 3D (2006). EPF of 3000 bopd exported via 26 km pipeline and 30,000 bopd FUN manifold[a] to QIT, gas is exported via 31 km pipeline to Uquo CPF. Future drilling of 2 NAG wells and installation of a new CPF to produce 10,000 bopd to QIT and 2MMSCF/d gas to Uquo CPF	Oil field containing oil wells and production facilities, pipelines and flowlines. Creation of access road and bridges
Tom Shot Bank (Associated Oil and Gas Services Company Limited (AOGSL) and Dansaki Petroleum Ltd)	Located at the continental shelf/shallow offshore adjacent to SCFR. OML14	Field discovered by SPDC in 1980 by drilling TSB-1 followed by TSB-2 in 1989. It was farmed out in 1996	Not yet operational

(continued)

Table 5.4 (continued)

Facility (operator)	Location relative to SCFR	History, activities, facilities and footprints	Type of facility
Abana field (Moni Pulo)	South of SCFR in OML 114 and lies in the Cross River estuary	The field was discovered in 1997, when 4 wells were drilled and came onstream 2 years later. Nine horizontal production wells and two deviated water injection wells have been drilled. 225 sq. km 3D seismic survey. The field has an estimated ultimate recovery of 70 million barrels of oil and 2.5 tcf of gas. The field is produced via two wellhead platforms and floating production facility. Oil is exported by a 40 km pipeline	

OML oil mining lease, *NGL* natural gas liquids, *NAG* non-associated gas, *CPF* Central Processing Facility, *SPDC* Shell Petroleum Development Company, *EPF* early production facility; *QIT* Qua Iboe terminal, *FUN* Frontier Universal and Network, *IPP* Independent Power Plant
[a] FUN manifold is operated by three marginal field operators (UERL, FOL and NEPN)

noted that since ExxonMobil began operations in the area, it has led to increased population, which has mounted pressure on infrastructure. Hence, the west end of the reserve, particularly close to QIT, has been heavily degraded, mainly due to clearing of land for agriculture. Additionally, some communities along the coast specifically reported problems with oil slicks along the beach as well as oil in their nets while fishing offshore. UNEP-WCMC (2009) considered oil exploration to be partly responsible for the declining fish stocks in the Niger Delta. Emissions and continuous light from gas flaring can negatively affect biodiversity (Umoren et al. 2020). Ogbemudia et al. (2013) linked gas flaring to thermal injury and necrotic leaf spots diseases of plants in SCFR. Also, oil field construction activities can have negative effects on biodiversity such as bush clearing, sand filling, drilling, piling and dredging. Solid and liquid wastes disposal during operations can be detrimental to biodiversity. Numbere (2019) reported that spillage from oil and gas exploration is a major cause of mangrove destruction in the Niger Delta. Major drivers of forest cover loss were attributed to oil exploration, population growth and infrastructural development (Akpan-Ebe 2014). Some authors have reported the negative impacts of oil spills in the Qua Iboe River (Essien and Antai 2005; Essien et al. 2012). Essien and Udoh (2015) considered oil exploration to be among the greatest threat to SCFR.

Oil exploration appears to facilitate nipa palm invasion of mangrove areas. Numbere (2018, 2019) listed some of the effects of oil exploration on the environment. They considered petroleum exploration as pioneering the opening up of forests, creating dredged canals and right of ways for seismic operations, access for drilling and installation of oil production infrastructure, such as wellheads, laying of pipelines and flowlines, flowstation and compressions station, and establishment of staff quarters and camps. Activities of the oil industry, which results in the disturbance of mangroves, might have inadvertently favoured the spread of nipa palms. Oil industry activities that might have contributed to the disturbance of mangroves includes clearing, dredging, sand filling, seismic exploration, oil spills, effluents and solid waste disposal, including drilling muds, pipeline installation and ROW. Numbere (2019) attributed the luxuriant growth of nipa palm around creeks and rivers in Okrika to the activities of Port Harcourt Refinery and other oil industry activities. Nipa palms are now conspicuous along most of the rivers in the Niger Delta region, including Imo, New Calabar, Bonny, Opobo, Saint Barbara, Andoni, Saint Bartholomew and Nun either as pure stands or mixed with mangroves. Nipa palm has also been reported in other river systems westward, including Warri, Forcados, Escravos and Benin River. Using remote sensing of satellite images obtained from different epochs, Wang et al. (2016) showed that increasing oil exploration coincided with decreasing mangrove area while increasing nipa areas in the Niger Delta. Using a reciprocal transplant experiment on mangrove soils with different levels of hydrocarbons pollution, Numbere and Camilo (2016) observed that nipa palm seedlings survive longer than mangrove seedlings when both are planted in crude oil-contaminated mangrove soil. Numbere (2019) also observed that mangroves planted on nipa palm soil were retarded.

5.6.3 Expanding Human Settlements

A large section of the SCFR area has come under serious threat as a result of increasing human encroachment. Although, there are indigenous communities in the area even before the forest reserve was established, but oil exploration activities have attracted more people to the area especially since the early 1970s to date. For instance, forest degradation is highest in the western flank of the forest reserve mostly due to migrants seeking for opportunities for business and employment in the oil sector. This trend is expected to increase especially with the coming on stream of four marginal field operators in the area. Besides, oil industry roads and pipeline ROW also create accesses for the establishment of satellite communities even in the forest reserve. New settlers are also commonly involved in other activities including wood logging and agriculture.

Numbere (2019) ranked urbanization as a major driver for nipa palm invasion because of several damaging activities on the mangrove such as clearing, dredging, sand filling, construction of houses, disposal of domestic wastes and other economic activities such as farming and creation of fish ponds. The advent of exploration activities in the area has led to the construction of residential quarters and camps for the accommodation of oil workers, resulting in the attraction of people for employment and business opportunities, which has resulted in gradual human encroachment into previously inaccessible areas.

Akwa Ibom State, which was founded on 23 September 1987, has 31 LGAs. The total land mass of Akwa Ibom State is 7081 km^2 which is 0.77% of the total land mass of Nigeria, 923,768 km^2. Owing to boundary disputes with other states, a slightly larger area of 8412.0 km^2 is reported in some literature. The size of the SCFR when it was established is 310.78 km^2, though there are other approximations in literature, including 310 km^2, 310.80 km^2 and 311 km^2. Hence, the reserve occupied 4.39% of the entire state. The communities in the forest reserve are mostly located in Mbo, Esit Eket and Ibeno LGAs. Government data obtained from National Population Commission (NPC) and National Bureau of Statistics (NBS) projected to the present (3.4% annual growth rate) shows that the population of Akwa Ibom State is 2.4 million, 3.9 m, 5.4 m and 6.2 in 1991, 2006, 2016 and 2020, respectively. The total population of the three LGAs where SCFR is located is 149,130 persons, 242,748 persons, 336,983 persons and 385,204 persons in 1991, 2006, 2016 and 2020, respectively, which therefore represented 3.82%, 4.49%, 5.43% and 6.21% of the state. Among the communities, host communities of oil and gas explorations are more populated especially Mkpanak and Unyenge group of communities. The population of Unyenge was 2561, 2919, 3892, 5697 and 6512 persons, while that of Mkpanak is more than doubled, being 6746, 7690, 10,743, 15,009 and 17,156 persons in 1991, 1996, 2006, 2016 and 2020, respectively. The rapid population increase is attributed to petroleum activities that attracts migrants to the area.

In 2020, the population of Mbo, Esit Eket and Ibeno LGAs is 163,625 persons, 101,726 persons and 119,853 persons, respectively, which summed up to 385,204 persons. The size of Mbo, Esit Eket and Ibeno LGAs are 216.69 km^2, 169.16km^2 and 244.95 km^2 with a total land mass of 630.80 km^2. Hence, the population density of each of the LGA as of 2020 is 755, 601 and 489 persons/ km^2, respectively, with overall 610 persons per km^2, which was a significant increase from the values obtained in 2006 being 480, 375 and 308 persons/km^2, respectively.

The major economic activities, i.e. agriculture, fishing, hunting and wood logging, have major direct impacts on biodiversity. Oil palm processing, palm wine tapping and distilling are common. Other economic activities that can have effects on biodiversity include marine transportation, crafts making, collection of fuel wood and non-timber forest products, such as snail, spice, medicinal plants, ogbono and wild fruits. Baker (2003) reported the main economic activities within the forest reserve as artisanal fishing, farming, wood logging, hunting and palm wine tapping and distilling.

Communities close to the QIT, like Mkpanak among others, receive electricity from QIT, while others including Unyenge are connected to the national grid. However, most of the communities in the coastal area of Ibeno LGA are not connected to the national grid. Due to unstable electricity in the communities connected to the national grid and the non-electricity in the off-grid communities, people in the area rely on self-generated electricity, which can also contribute to noise, vibration and release of small quantities of hydrocarbons to the environment, which could negatively impact wildlife biodiversity. Biomass energy is mostly used for household cooking, including fish processing/drying. Fuelwood (firewood) gathering affect both plant and animal biodiversity, and distort biomass degradation and recycling patterns.

Transportation activities have greatly affected forest reserves. Most of the coastal settlements in Ibeno LGA are accessed through marine transportation, apart from Mkpanak and Inua Eyet Ikot that are accessed through the Eket-Ibeno dual-carriage road. It should be noted that roads and pipeline ROW are linear structures that cause habitat fragmentation, which is detrimental to biodiversity, especially in forest reserves. Roads and ROW also create access for intensive biodiversity exploitation. Transportation is used to convey agricultural products including fish and fish products, timber and non-timber products, the noise, vibrations, and emissions from the various transportation modes could negatively affect biodiversity, especially wildlife.

5.6.4 Farming and Land-Use Change

Prior to the advent of oil exploration in the area, the indigenous people living in the area were predominantly rural farmers, who are dependent on the land for subsistence agriculture for survival. But intensive commercial farming is increasing among communities (Baker 2003). Biodiversity is impacted in the course of cultivation; forests including biota are destroyed under "slash and burn" agricultural practices. Shifting cultivation is the common practice, where cultivated plots of land are temporarily abandoned to fallow for a period, while encroaching on virgin forests for subsequent farming (Essien and Udoh 2015). Major crops include cassava, cocoyam, melon, maize, oil palm and cucumber. Coad (undated) observed that the degradation of the western section of the reserve was primarily due to land clearing for agriculture, especially by people who migrated to the area seeking for opportunities in the petroleum sector. Also, ROW and roads created by the oil industry facilitated agricultural activities, because most farms are located by the roadside. Roads are also used for the evacuation of agricultural products.

Oates et al. (2004) observed that much of the forest reserve has been converted to farmland or plantation. But as of 1990, an estimated 80 km^2 of relatively undisturbed swamp forest survived in the centre of the reserve, which has further reduced to about 48.22 km^2 (Ndoho et al. 2009). However, Olajide and Udofia (2008) provided a higher figure of the current size of the forest reserve to be 150km^2 of land. Ndoho et al. (2009) estimated that unsustainable farming practices accounted for over 80% of the deforestation rates. Studies have shown that indiscriminate land use practices have led to the destruction of a sizeable portion of SCFR (Amubode 1992; Akpan-Ebe 2005).

Using Landsat satellite imageries covering three epochs (1993, 2003 and 2013), i.e. at 10-year intervals spanning a period of 20 years, Ogar et al. (2016) conducted land use and land cover change analysis of SCFR and projected the data to 2033. The study covered an area of 146.15 km^2 of the forest reserve, of which dense vegetation occupied 63.5 km^2 in 1993, which declined to 42.43 km^2 in 2003 and further declined to 28.22 km^2 in 2013, which translated to a decline of 35.28 km^2 during the period, i.e. at an annual decline rate of 1.76 km^2. Hence, the dense forest, which initially occupied 43.45% of the area in 1993, declined to 29.04% in 2003 and further declined to 19.32% in 2013 which is a 55.56% change over the period, i.e. the annual decline rate of 2.78%. While rivers were relatively stable over the years, degraded vegetation and bare soil correspondingly increased during the period. Sparse/degraded vegetation occupied 55.26% in 1993, which increased to 68.77% in 2003 and further to 77.40% in 2013, translating to 40.02% change, which is an annual increase of 2%. Bare soil occupied 0.61% in 1993, increased to 1.57% in 2003 and further increased to 2.57% in 2013, which translated to 321.35% change at an annual rate of 16.07%. The decline in the dense forest was attributed to resources exploitation, biomass energy, agricultural and human settlements expansion into the reserve. At this rate of decline, the study predicted that by 2033 the whole SCFR could be lost. Other authors have reported forest decline in SCFR. Effiong (2011) reported the changing pattern of land use in the Calabar River catchment as the major drivers of forest loss, which ranged from small-scale shifting cultivation to large-scale conversion of intact forest to oil palm and plantain plantations.

5.6.5 Wood Logging/Lumbering

Logging activities in the reserve account for large-scale biodiversity depletion/deforestation through selective felling of mature timber-yielding tree species. Baker (2003) listed the drivers of wood logging in the area, including the demand for timber in the market and the desire to increase income, the use of timber for building construction and dug-out canoe making. There has been increased clearing, wood logging and forest degradation, particularly in the west end of the reserve, predominantly around Douglas Creek close to QIT. Most of the timber products found in many towns such as Uyo, Ikot Abasi, Eket, Onna, Etinan and nearby stated, were sourced from the SCFR (Essien and Udoh 2015). Logging has seriously endangered some plant species that are in great demand. Certain tree species are preferred by loggers and are generally removed selectively. Popoola et al. (2004) listed some of the valuable tree species that have been selectively logged extensively, including *Hallea ciliata* (Abura), *Piptadeniastrum africana*, *Uapaca togolensis*, *Lophira alata* and *Nauclea diderrichii*. Baker (2003) listed 42 species of trees that are selectively harvested for timber, including iroko, abura, walnut and mahogany. The fruits of some timber species are diets of monkeys.

The process of cutting down trees using powered chain saw causes noise and vibration that scare wildlife species in addition to destroying their habitats. While some wildlife is forced to migrate and change their habitat, others are driven away, even to other nations (Baker 2003; Essien and Udoh 2015).

In most settlements, the current level of logging was considered a relatively new activity, i.e. within the last 30 years. Timber extraction occurs all year-round but could be affected by transportation difficulties especially during the rainy season. In many communities, the proceeds from logging activities benefit only a few persons some of which are non-indigenes. The income generated from logging appears to greatly surpass other economic activities apart from oil exploration (Baker 2003).

The major road linking ExxonMobil QIT to Eket and other road created by the oil industry has also facilitated the transportation of wood from the reserve. Stubbs and Widenham Creeks are used for water transportation of wood mainly during the rainy season. Boats are used to transport wood west to the main road. Along the coast, timber is usually transported by lorries on the beach especially during low tide. Overall, logging activity is increasing in the reserve (Baker 2003).

5.6.6 Wildlife Hunting

Wildlife in the area is hunted mostly for food. Four hunting methods are used in the study area, namely, gun hunting, dog hunting, trap hunting and group hunting. Gun hunting, though carried out by few hunters, can create high-pitch noise and vibration that can scare wildlife. The hunting activities carried out deplete the wildlife species within the ecosystem (Essien and Udoh 2015). But according to Baker (2003), hunting does not appear to be a major activity in the forest reserve, because only a few local people are engaged in it on a part-time basis. The primary targets of hunting efforts include antelope (*Tragelaphus*), grasscutter (*Thryonomys swinderianus)*, bush pig (*Potamochoerus porcus*), porcupine (*Hystrix*, *Atherurus*), rats and crocodiles. Monkeys and other primates are also hunted. However, antelope and bush pig are now considered to be “rare” in the forest reserve. Udoma-Michaels et al. (2019) reported that many wildlife were lost in the forest reserve in the last 20 years. Roads and pipeline ROW created by the oil industry also facilitated access by hunters into the forest reserve. Hunters attributed the declining wildlife of the forest reserve to bushmeat trade, vegetation degradation and continuous gas flaring which makes the animals unsettled at nights (Umoren et al. 2020).

5.6.7 Fishing Activities

Due to the aquatic nature of the reserve, fishing is one of the major activities of host communities especially the coastal Ibeno LGA. Fishing activities are done mostly using hand-dug boats. Several factors have caused the decline of the fish stock of the area, including overfishing, oil slicks, waste disposal, habitat modification and nipa palm invasion. Also, the degradation of mangroves, which are breeding and spawning grounds for fish, including some offshore fishes, is a major biodiversity concern. The removal of the mangrove destroys the natural habitat of migratory fish, crabs, periwinkles, mudskippers and oysters (Essien and Udoh 2015).

5.6.8 Wine Tapping and Distilling

Another commercial activity in the forest reserve is palm wine tapping and distilling. Men are mostly involved in palm wine tapping. Palm wine is mostly extracted from the sap of raffia palms and subsequently distilled for ethanol (local gin) production using fuelwood as energy source. Palm wine and local gin produced from the forest reserve are sold in both local and distant markets such as Oron, Uyo, Eket, Ikot Abasi and the neighbouring states like Abia, Cross River, Imo and Bayelsa. The intensive extraction of palm wine has put pressure on the raffia palms. Some edible insects that are dependent on the palm are thus impacted. Other important products exploited from the raffia palm include roofing thatch, ropes, poles and raffia for raffia bags, shoes, beads and art works (Essien and Udoh 2015).

5.6.9 Over-Exploitation of Non-timber Products

Collection of snails especially of the genera *Achatina* and *Archachatina*, Ogbono and wild fruits appears widespread in the forest reserve. In small scale, the collection of these products is harmless to biodiversity. But at a high scale, since the population of the area is increasing, their collection could disrupt forest ecological processes, which could affect biodiversity.

5.6.10 Poor Waste Management

Due to lack of facilities, both municipal solid wastes and sewage are disposed off freely into water bodies without any form of treatment. This practice could facilitate the breading of disease vectors and transmission of infectious agents. Wastes can be toxic or sub-lethal to fish and wildlife and could be magnified along the food chain. In most of the communities, open defecation and waste disposal into surface water are common. Domestic water is often abstracted from shallow groundwater and surface water sources. Because of the open defecation and solid waste disposal into surface water sources, faecal coliforms are quite common in the water. Open defecation can cause algal blooms. However, the oil industry has also sunk boreholes in some of their host communities. Other activities like domestic effluents, engine oil disposal, washings, etc. can contaminate the environment which could affect biodiversity. Overland runoff can release agrochemicals into the environment, such as fertilizers and pesticides, which can be toxic to biodiversity.

5.6.11 Infrastructural Development

Akwa Ibom State is a fast-developing infrastructures, of which some encroached into the SCFR. For instance, the State Government has acquired a large portion of the SCFR at Ibaka and Mbo LGAs for development of a Seaport. Dredging for the seaport project could affect the hydrology of the area, which could be detrimental both to the freshwater and already stressed mangroves of the forest reserve. The International Airport at Okobo also encroached into a portion of the SCFR. Also, road construction to these project sites will obviously pass through and fragment the reserve. Also, the proposed federal Railway and coastal road from Calabar to Lagos will pass through the reserve, not only directly destroying biodiversity along the route, but also opening up the area for further infrastructural development and resource extraction (Essien and Udoh 2015).

5.6.12 Flooding and Other Activities

Owing to climate change and anthropogenic activities, flooding is increasing especially in coastal communities. The displacement of native mangrove vegetation by the exotic nipa palm made the area susceptible to frequent flooding events. During rainy season, flooding hinders trekking especially between the months of June and October, which could limit wood logging activities. But at such times, boats are used to convey wood logs from the reserve to major roads. Also, during the peak of the flood when wildlife migrates to some relatively higher grounds in the area, they become vulnerable to attacks. Other activities that have impacted the biodiversity of the forest reserve include bush burning and cattle grazing.

5.7 Conservation Priorities for Stubbs Creek

The current rate of uncontrolled exploitation of the biodiversity of the forest reserve is unsustainable, hence the need for intervention and conservation. Uncontrolled exploitation has caused the destruction and loss of habitat, loss of species and their genetic base.

Umoren et al. (2020) listed institutional weakness and unsustainable consumption patterns as factors responsible for the degradation of SCFR. Forest reserves are created as a strategy for conserving biodiversity. These reserves are ideally protected against unauthorized access (Ofem and Inyang 2019). Cannon et al. (2022)

highlighted the limitations of habitat restoration approaches, pointing out the difficulty in the restoration or regeneration of old and ancient trees in degraded habitats. Hence, they must be protected to preserve their invaluable diversity.

There are several considerations and priorities for the conservation of the Forest Reserve. First, it is the largest remaining natural forest in Akwa Ibom State and one of the last significant forests in the region (Oates et al. 1992; Tooze 1997; Tooze et al. 1998a, b; Werre 2001; Baker 2003). The reserve possesses fragile ecosystems with valuable species. Stubbs Creek, which is part of the Cross-Niger Transition Forest ecoregion, was ranked by the World Wildlife Fund (WWF) as "Critical/ Endangered". Hence, that the conservation and continued protection of SCFR present the only chance for the survival of important habitats and species endemic to the region especially the Sclater's guenon (*Cercopithecus sclateri*), and possibly actualization of the proposed SCGR (Werre 2001). The reserve protects the coastline from tides arising from the Atlantic Ocean and provides nesting grounds for the endangered hawksbill turtle (*Eretmochelys imbricata*), leatherback turtle (*Dermochelys coriacea*) and fishes of the Atlantic Ocean (Tooze et al. 1998a; Baker 2003). Also, indigenous people are dependent on the resources from the forest reserve for their survival, including edible fruits and leaves, tubers, flowers, herbal medicines, fuelwood, building construction materials, fodder, wine and other alcoholic beverages, wrapping leaves, mushrooms, snails, aquatic fish and honey (Ofem and Inyang 2019), hence the need to conserve the forest for environmental sustainability.

UNEP-WCMC (2009) highlighted the important conservation priorities of SCFR, because the ecosystem is classified as marine turtle nesting site, within the Nigerian-Cameroun chimpanzee range and Cross River Gorilla range, important primate area, containing mangroves and important fish breeding and spawning sites. Phil-Eze and Okoro (2009) listed SCFR among70 protected areas in the Niger Delta, comprising 1 strict nature reserve, 2 national parks, 4 game reserves and 63 Forest reserves. Unfortunately, the SCFRs, like many others in the Niger Delta, currently receive no special protection or budget from the state or Federal Government.

5.8 Conclusion

Stubbs Creek Forest Reserve is a biodiversity hotspot located at the south eastern edge of the Niger Delta. The forest reserve contains diverse habitats, including freshwater swamp forest, brackish mangrove swamp and coastal beach ridge, located adjacent to the Atlantic Ocean. The forest reserve is habitat to diverse assemblages of flora, fauna and microbial species occupying different niches in the reserve. The reserve is home to important primates especially monkeys, chimpanzees and gorillas. Indigenous people rely on the resources in the reserve for their survival especially for food and meat, water and beverages, spices and medicinal herbs, timber products for various construction works, non-timber forest products, such as snail, mushrooms and wild fruits, ropes and fibres, and crafts and tools such as baskets and hand-dug boats. Being surrounded by diverse water bodies, artisanal fisheries and processing of fish products is one of the traditional occupations of the people. The forest reserve was officially gazetted in 1930, but before then, nipa palm was imported and introduced into the area in 1900s, which is fast displacing indigenous mangrove and freshwater species. Petroleum exploration started in the area in 1950s, which attracted more people and opened up the area for exploitation of the forest reserve. Oil industry operations resulting in oil spills, gaseous emissions, noise, vibrations and continuous light affect biodiversity. In addition, oil industry activities inadvertently facilitated the expansion of nipa palm. Using oil industry ROW, anthropogenic activities increased in the area, including expanding settlements and construction of infrastructure, farming and fishing, palm wine tapping and distilling, wood logging and hunting, effluents and solid wastes disposal. The reserve is being impacted by multiple stresses, which has manifested in diverse ways, including decreasing natural forests, increasing flooding in recent years, low fish stock and rare sightings of wildlife species. However, adequate legal framework exists, which ought to protect the forest reserve, but unable due to weak enforcement. The reserve does not enjoy any special government protection or budget. This chapter concluded by highlighting the priorities for biodiversity conservation in the reserve. Except urgent steps are taken to reverse the trend, the world will soon lose a major biodiversity hotspot.

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Chapter 6
Therapeutic Potentials of Wildlife Resources and Options for Conservation

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Abstract Therapeutic practices for the treatment of ailments is a global practice in the world. Indigenous groups in Africa and some continents have used the approach of the ethno-zoological process to cure various defects and have reported quick recovery. In countries like China, Brazil, India, Vietnam, South Africa, Sudan and Nigeria, mammals can be used for several therapeutic purposes. The leg, skin, skull, head, eggs and various parts of the body of birds can be used for various therapeutic processes. Amphibians such as frog and toads can be used for curing diverse ailments in Chinese medicine. Reptiles such as snakes, lizards, turtles, crocodiles and geckos have been used for treating cancers, sores, rashes and diabetes in Mexico and India. Fishes have both therapeutic and medicinal functions and it contains n-3 polysaturated fatty acids as well as fat-soluble vitamins, all of which are important for human health. The population of wildlife resources is affected by various factors. Bush burning can destroy natural habitats, cause release of emissions and public disturbances, and displace animals and the slow ones are more vulnerable. Bush trade is expected along the roads and open markets and involves the sale of these

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animals for economic gains. In countries like Nigeria, South Africa and Zimbabwe, the sale of bushmeat is on the rise because they are used in religious, cultural celebrations and traditional rites. There is, therefore, need for conservation as described by the International Union for the Conservation of Nature (IUCN) Red list criteria. This review therefore presents the various wildlife resources that can serve therapeutic purposes, the factors that impact their presence and the management procedures for conservation of these resources.

Keywords Aquatic and terrestrial ecosystems · Sustainability · Therapeutic functions · Medicinal functions

6.1 Introduction

The discipline of science that deals with the treatment of disease or the art and science of healing has been described as therapeutics. Therapy is defined as the methodical administration of remedies to effect a cure for particular diseases, afflictions, discomfort or harm. Chemotherapy, biotherapy, hormone therapy, gene therapy, light therapy, physiotherapy, psychotherapy and many more forms of therapies have also been described, depending on the tools (drugs, surgery, radiation, mechanical devices, food, psychiatry) employed in the treatment of disease. Vaccines and other preventive or prophylactic therapy are used to prevent the spread of diseases. The active treatments are those that cure disease and require no further treatment after recovery. The treatment may be long term, meaning that the treatments keep the body functioning while the disease is being treated or supportive treatments which means the body functioning will be kept while the disease is being treated and also symptomatic treatments are those that relieve symptoms until the immune system heals the body. There are also palliative treatments that encompass the treatments that reduce pain for patients. Pharmaceuticals are chemical compounds with medical qualities that are utilized for therapeutic purposes. These are derived from natural sources or synthesized through chemical methods. Biopharmaceuticals are medications that are derived from living organisms. Nutraceuticals are food products that are used to cure ailments because of their medical and health benefits. Vitamins, minerals, fatty acids, nutritional supplements, particular diets, genetically altered foods, herbal goods, processed foods and so on are all included.

The indigenous ethnic groups in Africa and other tropical/subtropical regions culturally practise the use of different zootherapeutic resources for the treatment of illnesses and diseases. This is so because they believe these resources are free gift of nature and are cheap sources to obtain a quick recovery from complicated and/or common ailments. These ethno-zoological methods of therapeutic practice are seen as superstition by many since medicine materials hail from animal body parts (blood, meat, bones, skins, hooves, tusks, oil, feathers, etc.), wastes products (excreta and secretions) and other non-animal materials produced by them (nests, eggs, cocoons, honey, etc.). This has led to the believe that the healing process is from magical rituals while using these kinds of materials as a therapeutic source. Yet profound curative evidence on our folk medicines usefulness is dated back to the time when there were no modern medicines or pharmaceutical science. As reported by Janes (1999) and Young (1983), the indigenous people globally get this knowledge of traditional medicines from their indigenous cultural values, ideas, rituals and traditions passed on for the purpose of healing, preventing and controlling diseases locally. It was reported that over 75% of the world population sought for treatment by patronizing traditional medicine practitioners that uses plants and animals and their products to treat human diseases, which is age-long practice (Izah et al. 2018a, b, c, d, e, 2019a, b, c; Izah and Seiyaboh 2018a; Izah and Aseibai 2018; Epidi et al. 2016a, b).

The proportion of traditional medicine users is higher in developing countries than in developed countries globally. It is commonly practised in different parts of the world even now when pharmaceutical drugs are available (Jugli et al. 2019). It was also reported by World Resources Institute (WRI) (2000) that in recent time, the successful application of animal-based treatment had played a significant role in the formation of traditional pharmaceutical products locally and internationally for treatments. Over 1500 animal species have been utilized for the treatment of diseases. Likewise, in Brazil, it has also been documented that over 280 animal species are used as medicines for various ailments (Alves 2009; Alves et al. 2008; Alves and Rosa 2007; Costa-Neto 2004). It was reported that in Nigeria, zootherapeutic treatments involve spiritual, psychological or even mystical origin (Izah and Seiyaboh 2018a) and are widely practised in different ethnic groups in Nigeria (Soewu 2013).

In the line of their health benefit rendered, Samfira and Petroman (2011) presented zootherapy in two different points: Firstly, as a healing remedy for common and/or complicated human ailments like cold, weakness, malaria, cough, asthma, cancer, epilepsy, poor vision, rheumatism, kidney problems, etc. and by the use of therapeutic products derived from animals. Animals possess certain qualities, substances or chemicals that play significantly in the healing process globally to improve human's health (Costa-Neto 1999a). Hussain and Tynsong (2021) mentioned 20 most common diseases reportedly cured with the use of zootherapeutic medicines, which are malaria, wounds, burns, fever, cough and cold, fractures, dysentery, stomach disorders, tuberculosis, diabetes, rheumatism, liver problems, joint pain, asthma, fatigue, jaundice, animal bites, anaemia, male impotence and women's issues. Animal-Assisted Therapy (AAT) is a process where the therapist recommends socializing with well-trained animals as part of a patient's therapy for mental and physical treatment. These AAT methods help the patients successfully relate and establish trust, motivation, calmness and relaxation by the social support from trained animals like dogs, cats, horses, dolphins, guinea pigs, fish, farm animals, etc. It is possible that petting and interacting with animals could release certain hormones that can stir up ones mood and successfully yield great results as part of rehabilitation tool for patient's quick recovery from mental and physical health elevation (Samfira and Petroman 2011).

Therefore, the AAT contributes to the following:

- Mental health—helps in relaxing, lowers anxiety, bring about happy distraction, mental stimulations increases, provides comfort and reduce loneliness, etc.
- Physical health —helps in lowering blood pressure and slows breathing for those who are anxious, improves cardiovascular health, reduces physical pain and relax more during exercise.

Children learn how to develop themselves, be respected and face upcoming challenges and situations while playing with pets (Pentenero 2001). In South Africa, it was reported that plants and animals are commonly used as medicines for healing ailments and improving their lifestyle (Whiting et al. 2010). However, the traditional-based drugs from plants and its products are given more concern when compared with animal-based medicines. Marques (1997) reported that out of the 252 essential chemicals selected by World Health Organization (WHO) for medical research, 9% are of animal origin and 11% are of plant origin. Therefore, it is equally essential for extensive research to be carried out on the identification of animal resources for medicines in our health care sectors (Alves and Rosa 2005; Costa-Neto 2005).

The mode of administration/application of traditional medicines is of various types, which include eating, drinking, tying, anointing, banding, massaging and fumigation. The mode of entry/delivery to a sick person may include oral, dermal and nasal, while the methods of preparing these traditional medicines may include eating fresh, cooking, burning, crushing/grinding, wrapping, powdering and drying (Kendie et al. 2018). The knowledge from our indigenous traditional medicines globally has contributed immensely to identifying biological resources and its worth for economic marketability (Costa-Neto 2005). Ethno-biological data is the guide for the search for new pharmaceuticals from natural resources occurring naturally for treatment (Blakeney 1999). To this end, this review is centred around the identification of the therapeutic potentials in some animals (mammals, amphibians and reptiles), the factors that has led to their decline over time and how they can be conserved for effective utilization and availability for human therapy.

6.2 Concept of Wildlife Resources

A self-sustaining ecosystem is achieved by the interaction between biotic components and abiotic components in an ecosystem. This interaction creates a competition for resources among the biotic components, which could be either intra-species or inter-species competition. The impact of this competition determines the chances of survival of each organism within the ecosystem. Based on the general characteristics, ecosystems are either aquatic or terrestrial. Several smaller ecosystems could be found and each of these broader ecosystems has distinct species composition. Several organisms have been withdrawn from broader ecosystems based on their perceived economic, social or recreational benefits and domesticated by humans.

However, it is obvious that organisms in the wild far out numbers the domesticated species. This implies that there are loads of untapped resources in the wild space which could possibly contain therapeutic answers for the ailments of humans and domestic animals.

Energy flow among the aquatic and terrestrial ecosystems essentially carries a similar pattern, even though different organisms may be involved. Food chain/food webs are established, which facilitates energy production from inorganic carbon sources by primary producers, such as zooplanktons and green grasses, in the aquatic and terrestrial habitats, respectively. This process supplies the higher-trophic levels' consumers with energy for the ecosystem. Flooding occurs after torrential rainfall and originates from the upland areas and flows by gravity into the river bodies. The washing away of topsoil may be accompanied by the removal of organic and inorganic materials, such as fertilizers, pesticides and herbicides into the receiving water bodies. Illegal discharges, stormwater runoff, sewer leakages and sewer overflows constitute different sources of pollution that end up in the aquatic bodies. They can cause contamination of water bodies and the organisms inhabiting them (Tran et al. 2019). Similarly, anthropogenic pollutants, deposited in upland areas such as in landfills may run off into the receiving water bodies, thereby polluting the waters and the aquatic organisms which may be inhabiting them. The consequence could be seen in increase algal blooms due to organic nitrogen and phosphorus flow into the rivers, and toxic effects on the aquatic organisms which may increase through bioaccumulation and biomagnification through the food chain/food web.

Conversely, there is also the energy-demanding transport of contaminant nutrients from aquaticecosystem to the terrestrial ecosystem. Salmon (*Oncorhynchus* spp.), seabirds and penguins have been reported to convey contaminants from their habitat to terrestrial habitats (Mazeika et al. 2012). Larsson (1984) reported the transport of polychlorinated biphenyls (PCBs) from sediment by chironomid larvae and as it metamorphosizes into the adult form, the PCBs are transferred into the terrestrial space. These contaminants revolving between the aquatic and terrestrial ecosystems carry with its physiological modulatory effects on organisms inhabiting both ecosystems (Steele et al. 2018). Therefore, it is not just nutrient cycling or feeding relationships that may exist between terrestrial and aquaticecosystems but also the circulation of contaminants with its potential threat to biodiversity and it is a shared feature between the two ecosystems. Invasive microbes such as viruses, bacteria, protists and fungi could also affect both aquatic and terrestrial ecosystems because such invasive species often possess enhanced performance qualities, thereby quickly spreading through lower diverse communities altering the ecological dynamics in their favour (Litchman 2010).

6.3 Wildlife with Therapeutics Potentials

6.3.1 Mammals with Therapeutics Potentials

The use of mammals as traditional medicine has the highest therapeutic potentials compared with species of other animal groups. According to Hussain and Tynsong (2021), the already existing research literature on India Tripura's zootherapeutic application shows that mammals have the highest therapeutic use, followed by the use of insects, birds and other animals subsequently. This could probably be possible since mammals are easily available to humans for use in traditional medicine (Chellappandian et al. 2014; Jaroli et al. 2010). A lot of mammals have been reported to be used for conventional medicines globally as seen in China, India, Brass, Vietnam, South Africa, Sudan and Nigeria. Some of the zootherapeutic mammals and their body part or products used for various traditional treatments are summarized in Table 6.1.

6.3.2 Birds with Therapeutics Potentials

The use of avian species in zootherapy has been an age-long experience around different cultures of the world, including African cultures (Lev 2003). However, zootherapeutic practices in traditional medicine could be both a blend of traditional religious belief systems, fetish practices and perhaps, presence of chemotherapeutic agents (Friant et al. 2021; Loko et al. 2019; Adeola 1992). For instance, Friant et al. (2021) reported the use of birds for making aircraft charms among the studied ethnic nationalities of rural hunting Nigerian communities, just as Loko et al. (2019) reported the Beninoise use invertebrates substantially for religious and mystical purposes. Many birds are reported to have therapeutic potentials in African folk medicine (Edae and Mohammed 2018; Petrozzi 2018). However, the zootherapeutic exploitation of birds may tend to be religious–cultural centric rather than a wide distribution over all communities (Friant et al. 2021). A survey of specialized markets in ten (10) West African countries reported a total of 302 species sold in the West African states, of which the vulture (*Necrosyrtes monachus*) was found in nine states, being the most patronized bird in African folk medicine (Petrozzi 2018). Consuming fresh blood of black vulture (*Coragyps atratus*) is thought to confer resistance to disease and enhances immunity by transferring immune factors, which stimulates the hematopoietic system of the eater (Sánchez-Pedraza et al. 2012). In South Africa, Whiting et al. (2011) reported that 53 bird species were sold in the Faraday market, and common Ostrich was the most frequently distributed among the traders.

Generally, the most often encountered birds in African markets are Red-necked Buzzard (*Buteo auguralis*), Black kite (*Milvus migrans*), African Goshawk (*Accipiter tachiro*), Lizard Buzzard (*Kaupifalco monogrammicus*), Tawny Eagle (*Aquila

Table 6.1 Medicinal mammals, products/parts used and ailment treated

Common name	Scientific name	Products/ part of the body used	Treatment	Reference
Slender mongoose	*Herpestes sanguineus*	Fore and hind limbs	Rheumatism	Izah and Seiyaboh (2018a); Soewu (2008)
Gorilla	*Gorilla gorilla*	Bones	Bone fracture	
Elephant	*Loxodonta Africana*	Bones		
Roan antelope	*Hippotragus equinus*	Bones		
Colobus monkey	*Colobus* spp.	Skull		
Chimpanzee	*Pan troglodytes*	Skull		
Serval	*Leptailurus serval*	Carcass	Protection against evil manipulations	
Leopard	*Panthera pardus*	Head		
Leopard	*Panthera pardus*	Skin	Snake poison	
Hyena	*Crocuta crocuta*	Skin, claws		
Serval	*Leptailurus serval*	Skin, bones and claws		
Chimpanzee	*Pan troglodytes*	Placenta	Fertility in women	
Colobus monkey	*Colobus* spp.	Placenta		
Female Pangolin	*Manis tricuspis*	Internal organs		
Female Wild cat	*Felis silvestris*	Internal organs		
Gorilla	*Gorilla gorilla*	Male organs	Aphrodisiacs/potency for men	
Wild cat	*Felis silvestris*	Male organs		
Male Pangolin	*Manis tricuspis*	Whole		
Male Crocodile	*Crocodylus* spp.	Whole		
Male Serval	*Leptailurus serval*	Whole		
Chimpanzee	*Pan troglodytes*	Left arm	Appeasing witches	
Gorilla	*Gorilla gorilla*	Left arm		
Leopard	*Panthera pardus*	Head		
Serval		Head	Fortune rousers	

(continued)

Table 6.1 (continued)

Common name	Scientific name	Products/ part of the body used	Treatment	Reference
	Leptailurus serval			
Chimpanzee	*Pan troglodytes*	Head		
Pangolin	*Manis tricuspis*	Pangolin		
Patas monkey	*Erythrocebus patas*	Head, fore and hind arms		
Colobus monkey	*Colobus* spp.	Fore limbs	Prevention of accidents	
Patas monkey	*Erythrocebus patas*	Head		
Pangolin	*Manis tricuspis*	Whole	Seeking marital partner	
Slender mongoose	*Herpestes sanguineus*	Head		
Colobus monkey	*Colobus* spp.	Fore arm		
Patas monkey	*Erythrocebus patas*	Fore arm		
Leopard	*Panthera pardus*	Hide	Anti-snake venom	Izah and Seiyaboh (2018a); Oduntan et al. (2012)
Civet cat	*Civettictis civetta*	Anus	Anti-convulsions	
Squirrel	*Xerus inauris*	Whole		
mongoose	*Herpestes sanguineus*		Boosting immune system	
Gorilla	*Gorilla gorilla*	Penis	Anti-poison drugs preparation	
Squirrel	*Xerus inauris*	Hair		
Patas monkey	*Erythrocebus patas*	Skull	Whooping cough	
Porcupine	*Hystrix cristata*	Intestine	Stomach ache	
Pangolin	*Manis tricuspis*	Head	Control bleeding preparations	
Aardvark	*Orycteropus afer*	Bone	Back ache treatment	
Warthogs	*Phacochoerus africanus*	Legs	Prevention of lameness	
Grey duikers	*Sylvicapra grimmia*	Intestine	Stomach ache	
Buffalo	*Syncerus caffer*	Bone	Anti-vomiting	
Bushbuck	*Tragelaphus scriptus*	Head	Management of leprosy	
Bushbuck	*Tragelaphus scriptus*	Skin, placenta	Management of sleeping sickness	

(continued)

Table 6.1 (continued)

Common name	Scientific name	Products/ part of the body used	Treatment	Reference
Monkeys	*Macaca* spp.	Head	Management of mental disorder	
Duiker	*Sylvicapra grimmia*	Horn	Resuscitation	
Indian porcupine	*Hystrix indica*		Malaria	Hussain and Tynsong (2021)
Tiger	*Panthera tigris*			
Flying fox	*Pteropus* sp.			
Pangolin	*Manis* sp.	Scales, meat		
Bat	*Chiroptera* sp.	Whole		
Rhesus monkey	*Macaca mulatta*			
Musk Deer	*Moschus* sp.			
Black bear	*Ursus thibetanus*			
Donkey	*Equus asinus*		Cough and cold	
Cattle	*Bos* sp.			
Goat	*Capra aegagrus*	Milk		
Pig	*Sus domesticus*			
Otter	*Lutra perspicillata*		Female problems	
White-lipped peccary	*Tayassu pecari*	Teeth, testicles	Pneumonia, indigestion, asthma	Barros et al. (2012)
Giant armadillo	*Priodontes maximus*	Nails, fat	Snake bite, asthma, cold, rheumatism, menstrual pain, earache	
Lowland tapir	*Tapirus terrestris*	Fat, penis, nails	Hernia, menstrual pain, indigestion, stroke, rheumatism, male incapability	
Giant Anteater	*Myrmecophaga tridactyla*	Tail hair	Asthma, spasms in children	
Jaguar	*Panthera onca*	Fat	Asthma, rheumatism	
Woman	*Homo sapiens*	Milk	Hiccup	
Civet cat	*Civettictis civetta*	Anus	Treat madness	Ouoba et al. (2020)
Elephant	*Loxodonta africana*	Bone	Stunted children	
	Syncerus caffer brachyceros	Tail	Rib pain	
	Erythrocebus patas	–	Stomach aches, breast pain, dizziness, coughing	

(continued)

Table 6.1 (continued)

Common name	Scientific name	Products/ part of the body used	Treatment	Reference
Black caiman	*Melanosuchus niger*	Blood	Epilepsy, stroke	Costa-Neto (2005)
Dromedary	*Camelus dromedarius*	fresh manure	Alleviate arthritis	Costa-Neto (2005); El-Kamali (2000)
Lion	*Panthera leo*	Fats	Alleviate abdominal pains	
Hyena	*Crocuta crocuta*	Fats		
Hippo	*Hippopotamus amphibious*	Tusks	Aphrodisiacs and ornamentals	Costa-Neto (2005); Adeola (1992)
Manatee	*Trichechus senegalensis*	Fat	Rheumatism, boils, and backache	
Duikers	*Sylvicapra grimmia*	Hollow part of hooves	Special medium for concoctions with herbs to invoke/or appease gods and witches	
Antelopes	*Hippotragus equines*			
Deer	*Odocoileus virginianus*	Antlers	Backache	Costa-Neto (2005); Martin (1992)
Tiger	*Panthera tigris*	Bones	Rheumatism, backache	
Monkey	*Macaca* spp.	Skeletons	Pain reliever	
Pangolin	*Manis tricuspis*	Scales	Skin diseases	

rapax), Palm-nut Vulture (*Gypohierax angolensis*), African Harrier-Hawk (*Polyboroides typus*), Lanner Falcon (*Falco biarmicus*), Black-casqued Hornbill (*Ceratogymna atrata*), African pied hornbill (*Tockus fasciatus*), Little banded goshawk (*Accipiter badius*), Grasshopper buzzard (*Butastur rufipennis*), Brown snake Eagle (*Circaetus cinereus*), Western Marsh Harrier (*Circus aeruginosus*), Black-shouldered kite (*Elanus caeruleus*), Long-crested Eagle (*Lophaetus occipitalis*), Dark Chanting Goshawk (*Melierax metabates*), Grey Kestrel (*Falco ardosiaceus*), Common Kestrel (*Falco tinnunculus*), Helmeted guineafowl (*Numida meleagris*), Great blue turaco (*Corythaeola cristata*), Western Plantain-eater (*Crinifer piscator*) and Rose-ringed parakeet (*Psittacula krameri*) which are all of least concern (LC) according to IUCN Red list, while White-backed vulture (*Gyps africanus*) and *Ruppell vulture* (*Gyps rueppellii*) are endangered (EN); White-headed vulture (*Trigonoceps occipitalis*) and Hooded vulture (*Necrosyrtes monachus*) are critically endangered (CR), while the Crowned eagle (*Stephanoaetus coronatus*) is near threatened (NT) (Petrozzi 2018).

Although the number of birds harvested for ethnomedical purposes may be significant in specific settings, it is only expedient to consider the effect on the species in the context of IUCN Red list. Whiting et al. (2011) reported 4 out of the 53 species to be of conservationimportance, while Petrozzi (2018) highlighted 5 species of conservation importance out of 216 species he identified. The entire body parts of these birds could be important in the folk medical practice, which again depends on the ailment, locality and the trado-medical practitioner. Some of the commonly used body parts are feathers/furs, leg, skin, skull, toe, head, beak and eggs for the management of an array of diseases where the concoction prepared could either be topically applied or eaten at specific doses according to the recommendation of the practitioners (Friant et al. 2021; Whiting et al. 2011). The consumption of such birds raises concerns over the possibility of zoonoses being transferred between animals and humans (Friant et al. 2021). Generally, the application of birds in folk medicine could arise from exploiting the products of body metabolism (bodily secretions and excrements), or from external but associated materials such as nests and cocoons (Costa-Neto 2004). Much work must be done to elucidate the exact compounds associated with the avifauna which are being exploited in folk medicine.

6.3.2.1 Conservation Strategies for Birds

The use of domesticated animal parts as alternatives to wildlife could be beneficial in improving wildlife conservation. For instance, Abrao et al. (2021) reported the application of sheep fat (*Ovis aries*; Artiodactyla) as an anti-inflammatory agent in substitute for the commonly patronized Green-anaconda fat. The introduction of volunteer corps as well as the revered traditional institutions to help prevent indiscriminate bush burning could prove effective in curtailing the menaces associated with bush burning. The setting apart of licensed personnel with sole duties of harvesting birds/wildlife, as done in Brazil (Roldán-Clarà et al. 2017), could drastically reduce indiscriminate hunting down of avifauna. Governments at all levels are encouraged to enact legislation, and where such pieces of legislation are in place, they could be seriously implemented to ensure the setting apart of natural protected areas even in urban centres to ensure the conservation of natural resources and avifauna. The construction of recreational trails in the forests should be minimized to avoid interference with birds' distribution and normal living (Bostch et al. 2018). Moreover, preferential consumption of domesticated birds would also help conserve wild species. Jeke et al. (2018) reported the domestication of Japanese quails in Zimbabwe could reduce pressure on the harvesting wild quails.

6.3.3 Amphibians with Therapeutics Potentials

The use of amphibians in the treatment of different ailments and production of traditional medicines is a way long practice. In Chinese medicine, frog and toad extracts are used in curing a lot of sicknesses like a haemorrhage of gums, toothache, heart diseases and other diseases. Perhaps, the toxins they produce within them which could equally be used as therapeutic chemicals for combating human ailments (Gomes et al. 2007). The skin of amphibians contains bioactive chemical molecules, such as peptides, steroids and alkaloids. These molecules have therapeutic potentials (antibiotics) against infective bacteria, protozoa, fungi, diabetes, neoplastics, and analgesic and inducing sleep properties. The medicinalamphibians and their parts used for treatment of ailments are presented in Table 6.2.

Table 6.2 Medicinal amphibians, products/parts used and ailment treated

Common name	Scientific name	Products/part of the body used	Ailment treatment	Reference
Toad	*Bufo melanostictus*	Whole	Animal/insect bites, diabetes	Hussain and Tynsong (2021)
Frog	*Rana temporaria*	Whole	Wounds	
Frog	*Nanorana liebigii*	Whole	Cough and cold, dysentery	
Frog	*Lymnonecties* sp.	Whole	Burns	
Rainette Kunawalu	*Trachycephalus resinifictrix*	Pitch	Headache, toothache, pneumonia	Barros et al. (2012)
Giant Marine Toad	*Rhinella marina*	Abdomen, entire body	Erysipelas, wounds	
Chinese toad	*Bufo bufo gargarizans*	Skin secretions	Arrhythmia, other heart diseases	Gomes et al. (2007)
Indian toad	*Bufo melanostictus*	Skin methanoic extract TSE	Sleep inducing factor	
Frog	*Anura* sp.	Portions	Aphrodisiacs, impotence, prevent infertility, contraceptives	
Salamanders	*Urodela* sp.	Skin, whole, bodies parts	Traditional medicines	
Newts	*Pleurodelinae*	Skin, whole	Aphrodisiacs, other illnesses	

6.3.4 Reptiles with Therapeutics Potentials

Traditionally, the frequent use of reptiles, such as snakes, lizards, turtles, tortoises, geckos and crocodiles, especially by the indigenous people of many countries has been proved to be effective in recovery from ailments (Table 6.3). They are used for treating many terminal ailments, such as rattlesnake pills which functions in the treatment of cancers, itching, sores, rashes, haemorrhoids, welts, diabetes, stress, pimples, skin blotches, etc., (Rubio 1998) in Mexico and India. Land monitor lizard is used to treat rheumatism, haemorrhoids, body pain, burns, bites from snakes, etc. (Kakati et al. 2006). According to the Sierra Madre people has a saying that “The most poisonous animals are the most potent for its antipoison” (Werner 1970). An example is the poisonous rattlesnake (*Crotalus* sp.) whose internal parts treat different diseases from boils to bronchitis (Costa-Neto 2005). Irrespective of the fact most reptiles are consumed for their protein-rich meat at other parts of the world, it equally conforms to their folk medicinal beliefs (Klemens and Thorbjarnarson 1995). Some reptiles are used for religious and magical uses in countries like tribes

Table 6.3 Medicinal Reptiles, products/parts used and ailment treated

Common name	Scientific name	Products/ part of the body used	Ailment treatment	Reference
Python	*Python sebae*	Fats, bones	Rheumatism	Izah and Seiyaboh (2018b); Soewu (2008)
Crocodile	*Crocodylus* spp.	Whole tail bones		
Nile monitor lizard	*Varanus niloticus*	Whole	Protection against evil manipulations	
Chameleon	*Chamaeleo senegalensis*	Whole		
Python	*Python sebae*	Gall bladder, liver	Snake poison	
Chameleon	*Chamaeleo senegalensis*	Tail		
Crocodile	*Crocodylus* spp.	Scale		
Male crocodile	*Crocodylus* spp.	Whole	Aphrodisiacs/potency for men	
Python	*Python sebae*	Head	Appeasing witches	
Python	*Python sebae*	Whole	Fortune rousers	
Python	*Python sebae*	Head	Prevention of accidents	
Crocodile	*Crocodylus* spp.	Head		
Monitor lizard	*Varanus bengalensis*	Whole		
Python	*Python sebae*	Head	Seeking marital partner	
Crocodile	*Crocodylus* spp.	Intestine	Anti-poison drug preparation	Izah and Seiyaboh (2018a); Oduntan et al. (2012)
Puff adder	*Bitis arietans*	Intestine	Prevention of adultery in women	
Python	*Python sebae*	Bone	Backache and spinal cord impairment	
Python	*Python sebae*	Fat	Rheumatism, broken bones and joints	
Python	*Python sebae*	Head	Treatment of lunatics	
Tortoise	*Centrochelys sulcata*	Whole	Chest pains	
Chameleon	*Chamaeleo senegalensis*	Whole	Cure of dizziness	
Black cobra	*Naja* spp.	Head	To cause fear in opponent	
Agama lizard	*Agama agama*	Whole	Asthma	–
Python	*Python sebae*	Intestinal fat	Skin problems like scars, keloids, erase burns, stretch marks	–
		Whole	Malaria	

(continued)

Table 6.3 (continued)

Common name	Scientific name	Products/ part of the body used	Ailment treatment	Reference
Monitor lizard	*Varanus bengalensis*			Hussain and Tynsong (2021)
Turtle	*Melanochelys trijuga*	Whole		
Viper	*Viper rusell*	Whole		
Yellow-footed tortoise	*Chelonoidis denticulata*	Fat	Hernia	Barros et al. (2012)
Black and white tegu	*Tupinambis teguixin*	Fat	Earache, snake bite	
Green Anaconda	*Eunectes murinus*	Fat	Hernia, rheumatism, wounds, stroke	
Common Caiman	*Caiman crocodilus*	Fat	Pneumonia, rheumatism	
Red-footed tortoise	*Chelonoidis carbonaria*	Fat	Hernia, pneumonia	
Rattlesnake	Crotalus sp.	Intestine	Boils, bronchitis	Costa-Neto (2005)
Geckos	*Tarentola* sp.	Dried body	Aphrodisiacs	Costa-Neto (2005); Martin (1992)
Rattlesnake	*Crotalus* sp.	Pills	Cancers, itching, sores, rashes, haemorrhoids, welts, diabetes, stress, pimples, skin blotches, etc.	Rubio (1998)
Land monitor	*Varanus bengalensis*	–	haemorrhoids, rheumatism, body pain and burns, as well as spider and snake bites	Kakati et al. (2006)
Senegal chameleon	*Chamaeleo senegalensis*	–	recipient invincible to detractors/ charm	Sodeinde and Soewu (1999)

in India, Egypt, Brazil, Greece, Rome and China, for either protection charms, invoking spirits, traditional rites and as symbolic gods, etc. It was reported by Sodeinde and Soewu (1999) that in Nigeria, animals parts are used for charms and other health conditions. The Senegal chameleon is used to make people invincible to charms/detractors.

6.3.5 *Fishes with Therapeutics Potentials*

Fish has both nutritional and therapeutic properties. Fish has long been recognized for its medicinal and therapeutic properties. Fish's therapeutic qualities are used to prevent and treat heart disease, arthritis, asthma and various other disorders, allowing humans to maintain their general health. The utilization of fish as

Table 6.4 Therapeutic uses of some fish species

Fish species	Common name	Therapeutic use	Images
Clarias gariepinus *Clarias anguillaris*	Catfish	Barrenness, diarrhoea, anti-inflammatory, anti-microbial, antinociceptive, and anticancer properties Pile, yellow fever (scalp infections of children)	
Trachelyopterus galeatus	*Trachelyopterus galeatus*	Asthma, umbilical hernia	
Mystus tengara	Tengra	Anticancer properties	
Malapterurus electricus	Electric catfish	Dull memory, cancer, stroke correction of under-developed foetus	
Oreochromis niloticus	Tilapia	Under-developed foetus, insomnia, enhanced child delivery	
Heterobranchus spp.	Mud fish	Gonorrhoea	
Polydactylus quadrifilis	Thread fin fish	The fresh fish contain cray poison antidote in its alimentary canal	
Parachanna obscura	Snake head fish	In wound healing as well as reduce postoperative pain, anti-inflammatory, antimicrobial, antinociceptive and anticancer properties	

therapeutics may either be whole (Table 6.4), part or even certain nutrients found in a particular fish. The implication of this is that there is nutritional diversity among fish species, thus presenting them for different therapeutic functions.

6.3.5.1 Therapeutic Importance of Fish

Fish has long been known for therapeutic relevance to humans. Because of the presence of n-3 polyunsaturated fatty acids (PUFAs), oily fish such as cod, herring, salmon, and turbot have a high therapeutic benefit for humans. Several studies have revealed that eating fish or fish oil reduces the risk of CHD death and sudden death. It is another source of n-3 PUFA, notably eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), as well as fat-soluble vitamins, all of which are important for human health. Consumers see fish as a healthy diet, according to several studies, especially when compared to meat, which is the most common substitution for animal proteins.

Healthy Eye and Brain Performance

DHA is required for retina efficiency and is needed for clear vision. One of the possible reasons that frequent fish diet accelerates brain development is the presence of DHA. DHA is an important factor of the nervous system's grey matter (brain) and the phospholipids of the eye's retina. As a consequence, maintaining a balanced amount of DHA for both the brain as well as the retina is crucial to both nervous and visual capabilities to function properly. Elevated blood levels of n-3 fatty acids such as EPA and DHA have been linked to a lower risk of obesity, implying the importance of fish oils in weight management (Micallef et al. 2009). Those who had fish more than once per week had a 50% lower chance of developing early tissue impairment than men who consumed fish less than once a month. (Simopoulos 1999). Skin, hair and nails that are beautiful, healthy and shiny are likewise made up of omega-3 fish oil (Smith et al. 2000).

Healthy Bone Maintenance and Cardiovascular Diseases Management

In young boys, polyunsaturated fats, notably DHA, have been related to bone mineral production and peak bone growth. Previous studies have reported that a diet with a low omega-3 ratio enhances risk of osteoporosis. Also, because of the vitamin D level in fish, regular fish eating can help with bone formation. Fish consumption is linked to lower mortality in people at an increased likelihood of atherosclerosis (CHD), although the link is less evident in low-risk populations (Calder and Yaqoob 2009). In several ways, dietary n-3 fatty acids help decrease heart disease (Nordoy 1996).

Lupus Challenge

Systemic Lupus Erythematosus (SLE) is a chronic inflammatory disease that includes photosensitive facial rashes, tiredness, anorexia, weight loss and sweats, as well as potentially fatal heart, lung, kidney and central nervous system involvement (Levine 1997). Fish oil consumption has been reported to be effective with patients with lupus.

Rheumatoid Arthritis

Fish oil might successfully replace pharmaceutical treatment for Rheumatoid Arthritis (RA) sufferers. Traditional RA therapy may involve the use of dietary fish oil supplements (Duffy et al. 2004; Cleland and James 2000). Syntonic caused by RA can be treated with omega-3 fatty acids. Fish oil is a less expensive and safer treatment alternative that may be utilized to delay the onset of RA. The major component of fish oil, EPA, has been found to suppress the development of these inflammatory agents (Darlington and Stone 2001).

Psoriasis Challenge

Oral fish oil prophylaxis has been shown to help psoriasis patients (Kremer et al. 1987). Psoriasis is a common skin disorder noticeable by an irritated, red border. Leukotriene levels that are abnormally high are thought to play a part in the start-up and course of the illness (arachidonic acid metabolites). Fish oil's primary component EPA has been proven to lessen the harmful effects of leukotriene and has anti-inflammatory characteristics. Supplementing with fish oil can help with psoriasis treatment, especially if itching is a problem (Mayser et al. 1998).

Asthma

The deficiency of n-3 fatty acid in the blood has been related to autoimmune diseases. Omega-3 fatty acids have improved chronic respiratory illnesses, such as asthma. Inflammatory response of the bronchi is a significant cause of asthma. Fatty acids supplementation, according to Bittiner et al. (1987), does certainly lessen asthmatic problems in people with protracted chronic bronchitis.

Kidney Disorders

According to the findings, low-dose fish oil treatment is effective in IGA nephropathy, a joint renal dysfunction characterized by inflammation (Glomerulonephrophritis) in the blood capillary network that filters waste products from the blood (Nagakura et al. 2000). Arachidonic acid is converted to inflammatory eicosanoids, whereas fish oils induce anti-inflammatory eicosanoids to be produced. In response to renal injury, "good" eicosanoids likely reduce the course of renal sickness by lowering glomerular and interstitial inflation, mesangial cell contractility, platelet aggregation and vasoconstriction (Nagakura et al. 2000).

Cancers and Diabetes

Omega-6 polyunsaturated fatty acids, arachidonic acid and its derivatives stimulate tumorigenesis. Long-chain fatty acids found in fish oil help prevent spread of cancer cells. Alkylglycerols found in shark liver oil have been identified as tumour vascularization inhibitors (Pedrono et al. 2004). Fish oil supplementation has no effect on glycaemic control, and frequent consumption of fish must be acknowledged as a vital portion of a food aimed at diabetes treatment (Knowler et al. 2002). In patients with poor glucose tolerance, increased physical activity and dietary changes have been shown to 60% reduction in the risk of type 2 diabetes (Kahn et al. 2006).

6.3.5.2 Conservation Strategies of Fish Species

Since the preservation of fish biodiversity, as well as other biotic resources, is seen as necessary for human health, it is crucial to prevent future reductions in fish resources by developing all feasible conservation and restoration measures. Protection policies are expected to encourage management approaches that preserve the sustainability of aquatic habitats, avert extinction and help in the rehabilitation of endangered animals. There are two basic strategies to preserving biodiversity: in situ (inside the natural environment) and ex situ (outside of the natural habitat) (out of the natural habitat) (Hiddink et al. 2008)

Ex Situ Fisheries Resource Conservation:

Under this strategy, endangered fishes are safeguarded outside of their natural habitats. The ex situ conservation effort is built on three major pillars: (a) a living gene bank, (b) a gamete gene bank and (c) a DNA gene bank.

- *Live gene bank*: A live genome library, also known as a genomic information centre, is a facility where endangered animals are kept in captivity, bred and genetically managed to minimize genetic problems, domestication and unintentional selection. In the Mini Germplasm Repository, The National Center for Genetic Resources and Biotechnology (NACGRAB) keeps wild stocks of vulnerable species and significant genetic resources.
- *Embryo/gamete genomic repository*: Appropriate collections indicative of the natural genetic variation of threatened animals are retained in cold storage in

liquid nitrogen (LN2), availability of genetic resources of threatened groups and intense genetic enhancement of commercially valuable species. A live genome library, also known as a genomic information centre, is where endangered animals are kept in captivity, bred and genetically managed to minimize inbreeding depression, domestication and unintentional selection. Some research institutes have accomplished cryopreservation of milt from endangered and commercially important fishes for an extended period (Datta et al. 2008). Since the procedure is only effective for male gametes, but no technique for cryopreservation of eggs/embryos has so far been identified, it is thought that the technology has minimal importance for endangered species conservation at the moment. Attention will then be focused on androgenesis, the technique of assembling the whole genome from cryopreserved milt alone. Moreover, technological advancements have enabled the establishment of a genome repository that assures the availability of male gametes of numerous species throughout the year for breeding, along with basic germplasm transfer with genetic and hybridization operations
- *DNA-based gene bank*: The safe, long-term preservation of a living organism's genetic material is known as DNA banking. The most frequent source of DNA extraction is blood; however, it may also be acquired from other tissues. DNA banks allow for the preservation of genetic material as well as the comparison of an individual's genetic information.

In Situ Fisheries Resource Conservation (Within the Native Environment)

The preservation and recovery of viable species populations in their native habitats are referred to as in situ conservation. This conservation technique preserves not just the genetic variety of the species, but it also assures that, in addition to the target species, a slew of other interconnected species is kept as a byproduct (IUCN 2009).

- *Reserves or protected areas*: Specific locations are designated as protected sites as part of in situ conservation initiatives. A protected area is an area of land and/or sea that is notably committed to the conservation and maintenance of biological variety, as well as natural and cultural resources.
- *Restocking*: Captive breeding or hatchery programmes are one of the several methods for replenishing dwindling natural stocks (Hiddink et al. 2008; Datta et al. 2008). Juvenile fish are frequently taken from their original habitat and allowed to mature sexually inside the safe limits of an aquaculture or laboratory setting before being released back (ranching) into the natural environment (Hiddink et al. 2008). The goal of stocking activities is to create a long-term rise in fish populations that are currently in decline.

6.4 Factors Affecting the Decline in Wildlife Resources with Therapeutic Potentials

Several factors could be affecting the decline of birds population in different regions of the continent. These challenges confronting avifauna are like those of other wildlife and have been itemized as trading in bushmeat, habitat destruction, undue exploitation, bush burning and climate change (Izah and Seiyaboh 2018b). The population of several wild species has been on the decline, of which some are threatened or endangered (Soewu 2013). Some factors that can affect their decline are as follows:

6.4.1 Bush Burning

The act of bush burning is majorly done in Nigeria, and it is an essential part in agricultural purposes. Fire is often used as a form of land preparation for farming purposes and is specified to a particular area. If not controlled, the fire may spread to other non-target areas, thereby affecting the wildlife biodiversity in such areas. Apart from bush burning, wildfires can also occur (Izah et al. 2017) which destroys the natural habitats, can cause release of various emissions to the atmosphere and cause public disturbance and litter. It can displace both young and old animals, and the slow ones are more vulnerable. Wildlife such as rabbits, snails, mammals like grasscutters, snakes and amphibians like toad can be displaced from burnt environments and this has implicated their therapeutical potentials. The impact of bush burning has the attendant consequences of soil degradation destruction of birds especially newly hatched ones living in nests, which could affect such population. Moreover, the burning of insects has been shown to facilitate the decline in the growth/sustenance of insectivorous birds (Tallamy and Shriver 2021).

6.4.2 Bushmeat Trade/Direct Consumption

The sale of wildlife along the road and open markets is widely done in most African countries (Izah and Seiyaboh 2018a; Izah et al. 2018e), but the unitization of the animals for medicine is not known widely (Alves et al. 2011) as compared with plant species. Akani et al. (2015) reported the composition of mammals in bushmeat markets and were mainly consumed as diet. The highly priced ability of most of these wildlife species had made their trade lucrative, thereby the hunting for these species has increased (Ohimain et al. 2014).

Direct harvesting of wildlife for human consumption (food, subsistence or to defend against a threat, ethnotherapy, religious rites, cultural rites, fetish practices, economic purposes) is a major way by which aves are threatened. Identifying quails as a rich source of nutrient and tasty meal endangers the conservation of wild quails in Zimbabwe (Jeke et al. 2018). The celebrations of religious and cultural festivities are traditionally accompanied by the sacrifice or related use of wildlives, the kind of which may be peculiar to either Muslims or traditionalists in different parts of Nigeria (Adeola 1992). In South Africa, the cost of items sold in the markets ranged from 1 USD to 1566 USD (Nieman et al. 2019). The sales of birds may not just be within local contexts of national boundaries, it may well be an international trade as well, with attendant pressure on harvesting local avifauna for exportation.

6.4.3 Climate Change

This occurs from increased greenhouse gases in the atmosphere over an extended period of time. Bush burning can contribute to global warming by releasing gases that are pollutants (Jamala et al. 2012; Hamid et al. 2010). A link has been established between land degradation, biodiversity loss and climate change (Obayelu 2014) and activities that can cause adverse effects in ecosystem can affect biodiversity composition directly or indirectly. Hence, climatic change can impact the wildlife population with therapeutic properties.

6.4.4 Habitat Destruction

Habitat destruction and unsustainable use of resources due to the increasing human population also contribute substantially to declining wildlife resources. African population has dramatically increased. All these people need to be housed, fed and acquire material needs to provide for their wellbeing. Achieving these requires urbanization, destruction of established ecosystems to pave the way for creating urban centres, industries, social and recreational facilities and road networks for which all such activities are known to interfere with established avifauna communities (Bilal et al. 2021). These urban developments may force biodiversity, especially birds to either accept or avoid their altered natural habitats. A substantial loss in local biodiversity following urbanization where other species adapt within the urbanized setting suggests phenotypic differences in their behavioural, morphological and physiological patterns compared against their natural habitat dwelling conspecifics. They may be due to urban specific change drivers, such as noise, the light at night, air pollution, human pressures and disturbances.

A solution to reduce this effect was the gazetting of forests in different locations to preserve biodiversity and legislation. Despite these measures, the sizes of protected areas are declining (Ayanlade 2014). The destruction of habitats can expose the wildlife to human attacks and migration of species, thereby reducing their abundance and hence their therapeutic potentials.

6.4.5 Excessive Exploitation

The mangroves and Niger Delta regions are the core centre in excessive exploitation of endemic wildlife resources. This is carried out by hunting using various local and sophisticated devices and it is a significant form of exploiting wildlife in most areas. This is so because wildlife serves different processes from food sources of protein to hunting for traditional medicine activities, income generation from sale and when they cause menace on agricultural crops. All these activities can reduce their abundance and hence their therapeutic potential (Izah et al. 2018a). Obviously, the overexploitation of birds employed in zootherapy in the localities could endanger such birds, and ultimately create imbalances in the ecosystem, which could affect humans and animals within such communities (Jugli et al. 2019). This view is critical to harnessing conservation efforts, especially in rural African societies where ethnomedical practices are very common, owing to the poor or near absence of orthodox primary health care facilities. The need for conservation arises based on empirical assessments as described by the International Union for the Conservation of Nature (IUCN) Red List.

6.4.6 Others

Other factors leading to the decline of biodiversity, especially birds, including the creation of wind turbines and high-tension electricity cables directly affects birds through collisions against turbines and eventually death, or indirectly by fragmentation or habitat loss (Smeraldo et al. 2020).

6.5 Conservation Strategies of Wildlife Resources with Therapeutics Potentials

With the immeasurable importance of wildlife ranging from its mythological potentials to medicinal solutions, the conservation of animals is important for the sustainability of biodiversity so their functions in therapeutics will not be jeopardized. The level of exploitation has increased over the last three decades with some species becoming rare and some extinct as they were not sighted in the last decades; therefore, the functions they serve therapeutically has been jeopardized (Izah and Seiyaboh 2018a). There is a need to ensure sustainable strategies, so the animals are represented all year round. The following measures can be undertaken:

- In-depth knowledge of environmental factors that can affect biodiversity and safe approaches.
- Understanding the context between the relationship of humans and nature.

- There is a need to understand the cultural dimensions towards the conservation of wildlife.
- Protection of the resources via legislation and policies.
- By imposing restrictions on some animal species and their products.
- By maintaining diversity and restocking when necessary.
- Enacting laws regarding wildlife.
- The signing of international treaties.
- Workforce development.
- Non-governmental organizations should influence conservation policies.

6.6 Strategic Approaches to Wildlife Conservation in View of Its Therapeutic Potentials

Wildlife has various unique properties and contributes to the ecosystem diversification, seed dispersal, grassland expansion and reduction in bushlands. The value is intrinsic (Sifuna 2012) and the efforts of various actor's conserve wildlife diversity is essential. The actors are the international community, national and regional institutions, and local and community institutions and their approaches vary with time and space. There are two major strategies which are the protected areas and community conservation in the colonial and post-colonial era.

6.6.1 Colonial Wildlife Management Strategies of Protected Areas

This strategy involved the study on the creation and rise of protected areas and this which was a dominant colonial strategy at the beginning of the twentieth century. These measures were used to separate humans from animals by creating a protected area where the animals will be domiciled, exclusion of human residents and minimization of the impact of humans (Adams and Hulme 1999). International Union for the Conservation of Nature (IUCN) describes protected areas as a space recognized and managed through various means for long-term conservation of nature and its association with the ecosystem and cultural values (Dudley 2008). This is aimed at preserving wildlife based on its functions which was championed by colonial policymakers, international organizations and hunters for the provision of a safe haven for important wildlife species.

On the long run, it served as an area for promoting biodiversity conservation (Hayes 2006). During the colonial era, it was believed that communities adjoining wildlife habitats were the cause of threat to their biodiversity by poaching on them. Guards were also stationed at the protected areas to ward off illegal exploitation of wildlife and the services of technical experts and field ecologists were also employed

(Sifuna 2012). Apart from hunting for food and cultural purposes at that time, some groups held the animals sacred and it was taboo to poach on them. This helped check on poaching on wildlife during this period (Jimoh et al. 2012). The community dwellers that strayed into the protected areas were apprehended, and they responded by fighting against the authorities because they believed they are being deprived of their rights (Etiendem et al. 2011). These measures were complex and strict on the community dwellers, but it was aimed at managing and sustaining wildlife resources because of its therapeutic properties.

6.6.2 Post-colonial Wildlife Management Strategies of Protected Areas

This strategy is a continuation of the colonial wildlife management strategies protected areas. The control of natural resources was not handed to the local communities as promised during the pre-independence campaign; it continued with the models instituted by the colonial governments (Murombedzi 2003). Protected areas increased and these areas were symbolized by park rangers with ammunitions to ward off community dwellers. After independence, personnel in most offices were replaced with people with the idea of Western management systems as against the traditional wildlife management system that was in place. Policies were later initiated which were generated from results on scientific studies of respective states. With this, monitoring and implementation was easy and each area had autonomy in domestic policymaking. The continuation of protected area strategies continued during the post-industrial era despite the non-fulfilment of promises during the campaign, while others who did not flow with the policies engaged in acts of sabotage. The tasks of wildlife protection in were a daunting one; with the lack of adequate infrastructures and funding, the measure was being frustrated. After long dominance by the state, the concept of shifting power of domination to the community was initiated at the beginning of the 1980s.

6.7 Community Conservation Strategy

This involves involving the community into the process of wildlife conservation and their role is to manage resources in protected areas (Kellert et al. 2000). Emerton (2001) stated that the community approach to preservation of wildlife has a strong economic rationale because if community participate and they have financial benefits from this activity, it is a win-win situation because the community will develop and their livelihood will be sustained from economic returns. Based on this, the World Wide Fund for Nature developed a programme in the 1980s called Wildlife and Human Needs Programme, which takes into cognizance the conservation costs by locals, hostility problems of local communities and ensure utilization of wildlife policies geared towards wildlife conservation (Adams and Hulme 1999).

The IUCN and Conservation Monitoring Centre devised guidelines for protected areas based on the understanding of the limited resources to meet the local requirements of the ecosystem and biodiversity. It described the principles of complementing national parks and protected areas and explicit guidelines on the interactions between nature and humans in the environment. This strategy was well accepted by the locals and international community towards the management approaches to human–wildlife conflicts in the background (Brandon and Szabo 2011). To a great extent, community management can reduce conflicts between park communities and animals, thereby sustaining their activities and their immersed contribution to the environment and humans that depend on them for various reasons.

6.8 Conservation and Sustainability

According to Glowka et al. (1994), the IUCN outline guidelines for the sustainability and biological conservation of animals against uncontrolled exploitation, including the following:

- The long-term viability is preserved or the future use potential of the target population is not reduced.
- Support and maintain the long-term viability and dependent ecosystems.
- It does not impair the long-term viability of other species.

However, this can only travail when environmental conservation programme is set up to by governments of countries to control and monitor the natural resources in a way that would protect man's needs and support biodiversity (Andriguetto-Filho et al. 1998). Animal species that are directly used in traditional medicines should be given top conservationpriority since stopping people from using these animals will not save them from being extinct (Kunin and Lawton 1996). These endangered animals could be managed if reared in different agricultural systems traditionally or scientific methods (Costa-Neto 1999b) and thus making it possible to recover and recycle these endangered animals for long-term viability. Lastly, there should be modern artificial medicines to serve as a suitable alternative for the use of depleting zootherapeutic animals as a treatment for ailments (Oldfield 1989).

6.9 Conclusion

The advantages of wildlife resources as therapeutic agents are numerous. They can be used for medicinal purposes such as the curing of ailments and diseases, which may be external or internal, traditional and religious purposes, and social activities.

Indigenous people believe they have magical properties and used as rituals for several protective activities. They also function in AAT in which trained animals are used for rehabilitation of patients and quick recovery from all forms of mental and physical defects.

Wildlife resources are essential components in the ecosystem and their abundance can be effected principally by human activities. When these activities occur, the slow and small animals are very vulnerable to the effects. Conversely, aquatic wildlife resources are dictated by the activities on land. In areas exposed to agricultural pollution from excessive use of chemicals, the water bodies are at the receiving end of all pollutants and nutrients, which may become excessive and lead to eutrophication. This inhibits oxygen and reduces aquaticbiodiversity. Mammals function in diverse therapeutic activities, such as treatment of rheumatism, bone fraction, curing of snake poison, fertility issues in women, potency for men, mystic activities and boosting immune system. The parts such as bones, limbs, claws, internal organs, carcass, head, fore arm and penis can be used as therapeutic activities. Birds such as ostrich, vultures, eagles, kite and guinea fowl have been used for medicinal purposes. Body parts such as feathers/furs, leg, skin, skull, toe, head, beak and eggs are used for medicinal purposes. Amphibians such as frog, newt, salamanders and toad are used whole for treatment of diabetes, human wounds, cough, cold, dysentery and animal or insect bites.

Reptiles such as snakes, lizards, turtles, tortoises, tegu, tortoise, anaconda, caiman, geckos, chameleon and crocodiles have been used traditionally to cure various ailments. The fats, bones, whole body, gall bladder, tail, head, intestines and intestinal fats are the parts used for treatment of rheumatism, snake bites, pneumonia, rashes, haemorrhoids, sores, itches and potency for men, aphrodisiacs, pains and spinal issues. It is also used for protection, such as prevention of accidents, appeasing witches, prevention of adultery in women, invincible charms and those seeking marital partners. Fishes are rich in n-3 polyunsaturated (PUFA), notably EPA and DHA, as well as fat-soluble vitamins, all of which are important for human health. Species such as *Clarias gariepinus, C. anguillaris, Trachelyopterus galeatus, Mystus tengara, Oreochromis niloticus, Heterobranchus longifilis, Polydactylus quadrifilis* and *Parachanna obscura* serve as various medicinal and therapeutical purposes when consumed. They cure ailments like diarrhoea, yellow fever, pile, asthma, cancer, gonorrhoea and dull memory. They have anti-inflammatory, antimicrobial, antinociceptive, anticancer properties and function in healthy eyes, brain and body development.

Finally, human activities that may affect their biodiversities, such as bush burning, bushmeat trade and consumption, destruction of habitat and excessive exploitation, must be addressed for a sustainable environment. The issues of climate change should also be addressed by encouraging climate-smart practices in human approaches. The need for knowledge on environmental factors and how it connects with biodiversity conservation are essential. Conclusively, laws and policies for the protection of wildlife resources and treaties must be enacted, notwithstanding the issues of cultural dimensions to the conservation of wildlife resources.

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Chapter 7
Threats to African Arthropods and Their Biodiversity Potentials on Food Security, Environmental Health and Criminal Investigation

Tambeke Nornu Gbarakoro and Maduamaka Cyriacus Abajue

Abstract Arthropods are the most diversified group of animals on every ecosystem. Their presence or absence in a defined ecosystem denote useful information of environmental concern. At a glance, Africa is renowned for her rich flora and fauna biodiversity which attract moderate conservation attention for the ungulates but not for the insects and other arthropod groups that are generally regarded as nuisance, pests and vectors of plant and animal diseases. Arthropods in Africa are envisaged to be under a threat notwithstanding that their biodiversity are yet to be documented. Threats to African arthropods biodiversity are mainly linked to habitat destruction, land-use change, deforestation, intensive mono-agriculture, use of broad-spectrum pesticides, invasive species and industrial pollution among others. Nevertheless, a holistic approach by the developed world showed that arthropods provide enormous benefits to man and his environment. Hence, insects among the arthropod groups provide ecological services (anthophilous) and serve as food for man and potential feed for animals (entomophagy). Ecologically, the species richness and abundance of insects and other related arthropods (soil mites) play crucial roles in cascading the potentials of arthropods biodiversity in food security; biomonitoring of polluted environments orchestrated by anthropogenic activities is anchored on insects and acarines. Interestingly, insects on decomposing vertebrate carcasses do not only act as decomposers and soil enrichment agents but also as forensic tool for estimating the post mortem interval of carcasses. Strategies on organically based pest management in agroecosystem, augmented by cultural practices to conserve the arthropods biodiversity, are sought after. Unpredictably, the potentials of African arthropods in food security, environmental health and medico-criminal science are scarce. This chapter therefore succinctly discusses the reasons for the gaps and suggests mitigation approaches to threats to arthropods biodiversity

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in Africa and their food security potentials, indicators of environmental health and tool for criminal investigation.

Keywords Biodiversity · African arthropods · Farm practice · Habitat fragmentation · Food security · Environmental health · Criminal investigation

7.1 Introduction

There are quite a number of various species of organisms, including arthropods in Africa because of tropical forests that abound the entire continent. A major proportion of the earth's biodiversity occurs in the tropical forests (Myers 1998). A number of these species are threatened to extinction due to the influence of over-demand for consumption, increase in human population growth and the reduction in resource input into their habitats. Any of a member of animal species that possesses jointed appendages that are likely to attain extinction in the foreseeable future is termed threatened arthropods. Consequently, the decline or disappearance of variety of any species that belongs to the Phylum Arthropoda in Africa is referred to as threats to African arthropods biodiversity. It is simply a biodiversity loss of a number of African arthropod species. Three hundred and ninety-four (394) species are listed as critically endangered arthropods species worldwide (IUCN 2016). The International Union for Conservation of Nature (IUCN) further added that 4.1% of all evaluated arthropod species are listed as critically endangered.

Accordingly, only 4478 species are categorized not threatened at present (IUCN 2016), 2100–4990 are threatened while 2875 arthropod species are listed as data deficient, meaning there is no sufficient information for a full assessment of conservation status, and thus are considered threatened until their status can be assessed. The causes of biodiversity threats influenced by the three influencers mentioned earlier are divided into two: direct and indirect factors. The direct causes or drivers of arthropod biodiversity threats in Africa are habitat change, unsustainable agricultural practices, over-exploitation of edible species, introduction of invasive species, climate change and pollution. Factors that interact in such a way that influence human-induced changes in biodiversity are collectively referred as indirect factors and include economic, cultural, religious and scientific factors, and distortion of the nitrogen cycle.

One of the major ill effects of arthropod biodiversity threats in Africa is the reduction or decline of ecosystem functions leading to low agricultural crop production and food scarcity in the region. It has also generated poverty among the people of the continent. In fact, the absence of the ecological roles of threatened arthropods will cause serious havoc on the ecosystem, including nutrient cycling and retention, enhancement of decomposition processes and degradation of the ecosystem. The reports of (World Health Organization (WHO) 2018; World Bank 2018) stated that one-fifth of the population in Africa experiences hunger, while almost half of the population in sub-Saharan Africa live below the poverty level. In addition to the efforts and approaches made by international organizations, such as United

Nations Environmental Programme (UNEP) to prevent, halt and reverse the degradation of ecosystems worldwide through support for sustainable land management and ecosystem restoration, it is suggested that the application of organic restoration approach and other techniques can help reverse declining biodiversity of arthropods in Africa. This chapter focuses on the causes of threats to arthropods biodiversity in Africa, effects of such threats and approaches made to salvage the threats.

7.2 Causes of Threats to Arthropods Biodiversity in Africa

7.2.1 Habitat Threats to Arthropod Biodiversity in Africa

Habitat change refers to changes that occur in the natural environment where organisms, including arthropods, inhabit or reside. It includes changes caused by the activities of human beings that is capable of leading to pollution, sand mining and deforestation. Others include natural phenomenon, such as flooding, drought that result in land modifications and consequently loss of habitats (Fig. 7.1). These changes cause a serious reduction in biodiversity to an extent that habitat loss has

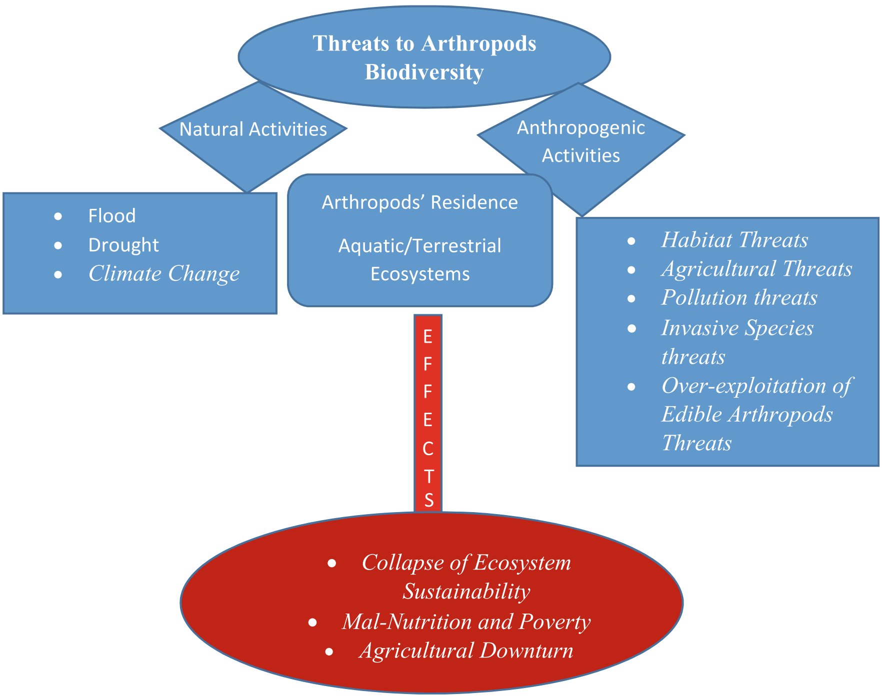

Fig. 7.1 Causes of threats to arthropods biodiversity in Africa

been pointed out as a “hefty menace to biodiversity and vital discernment for species extinction” (Singh et al. 2021).

Habitat change or loss that reduces biodiversity can be divided into three types: habitat degradation, habitat fragmentation and habitat destruction (Klappenbach 2020). Degradation of habitat is the reduction in the quality of resources and ecosystem services provided by the affected habitat. This causes a decline in biodiversity of arthropods inhabiting the habitat. Carrete et al. (2009) identified erosion, nutrient depletion and desertification as causative agents of habitat degradation. In Africa, particularly the Sahel region, biodiversity loss is caused by desertification (Walter 2016), such that arthropod diversity, beetles, spiders and ants were reported to be greater in protected areas of forests than desert areas in Senegal (Brandon et al. 2017).

Habitat fragmentation is the conversion or splitting of habitat which is usually larger in size to smaller habitat called fragments. It is driven by human development tendencies and cause isolation of animal communities (Bright 1993), creation of boundaries between species and loss of breeding sites. In Nigeria, particularly petroleum oil producing areas, fragmentation in forested and farmland habitats is caused by oil exploitation and exploration pollution. This creates physical demarcation between the impacted and non-impacted landscapes and is responsible for a decline in biodiversity in both above- and below-soil surface faunal communities. The third factor which is habitat destruction is defined as the massive destruction or removal of the natural habitat where the species live, thereby making the habitats incapable of upholding the native ecosystems and their species (Singh et al. 2021).

Pollution, deforestation and land-use conversion are principal contributors to habitat destruction in Africa, leading to loss in biodiversity and extinction of species. Land-use conversion of forested land for developmental projects such as housing and road construction has immensely caused decline in arthropod diversity. Similarly, land-use conversion to agricultural projects also accounts for the loss in biodiversity of arthropod as their local habitat is destroyed. Conversion of natural habitats of arthropod species for development and agriculture is very prominent in Africa, and this has affected arthropod species, more so, as impact assessment of the desired projects on arthropod inhabitants is usually ignored and not taken into consideration. The most affected of the natural habitats are the breeding sites of these arthropod species which are destroyed due to the ignorance of their ecological roles to the ecosystem and humanity. Lucey and Hill (2012) in a comparative study of insect habitats pointed out there are lesser number of insect species in homogeneous forests and tree plantations than there are in forests richer in number of plant species, herbs and shrubs. This indicates that insect diversity occurs more in natural forested ecosystems than human created tree plantations, and their destruction will certainly impact the ecosystem and consequently caused a reduction in biodiversity.

Changes in the quality of arthropods habitats caused by destruction, fragmentation and degradation of habitats definitely reduce species richness and abundance of the affected ecosystems, and this is discussed separately as we examine the contribution of pollution and agricultural activities to threats in African arthropod biodiversity.

7.2.2 Agricultural Threats to Arthropods Biodiversity in Africa

The various ways in which agricultural practices threaten arthropod biodiversity in Africa can be grouped into two: (1) agricultural landscape preparatory way and (2) unsustainable agricultural practices. During preparation of agricultural landscape, forested lands are converted to cropland, thus threatening the richness and abundance of arthropod species. The conversion or removal of forests causes a decline in biodiversity because forests serve as suitable habitat or biodiversity hotspots. In Africa certain methods of agricultural practices, such as indiscriminate and non-target use of pesticides, and other methods that cause nutrient depletion are termed unsustainable agricultural practices as they encourage ecosystem degradation and inadequate services. Unsustainable agricultural practices threaten biodiversity of an ecosystem and more so, as biodiversity contributes to the sustainability of an ecosystem, the more the threatened ecosystem, the lower the biodiversity and the less the sustainability. Sustainable agricultural practices that encourage higher biodiversity enhance more sustainability, indicating that an ecosystem with this quality is better able to carry out its natural processes in the presence of any disturbance. Unsustainable agricultural practices that threatened biodiversity of arthropods in Africa are the non-target insect pests control services, wastewater irrigation system and casual agricultural practices.

Most farmers in Africa apply pesticides that do not target any particular pest(s) in the management of pest incidence, and this destroys many arthropods, including those beneficial to the environment and man. This practice has posed a serious threat to the indigenous biodiversity of arthropods in both terrestrial particularly soil and aquatic ecosystems. In the soil ecosystem, this practice cause a reduction in soil mites that facilitate the process of decomposition and other soil insects (beetles) that create burrows used as channels for mineralization and easy water infiltration. Similarly, in the aquatic ecosystem, run-offs from pesticide-treated farmlands enter the water-system and are threats to the life of arthropod species. The situation in the aquatic ecosystem is worsened when run-offs from chemical fertilizer-treated farmlands which contain nitrogen and phosphorus increase the nutrient content of the water body (eutrophication), causing a depletion of available oxygen and a consequent decline in species that depend on dissolved oxygen. Pesticides and fertilizers when properly applied sustain the biodiversity of arthropods in the soil but when improperly applied impact biodiversity negatively. Nitrogen from chemical fertilizers, for instance, alters the pH and nutrient composition of the soil and in turn causes stunting of growth of suitable grass habitat that is essential for bees and pollinating insects, thus reducing their biodiversity (Klein et al. 2007).

Another way African arthropod biodiversity is threatened is the casual farming technique or system, usually practiced in the urban and semi-urban areas by persons who are not engaged in active farming. It is usually practised within and around human homes and called urban and peri-urban agriculture (UPA) (Amprako et al. 2020). In West Africa, this system has caused a dependence on wastewater and arthropods, leading to a threat in biodiversity. Water supply to the crops in casual farming systems is not readily available in West Africa and farmers involved resort to the use of waste water irrigation which is not only untreated but also contains mixture of natural dilutes and chemicals, readily available from municipal wastewater open channels. The irrigation system according to Githongo (2020) is worrisome to arthropod biodiversity.

In Africa, casual farming or UPA is dependent more on the available arthropod biodiversity existing in the city where it is practised. This is because of the type of crops predominantly cultivated which are vegetables: Okra (*Abelmoschus esculentus* (L.) MOENCH, Pepper (*Capsicum annum* L.) and garden eggs that rely more on insects for pollination, unlike cereal crops such as maize (*Zea mays* L.), millet (*Pennisetum glaucum* L.) and sorghum that depend on wind for pollination (Stenchly et al. 2017). The shift in the type of crops cultivated in UPA system has caused an increased dependence on the existing arthropods biodiversity, resulting in a threat in biodiversity (Tilman et al. 2017), caused by stress. Threats to insect biodiversity in casual farming system are aggravated by the insecticidal management of arthropod species associated with the cultivated crops. Casual farmers apply all sort of insecticides that destroy both the desired pests and beneficial arthropods, thus threatening the arthropod species.

7.2.3 Pollution Threats to Arthropod Biodiversity in Africa

Pollution from acid rain, pesticides, heavy metals, hydrocarbon and a host of others when introduced into the soil and water ecosystem threaten the biodiversity of arthropods in Africa. Pollution is a type of disturbance, a relatively discrete event that alters the natural condition of discharge of pollutants, such as petroleum and crude oil products (benzene, naphthalene, toluene, total petroleum hydrocarbon (TPH), spent engine oil), and other pollutants from industrial and agricultural activities. In Africa, agricultural pollutants, oil tanker spills, ruptured chemical tanks and oil pipelines, vandalized oil pipeline and artisanal refineries are major sources of pollution.

In Nigeria, expired pesticides are thrown into water bodies, and this contaminates the aquatic ecosystem and causes a threat to biodiversity of arthropods (Gbarakoro et al. 2019). Farmers in Africa applied chemical fertilizers to boost the nutrients in the soil and increase output, and such application increases concentration of nitrates (nutrients commonly derived from fertilizers). The high concentrations of nitrates flow into the aquatic ecosystem through run-offs from the agricultural landscape and cause eutrophication (nutrient enrichment in fresh waters). This situation reduces the stability of the ecosystem as the inhabiting organisms could not tolerate the impact of the nutrient enrichment, resulting in loss of biodiversity. Another way eutrophication threatens biodiversity in the aquatic ecosystem is the increase in productivity, in which algae production will be tremendous, such that scums will be formed to cover the water surface and reduce transparency. The scum cover prevents the penetration of light and arthropods that visit the water surface and those that inhabit just below the surface are affected, leading to death as they could no longer replenish their gases by obtaining atmospheric oxygen. The insects affected mostly those that respire through the use of hydrofuge hairs, and post-abdominal structures which are usually extended to the water surface to obtain oxygen, while the insect remains submerged. The inability of the insects to obtain atmospheric oxygen pose a serious threat to the biodiversity of these insects and their ecosystem services.

Availability of oxygen in the water body is affected by the increase in algae pollution caused by eutrophication because when algae die and biodegrade, oxygen is consumed. This reduction in available oxygen changes the condition of the water body and causes a loss in biodiversity of arthropods. Excessive application of fertilizers and pesticides in agriculture has been described as being deleterious for soil biodiversity (Singh et al. 2021) because nitrogen from fertilizers alters the pH and nutrient level of the soil. The changes in the condition of the soil threaten soil biodiversity by directly reducing the species richness and abundance and indirectly by encouraging the overwhelming growth of grass species and stifling growth of wildflowers, essential for arthropods species (Singh and Verma 2018), causing loss of insects, such as bees.

In the Niger Delta region of Nigeria where hydrocarbon pollution from petroleum oil refineries, including artisanal refineries abound, threats to arthropod biodiversity occur. The soot generated from the refining activities covers the surface of vegetation particularly leaves and reduces herbivorous insects' biodiversity. This affects the ecosystem services of the herbivores, leading to a reduction in leaf fall and frass, and causes a reduction in nutrients or energy input into the soil ecosystem and reduction in ecosystem services. The reduction in the abundance of soil mesofauna, for instance, reduces the secretion of frass aggregation substances, leading to loss of water retention capacity of the soil and inadequate distribution of mineral nutrients in the soil ecosystem.

In the soil, petroleum hydrocarbon pollution may bioaccumulate in soil arthropods and become toxic to soil-dwelling species at the range of 20–100 mg/kg (Maliszewska-Kordybach and Smreczak 2010; Sverdrup et al. 2002) and cause threats to biodiversity. A relatively high concentration of TPH threatens soil biodiversity, particularly soil microarthropods. Okiwelu et al. (2011) reported that soil microarthropods biodiversity (*Scheloribatids* spp., *Galumnidae* spp., *Parallonothrus nigeriensis*, *Bicrythermaimia nigeriana*, *Mixacarus* sp., *Aunecticarus* sp., *Atropacarus* sp., *Belbidae* sp., *Cephalidae* sp., *Oppia* sp., *Basilobelbidae* sp., *Epilohmaunia* sp., *Mesoplophora* sp., *Archegozettes magnus*, *Polyaspidae* sp., *Trachyllropodidae* sp., *Prodinichidae* sp., *Uropodidae* sp., *Parasitidae* sp., *Rhodacaridae* sp., *Asca* sp. and *Bdellidae* sp.) was higher in a pristine soil ecosystem as compared with soil polluted with TPH with the lesser microarthropods (*Scheloribatids* spp., *Galumnidae* spp., *Parallonothrus nigeriensis*, *Bicrythermaimia nigeriana*, *Parasitidae* sp., *Rhodacaridae* sp. and *Northrus lasebikani*). According to the authors, the species that could not tolerate the PTH pollutant die out of the ecosystem, while others migrate to deeper soil profile and later died while the tolerant species were less abundant.

Other types of pollution that greatly impact biodiversity of arthropods in Africa are acid rain and light. Pennanen et al. (1998) stated that soil prone to acid rain has reduced microbial activity and causes a threat to biodiversity of arthropods that depend on food chain influenced by such microbial activity. Light-attracted arthropods such as immature stages of termites and adult moths, are threatened by artificial light disturbances. On the streets of African cities, dozens of these organisms are crushed by moving vehicles, particularly during the raining season. The importance of these species, particularly moths, cannot be underrated as they are anthophilous (Mcgregor et al. 2017). Light therefore poses a threat to the existence of these species.

7.2.4 Invasive Species Threats to Arthropod Biodiversity in Africa

One major cause of threats to biodiversity is through the introduction of species that are non-indigenous to an environment or ecosystem. The non-native species are called exotic or invasive species and can be introduced intentionally and non-intentionally into a foreign or non-native habitats. The exotic species are introduced either in biological control programmes. Certain arthropods which are natural enemies to other arthropods that are pests are introduced into an environment to control pest outbreak. In this programme, the newly introduced species (exotic species) become established and eliminate native species by out-competing them for food and shelter and cause more harm to the ecosystem, thereby threatening arthropod biodiversity. This situation occurs when the biological control programme is not properly implemented and other un-targeted arthropods are eliminated. Improper implementation also causes the release of generalist natural enemies which lack high level of host and habitat specificity, become invasive and attack native species other than the target pests.

Another way invasive species threat occurs is during the cleaning or bioremediation of hydrocarbon pollution in which certain hydrocarbon feeding microorganisms are introduced from other habitats into the polluted sites. These exotic species when established eliminate native species upon which arthropods obtain food, and thereby pose serious threats to the arthropods biodiversity. Exotic species threaten arthropod biodiversity by diluting the endemic biodiversity through homogenization of global biota. This occurs when the same species are involved in biological control or hydrocarbon cleaning in various countries, and results in the establishment of the same biodiversity of species in the affected countries. This changes the community structure and threatens the native biodiversity. Agricultural practice in the urban cities in Africa called UPA assists in the invasion of non-native species and causes biotic homogenization where native species are eliminated, because the cities are transformed to hotspots of biological invasion (McKinney 2006; Sanchez-Bayo and Wychkuys 2019).

Another source of biotic homogenization that contribute to biodiversity threats is the hybridization of exotic species with native species which cause a decline in genetic diversity (Dorherty et al. 2016). Sand mining in aquatic ecosystem in Africa poses a tremendous threat to arthropods biodiversity because of the removal of suitable habitats. Sand mining involves the removal of aquatic macrophytes which provide suitable habitats for aquatic arthropod species which could negatively impact arthropod biodiversity. Gbarakoro et al. (2021a) showed that various types of sand mining vary in impacts on arthropod diversity in Eleme Rivers in Rivers State, Nigeria. Accordingly, mechanical method of mining has a higher impact by reducing arthropods diversity, such that arthropod species (*Nais* sp., *Diplonychus rusticus*, *Naucoris* sp., *Daphina barbata*, *Macrobrachium* sp. and *Sudanonautus africanus*) collected from the mechanical mining location were fewer than the arthropod species (*Ophidonais* sp., *Nais* sp., *Chaetogaster* sp., *Aeolosoma* sp., *Elseniella tetrahedral*, *Macrobrachium* sp. and *Sudanonautus africanus*) collected from the manual mining location and not mining station with higher arthropod species (*Diplonychus rusticus*, *Lethocerus indicus*, *Naucoris* sp., *Leptonea* sp., *Aphelocheirus grik*, D*ytiscus* sp., *Chironomus* sp., Dragonfly nymphs, *Daphina barbata*, *Apus* sp., *Macrobrachium* sp. and *Sudanonautus africanus*). Shannon–Wiener index proved that diversity was higher at the station with no mining activity than the mechanical and manual mining stations.

7.2.5 Over-exploitation of Edible Arthropods Threats to Arthropod Biodiversity in Africa

Edible arthropods are arthropods that include insects that are eatable and consumed by man. In Africa, edible insects include *Rhynchophorus phoenicis*, *R. ferrugineus papuanus* consumed in Nigeria and Guinea, respectively, *R. palmarum* in Venezuela, caterpillars of *Cirina forda* in Democratic Republic of Congo, termites in Togo, Nigeria, and mole crickets (*Brachytrupes membranaceus*) and grasshoppers (*Zonocerus variegatus*) in Nigeria. The prevailing economic hardship in Africa has made the collection of these edible insects to be over-exploited in such a manner that the number of insects collected from their natural habitats exceeds regeneration capacity of the local communities and poses serious threats to sustainable entomophagy (edible insect collection). Collection of edible insect is carried out without any preference to the age of the insects, making mature insects to be collected prior to oviposition. The over-exploitation or over-collection of edible insects is one of the factors responsible for reduction of arthropods biodiversity in Africa.

7.2.6 Climate Change Threats to Arthropod Biodiversity in Africa

Photochemical oxidants in the form of smogs increase atmospheric carbon dioxide and conversion of forested land to agricultural land contribute immensely to climate change that have impacted on arthropod biodiversity. In Africa Smogs produced from exhaust of old automobiles and artisanal refineries contain carbon monoxide and particulate matter that are seen on roofs of buildings and on cars in cities of the Niger Delta area of Nigeria, in particular. The high level of Smogs production is so noticeable that fresh air masses are not sufficient to dilute it and may impact biodiversity.

One major way climate change threatens arthropods biodiversity is the reduction in nutrient input into the soil ecosystem which causes a reduction in arthropods that depend on such nutrients. The inadequate and insufficient addition or supply of necessary nutrients to the soil ecosystem will cause a decline in soil arthropod and consequently threaten soil arthropods biodiversity. The nutrients are contained in soil surface inputs such as grass deposits and green fall inputs collectively referred to herbivore inputs. Climate change that increases carbon dioxide (CO_2) and ozone (O_3) concentration in the atmosphere reduces herbivore inputs through the reduction in the species richness and abundance of herbivores. The lower the population density of herbivores, the lower the herbivores inputs into the soil ecosystem as the growth, survivorship and abundance of herbivores are altered by climate change which alter the quality of forest trees (Hillstorm et al. 2010). Climate change threatens the density of both arthropod particularly herbivores and arthropod biodiversity that depended on the nutrient inputs contributed by such herbivores.

In addition to climate are floods and droughts, though do not occur frequently in Africa. Floods, for instance, reduce biodiversity through reduction of breeding sites as water covers their natural habitats. Extreme droughts reduce the moisture contents of soil ecosystem and reduce soil microarthropods (Okiwelu et al. 2011), as the organism could not tolerate such soil moisture.

7.3 Effects of Threats to Arthropod Biodiversity in Africa

There are various effects of threats to biodiversity of arthropods, and they include non-maintenance of ecosystem health, malnutrition and poverty of the rural population, agricultural downturn and collapse of ecosystem services and sustainability. Non-maintenance of ecosystem health due to low arthropods biodiversity in an ecosystem indicates a weakness of the ecosystem and poor health status because there are less varieties of genes and species in that ecosystem. This type of ecosystem is unhealthy as it cannot carry out its natural processes in the presence of external disturbance. Generally, the ecosystem cannot completely maintain its health status without the arthropods.

7.3.1 Collapse of Ecosystem Sustainability

Threatened arthropods biodiversity in the ecosystem which cannot effectively carry out its services will be less sustainable and cannot sustain the environment and its inhabitants. An ecosystem is more sustainable when the arthropod biodiversity is higher and provides source of food, medicine and economy, and other services. Centrally, threatened ecosystem with low arthropod biodiversity will not be able to provide such sustainability. A less sustainable ecosystem is poorer in health and incapable of dealing with external disturbance.

7.3.2 Malnutrition and Poverty

Malnutrition and poverty are created among the rural people in African countries where arthropod biodiversity is reduced. Rural population that rely on edible arthropods for nutrient supply are worse affected, and income earners from the commercial sales of such arthropods are left frustrated. Reduced abundance of edible arthropods biodiversity results in poverty among the rural dwellers.

7.3.3 Agricultural Downturn

Agricultural development will be at stand still in areas where arthropods biodiversity is tremendously reduced. Herbivore inputs of necessary nutrients into the soil ecosystem will be reduced and crops cultivated on such soil will be starved of the nutrients. Furthermore, soils that lack arthropods that construct burrows will not have adequate distribution channel for available nutrients, and the ability to glue soil particles together, thereby leading to weakening the water retention capacity. The rate of decomposition of organic matter and its formation into soil organic matter will be slow in the absence or presence of low arthropod biodiversity. These will enhance agricultural downturn as it will reduce the amount of agribusinesses. Threats to arthropod biodiversity will cause serious problem with agricultural development, particularly when the species involved are pollinators, predators and biological control agents. The reduction in this group of species will reduce the development of agricultural sector.

7.4 Potentials of African Arthropods Biodiversity

Africa as a tropical continent is endowed with evergreen flora and abundance of fauna across all taxa that are dominated by arthropod biodiversity. The arboreal, aquatic and terrestrial ecosystems in the continent are copiously enriched with

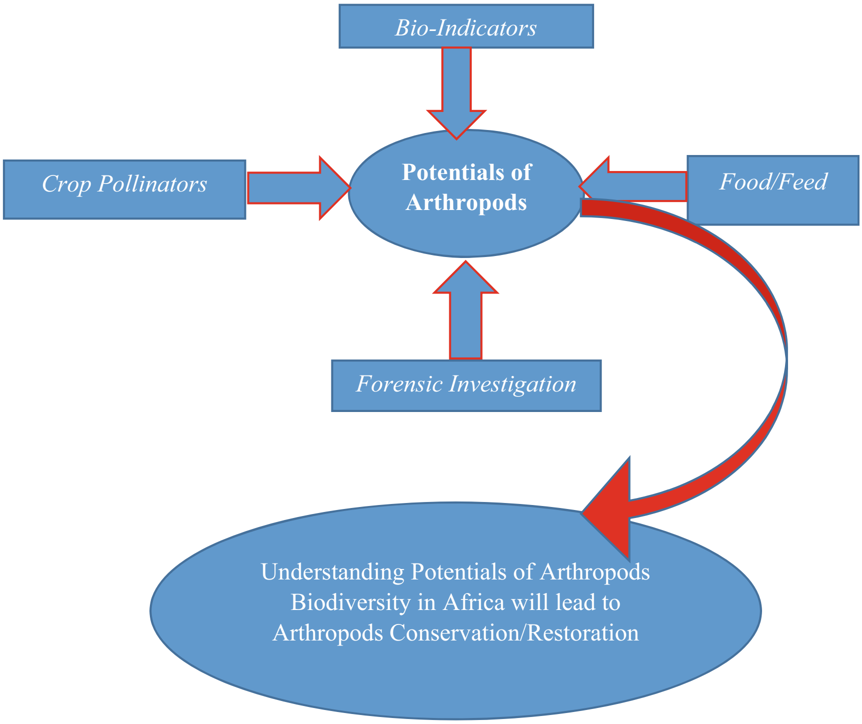

Fig. 7.2 Potentials of insects biodiversity in Africa

arachnids and insects. Their potentials on the reproductive sustenance of food crops and their bodies and products contributing to food security (Fig. 7.2), commerce and pharmaceuticals have not been accentuated as a rare gift of nature in Africa. Many of these arthropods have as well-played unquantifiable roles in maintaining and enriching the soil fertility and improving the environmental robustness for ecological sustainability. Their presence or absence in a particular ecosystem(s) is, however, indicators of pollution and forensic relevance. However, litigation in Africa has not inculcated insect science to her judiciary, but empirical studies are glaring that insects on deceased bodies provide a measure of evidence of the time of death (Abajue and Ewuim 2016) or absence in water body signifies some level of pollution. In the preceding discussion, the potentials of African insects diversity in relation to agricultural crops as anthophilous species (Daphne, 2011) and as entomophagous species (Abdalbasit, 2020) will be explored. There will also be few dissections of potentials of insects as environmental bioindicators (Manuel and Gbarakoro, 2021) for sustainable environment and tools for indicting criminals in relation to homicides (Cuthbertson, 1933; Smit and du Plessis, 1926; Abajue, 2016).

7.4.1 Anthophilous Potentials of African Insects in Agricultural Crops and Orchards

Anthophilous insects are one that carry out pollination activities on plants especially agricultural crops for man and animals. Without them, there would be a gap between crop production and yield (Otienoae et al. 2020). Insects of different taxa are responsible for pollinating most of the reproductive parts of food crops man eats and other florescent plants that sustain biodiversity (Gbarakoro et al. 2021b) as they explore different plants for food. Thus, their existence has continually provided man with services in relation to food security which is very essential in Africa as the continent has been perennially afflicted by zoonotic diseases that are compromising the body defence of her citizens.

Legume for instance as staple crops in Africa are partially reliant on pollinating insects for enormous yield. Among the insects that are regular pollinators in Africa as reported by Otienoae et al. (2020) are honey bees (*Apis mellifera*), carpenter bees (*Xylocopa* spp.), leaf cutter bees (Megachilids), halictid bees (Lipotriches), digger bees (Anthrophorids and Amegillas), Stingless bees, *Colletes,* Bumble bees *Eucera* and some flies in the families of Syrphidae and Calliphoridae, respectively. According to insect pollinators census by African pollinators initiative, four insect orders, Hymenoptera, Diptera, Coleoptera and Lepidoptera, were among the insect taxa that continued to visit different orchards (Food and Agriculture Organization 2007). Casually the hymenopterans seem to be conspicuous pollinators, but their study showed that the coleopterans are more abundant and diversified.

The diversity of insects visiting the flowers of various plants at Bien Donne (Food and Agriculture Organization 2007) revealed that not much have been reported about the anthophilous insects of Africa. In orchard of about eight plants, cape marigold (*Arctotheca calendula*), wild radish (*Raphanus raphanistrum*), Arum lily (*Zantedeschia aethiopica*), goose daisy (*Cenia turbinata*), purple vetch (*Vicia atropurpurea*), broad-leaved purple vetch (*Vicia sativa*), bug weed (*Solanum mauritianum*) and yellow lupin (*Lupinus luteus*) have many insect species visiting their floral parts. The species were diversified in the following orders, Hymenoptera, Diptera, Coleoptera and Lepidoptera with many species. Apidae, Halictidae, Colletidae, Andrenidae, Scoliidae and Eumenidae were among the major families of Hymenoptera with about thirteen species. Others are Anthomyiidae, Syrphidae, Muscidae, Bombyliidae, Empididae, Tipulidae and Bibionidae families of Diptera with about ten species which include the *Eristalis* sp. and *Delia* sp. The Coleoptera has many families, Chrysomelidae, Dermestidae, Nitidulidae, Buprestidae, Cerambycidae, Meloidae, Anthicidae, Melolonthinae, Tenebrionidae, Melyridae, Cleridae and Phalacaridae, with about 20 species, including *Attagenus* species. The Lepidoptera are represented by Pieridae and Nymphalidae with about three species among which are *Lixeia* sp. and *Colias electo*. Ordinarily, the bees among the hymenopterans and butterflies among the lepidopterans are easily recognized as anthophilous insects. But the singular survey of the Bien Donne orchard with few plants has shown that anthophilous insects are more diversified with the coleopterans dominating the insect species. The reasonable number of dipteran species is a contradictory believe that they are more of medical and veterinary importance. In Southern African, hopliine beetles (*Platychelus* sp.) are pollinators of *Ixia dubia* in the family (Iridaceae), while the long-proboscid fly (*Prosoeca ganglbauri*) in the family Nemestrinidae is the major pollinator of the long-tubed flowers (*Zaluzianskya microsiphon*) in the family Scrophulariaceae (Johnson et al. 2002). The *Disa cooperi* that is found in the grassland orchid is pollinated by medium-sized hawk moths *Basiothia schenki* (Johnson 1995). Large carpenter bees (*Xylocopa caffra*) are pollinators of a Cape plant *Orphium frutescens* in the family Gentianaceae, with poricidal anthers. Cape honeybees (*Apis mellifera capensis*) are the major pollinators of bladderwort (*Utricularia capensis*) in the family of Lentibulariaceae (Johnson 2004).

Taxonomic challenges may be one of the banes in documenting the anthophilous insect diversity of Africa in addition to unavailability of resources for such studies that are not directly beneficial to the political leaders in Africa. Thus, anthophilous data are scanty in Africa comparably with the advanced continents. Some of the reported anthophilous insects are based on continuous casual observation without detailed ecology of the insects. May be curiosity could also count when some authors mention anthophilous insects in Africa. Thus, Gbarakoro et al. (2021b) reported some insect species that visit the floral parts of *Hamelia patens* in a university landscape in Nigeria. A closer look on the insect taxa showed that many of them are anthophilous insects. *Hamelia patens* was reported as ornamental plant that can attract beneficial insects for anthophilous purpose and sustaining their diversity. In that report, fifteen insect species were collected on the floral parts of the plants with *Megachile mephistrophelica* (Grib.), *Megachile cinta* (Fab.), *Braunisca bilunta* (Enderloein.), *Pterandus* sp., *Lilioceris* sp. and *Virachola antalus* (Hoph.) as morning hours visitors. *Chelonus bifoveolatus* (Szepg.) and *Chrysolagria nairobana* (Borch.) were evening visitors. About seven insect species were regular on the plant among which are the *Xylocopa torrida* (Westw.) and *Apis mellifera* (Linn.). These insect species spanned into four orders (Coleoptera, Diptera, Hymenoptera and Lepidoptera) with the hymenopterans dominating with ten species, the coleopterans and lepidopterans are with two species each, while the dipteran has one species. By extension, it is glaring that the flowering plants that are abound in Africa are laden with array of anthophilous insect biodiversity.

7.4.2 *Entomophagous Potentials of African Insects Biodiversity in Food and Feed Formulation*

Edible insects have played a major role in supplementing the nutritional requirements of the African people. Both old and young at one point in life in Africa had eaten insects of different species depending on geography, culture and class (Ebenebe et al. 2020). About four hundred and seventy edible insect species in

Africa were reported by van Huis (2020) with caterpillars, grasshoppers, beetles and termites the most consumed insects. All the edible insect species though playing important role in food security are being collected continuously and yearly from the wild without conservation effort. The diversity of the insect orders that are continually harvested in Africa for consumption is Orthoptera, Coleoptera, Isoptera, Hymenoptera, Homoptera, Hemiptera and Diptera in their decreasing order of percentage (Jongema 2017). Others include Dictyoptera, Ephemeroptera and other arthropods in the families of Ixodidae (ticks) and Araneae (spiders). Termites survive mainly in the tropics; hence, they are more diversified edible insects in Africa (Lewis 2003).

Many species of orthopteran families are reported as agricultural pests of field crops. Nevertheless, they have been one of the savory delicacies in some parts of Africa. For instance, four species of locust, *Locusta migratoria*, *Locusta napardalina*, *Schistocerca gregaria* and *Nomadacris septemfasciata,* in Africa all in the family Acrididae have played essential role in food security in Africa especially in Ghana and Nigeria. Others include *Zonocerus variegatus* in the family Pyrgomorphidae. *Ruspolia differens* and *Ruspolia nitidula* in the family Tettigoniidae (Orthoptera) are edible crickets that their delicacies have been revered with so much nostalgia in Uganda, Kenya, Rwanda, Tanzania and Madagascar. Interestingly, there is a new cricket species *Scapsipedus icipe* n. sp. (Tanga et al. 2018) which has a promising potential in mass rearing to curb hunger in Africa.

The Lepidoptera also have many species that are capable of providing man with food and serve as feed for livestock because of their characteristic nutrient values (Akinnawo and Ketiku 2000; Omotoso 2006). In South Africa, mopane caterpillar *Imbrasia belina* in the family Saturniidae is a cherish food that generates income to the local people (van Huis 2020). *Cirina butyrospermi* (Saturniidae: Lepidoptera) is a shea caterpillar that is greatly treasured as human food in Burkina Faso and Mali because of its nutritious prowess (Anvo et al. 2016) and its potential in animal feed formulation (Anvo et al. 2016; 2017).

The use of termites especially the *Macrotermes* species in feeding chickens and guinea fowls is known to be a cultural practice of smallholder poultry farmers in Africa (van Huis 2020). The grub of African palm weevil *Rhynchophorus phoenicis* (Curculionidae: Coleoptera) is a delicacy sought after mainly in the western Africa because of its nutritious value (Cito et al. 2017; Mba et al. 2017; Koffi et al. 2017; Okunowo et al. 2017). The potentials of African insect biodiversity in food security is glaring, but the crude means of harvesting them from the wild would hamper their sustainability and lead to insect biodiversity decline in the future. There is a relationship between insect biodiversity and forest ecosystem that are abound in Africa (Leal et al. 2016). Insects play essential part in the forest ecosystems by impacting the primary production and evolution of plants and thus form a link between plants and higher trophic levels (Alaloiun 2014). Insect biodiversity is high in Africa; hence; about one thousand five hundred edible insect species were reported by Ebenebe et al. (2020) correlating to richness of tropical climate and amount of tropical rainforest favourable to many insect species, including edible ones that are contributing to food security in Africa.

Rich biodiversity of entomophagous insect species was reported by Malaisse et al. (2017) with about thirty-eight species of caterpillars alone from Democratic Republic of Congo, Zambia and Zimbabwe. To correlate the report of Roulon-Doko (1998) ninety-six insect species are consumed in the Central African Republic. The diversity of edible insects in Africa was presented by Adu and Oyeniyi (2019) and Raheem et al. (2019) ranked the ninety-six edible insect species in percentages according to their level of consumption. Hence, locust and grasshoppers among the Orthoptera ranked 40%, Lepidoptera 36%, Isoptera 10%, Coleoptera 6% and others (crickets and cicadas) 8%. In Kenya, Kinyuru et al. (2013) reported six edible insect species out of which four species belong to the termite families, one black ant and one long-horned grasshopper. In Ghana, Anankware et al. (2016) reported nine edible insect species ranging from scarab beetle 2%, house cricket 5%, shea butter caterpillar 8.7%, house cricket 9.5%, locust 10%, African palm weevil 47.2%, termites 45.9%, ground cricket 33.3% to grasshopper 30.5%. According to Raheem et al. (2019), the Ugandan people prefer termites and grasshoppers. In Nigeria, edible insect species consumed according to Alamu et al. (2013) are Lepidoptera 27.3%, Coleoptera 27.3%, Orthoptera 22.7%, Isoptera 13.6%, Hemiptera and Hymenoptera 9.0%.

7.4.3 Biomonitoring Potentials of African Insects Biodiversity for Monitoring Pollution

Aquatic ecosystems in Africa are continually impacted by anthropogenic activities (Nnoli et al. 2019). There are insect indicators of environmental change and their biodiversity in Africa is premise to understanding the level of degradation that has taken place in the ecosystems. The biodiversity of aquatic insects in Africa was high with thirty-eight insect families in the orders, Ephemeroptera, Diptera and Trichoptera (Hynes 1975a, b), as cited in Nnoli et al. (2019). There was a numerical fluctuation of the insects as reported by Amakye (2001). About forty-one insect families were reported by Nnoli et al. (2019). In the face of the current burden of global climate change, the diversity of aquatic insect indicators for biological monitoring may decline. Samman and Amakye (2009) recorded nineteen families from two fresh water bodies which were dominated by chironomids, baetids and dytiscids families. Earlier report of Thorne et al. (2000) had shown that chironomids are the dominant arthropod fauna out of the twenty-seven families of insects of Odaw stream an indication that the stream was not degraded. The report of Nnoli et al. (2019) showed that diversity of insects in Pawnpawn River was not impacted, but there was a reduction in their abundance which was presumed as a case of climate change. The diversity of African insect species may be negatively impacted especially the arthropod vector species such as Simulium species which are under government control programmes (Nnoli et al. 2019). The dominance of chironomid species among the arthropods of fast flowing rivers make them potential biological indicators of environmental change in Africa.

Habitat loss in Africa is occasioned by deforestation primarily for agricultural purposes and partly due to urbanization. Deforestation in Africa has not been clearly singled out to cause arthropod biodiversity decline especially the insects except that their abundance was partially reduced (Fugère et al. 2016). A comparative study on the biodiversity of a river in Ghana between 1970 and 2014 showed that that biodiversity of the insects is assumed to be the same (Nnoli et al. 2019). Most of the insects found in the fresh water aquatic environment are very important species that aid in the cycling of nutrients as link to aquatic food chain, serve as pathogen carriers and act as biological indicators of water quality (Komolafe and Imoobe 2020).

Understanding the guild structure of insects in aquatic ecosystems is a key component in the study of biodiversity of fresh water ecosystems. There are about ten insect species in three orders dominated by Hemiptera and Coleoptera in a pond in Nigeria (Komolafe and Imoobe 2020) in collaboration to insect diversity of other inland waters in Nigeria (Arimoro and Ikomi 2008; Popoola and Otalekor 2011). There was a low diversity in the pond which was attributed to one season of sampling. The pond was reported to be moderately polluted (Komolafe and Imoobe 2020) because intolerant insect indicators such as Ephemeroptera, Plecoptera and Trichoptera were not found in the water. Thus, the absence of the sensitive insect orders and the dominance of the pond by the hemipterans show the potentials of insects in biological monitoring of polluted water ecosystems. The fauna of inland water ecosystems are usually dominated by macroinvertebrates especially the arthropods. The insects among other arthropods in aquatic ecosystems have different response mechanisms to changes in their environment occasioned by anthropogenic activities; hence, they are key biological indicators of water quality (Odume et al. 2012). The order Diptera was reported as dominant insect species in Ahoo stream in Nigeria (Adu and Oyeniyi 2019) in collaboration to the submission of Ikomi and Arimoro (2014) that chironomids are the dominant insect species among the benthic fauna of Ethiope River, Nigeria. The numerical abundance and species richness of the chironomids was evidence of slightly polluted stream. Insect species in the order Odonata are generally tolerant to some level of pollutions; hence, they were among the insects that were recorded in the river. Another tolerant insect species is the *Ilyocoris* species in the family Naucoridae which is known to adapt to changing environmental factors (Gelbic et al. 1994). The diversity is low; nevertheless, their presence are biological indication of polluted water.

Insects and other benthic invertebrates that are resident in fresh water habitats are used in biomonitoring of the impact of anthropogenic activities. The biodiversity of insects that are potentially viable in biological monitoring of the impact of human activities in aquatic ecosystems according to Solanki and Shukla (2015) is springtails (Collembola), mayflies (Ephemeroptera), dragonflies, damselflies (Odonata), Stoneflies (Plecoptera) and true bugs (Hemiptera). Others include alderflies, dobsonflies and spongilla flies (Neuroptera/Megaloptera), caddisflies (Trichoptera), beetles (Coleoptera), diving wasps (Hymenoptera) and true flies (Diptera). The

Table 7.1 Insect orders as biological indicators of different freshwater bodies

Common name	Order	Freshwater body
Springtails	Collembola	Ponds
Mayflies	Ephemeroptera	Lakes, streams
Dragonflies	Odonata	Lakes, streams
Damselflies	Odonata	Lakes, streams
Stoneflies	Plecoptera	Streams
True bugs	Hemiptera	Lakes, streams
Alderflies	Neuroptera	Streams
Dobsonflies	Neuroptera	Streams
Spongilla flies	Megaloptera	Streams
Caddisflies	Trichoptera	Lakes, streams
Beetles	Coleoptera	Lakes, streams
Diving wasps[a]	Hymenoptera	Ponds, lakes, streams
True flies	Diptera	Ponds, lakes, streams

[a] Diving wasps are terrestrial but parasitize aquatic insects

diversity of the insects in different water bodies as biological indicators is summarized in Table 7.1.

The biodiversity of aquatic insects that are globally sensitive to water quality changes is the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders. According to Gbarakoro et al. (2021a, b), only 2%, 6% and 4% of EPT were collected at Isiokpo River, Nigeria. The presence of the insect indicators though lower in abundance was an evidence that the insect species of the river were diversified irrespective of the minor impact of human activities on the river. The diversity of the insects of the river and relatively pollution level was affirmed by Shannon–Weiner and Margalef indices, respectively. The potentials of insects as indicators of biological status of freshwater habitats in Africa are an evidence of biodiversity potentials of African insects. This is orchestrated on the species richness of twenty-one insect species at Isiokpo River with seven orders (Odonata, Diptera, Hemiptera, Coleoptera, Ephemeroptera, Plecoptera and Trichoptera). Similar findings were made on insect diversity of Nwaniba River in Nigeria by (Esenowo et al. 2017). They recorded Coleoptera, Hemiptera, Orthoptera, Dermaptera, Diptera, Hymenoptera and Odonata. The family Gomphidae in the order Odonata was reported to dominate the insect fauna of the river. The gomphids accounted for about 55.8% of the total collection of the insects at Nwaniba River which they reported as a highly tolerant insect of a polluted water body. Studies on aquatic insects and their biodiversity are poorly documented in Africa despite the continent being hub of flora and fauna biodiversity of the tropics. Many of the insects are ecologically sensitive to environmental changes that are occasioned by activities of man (Deacon and Samways 2021).

7.4.4 Forensic Potentials of African Insects in Medico-criminal Investigation

The use of insects in medico-legal cases is one of the modern applications of entomology to humanity called forensic entomology. The history of forensic entomology dates back to thirteenth century AD in China, but its practice became relevant in the developed countries of USA and Europe in the nineteenth century. Forensic entomology uses insects to prosecute civil (urban and stored-product) and criminal (medico-legal) cases (Williams and Villet 2006). Forensic entomology was noted in 1980 in South Africa which seems to be the earliest in Africa without recounting the study of South African blowflies in 1921 which was geared towards veterinary and animal health entomology.

Historically, the study of blowflies which is a key insect species in forensic entomology started in 1921 with unclear taxonomy of *Lucilia sericata* and *Lucilia cuprina* which are the green bottle flies. The seasonal distribution and life-history of Southern African blowflies in attempt to manage sheep blowflies gave rise to the painting of four species of blowflies *Lucilia cuprina*, *Chrysomya chloropyga*, *Chrysomya albiceps*, and *Chrysomya marginalis* (Smit 1929) in Williams and Villet (2006). The biodiversity of African blowflies also includes *Chrysomya putoria* which is found in the northern Africa, while *Chrysomya chloropyga* is found in southern Africa (Smit 1931). Other African flies of forensic relevance are *Sarcophaga africa, Sarcophaga haemorrhoidalis* and *Sarcophaga tibialis*. The role of insects as decomposers of carcasses in Kruger National Park gave rise to two hundred and twenty-four insect species in thirty-three families (Braack 1984, 1986), thus making the biodiversity of insects associated with carcasses potential tools in forensic science relating to homicide. The diversity of the insect fauna showed that *Lucilia cuprina* is predominantly a rural blowfly species, while *Lucilia sericata* is an urban species (Smit 1929, 1931; Braack 1984, 1986).

The use of insects in forensic investigation is primarily to estimate the post mortem interval of a corpse (Olivia 2001). It can as well extend to drug evaluation (Wolff et al. 2001; Harvey et al. 2003), and check for ante-mortem trauma and identify the place of death if post-mortem movement is suspected (Janse 1940; Lounsbury 1940). Decomposition of corpses is in stages (fresh, bloated, wet decay, dry decay and skeletonization) and distinct insect species are peculiar to the stages of decay. The decomposition stage dependent on the insects is the biology of using the insects in estimating the post-mortem interval of a corpse when it is infested with insects (Brown 2003; Hepburn 1943). The diversity of insects that are fresh stage dependent includes mainly the blowflies (calliphorids) and houseflies (muscids). They usually remain on carcasses till bloated and wet decay stages. Other insect species that join the community structure are flesh flies (sarcophagids), dermestids, clerids, histerids and others. Dermestids and clerids are dry decay dependents and they play major roles in skeletonizing the carcasses (Braack 1987). In terms of carcass differences and locations, carcass under sun attracts *Lucilia cuprina*, *Chrysomya albiceps* and *Musca domestica*. They persisted during the bloated stage. The *Sapprinus* species and *Dermestes* species infested the carcass during active decay and dry decay stages. *Pheidole* species persisted in all the stages of decompositions. Comparatively, no significant difference would be observed between the insect diversity of sun-exposed and shaded carcasses in Africa. The insect diversity of forensic relevance is not seasonally dependent (Abajue 2016), but their time of arrival on carcass and their duration may slightly differ; hence, the diversity remains the same.

Succinct identification of insects of forensic investigation is one of the banes of forensic entomology in Africa. Most of the forensic insects species identified in Africa are based on the keys of the western countries. To keep hope alive for the potentials of African insects especially the blowflies for forensic investigation of homicides, a very detailed and colorful pictorial key was presented for African blowflies by Lutz et al. (2018). The African blowflies identified include *Chrysomya albiceps*, *Chrysomya vicina*, *Chrysomya marginalis*, *Chrysomya laxifrons*, *Chrysomya vomitoria*, *Chrysomya croceipalpis*, *Chrysomya putoria*, *Chrysomya cuprina*, *Chrysomya megacephala*, *Chrysomya chloropyga*, *Chrysomya inclinata and Chrysomya bezziana*. Others include *Lucilia sericata*, *Lucilia infernalis*, *H. fernandica* and *H putoria.*

The succession sequence of insects species in Okija, Nigeria shows that blowflies *Chrysomya albiceps*, *Chrysomya chloropyga* and *Chrysomya regalis* are fresh body colonizers that are succeeded by *Chrysomyza africana*, *Hermatia illucens* and later *Dermestes frischii*, *Necrobia rufipes* and *Necrobia ruficollis* (Abajue and Ewuim 2016). The checklist of the insect biodiversity showed 6 orders, 21 families and 31 species. Arthropod succession on carcasses exposed in shade and under sun at Nsukka, Nigeria showed variety of arthropods which include six orders, Diptera, Coleoptera, Hymenoptera, Orthoptera, Aranea and Isopoda, and seventeen families and 26 species (Onyeishi et al. 2020). The succession of the insects was similar to the submission of Abajue and Ewuim (2016). A preliminary study of arthropods associated with carrion in Yaounde, Cameroon showed seven arthropod orders with many species of forensic relevance (Dupont et al. 2011). Forensic insects collected among the arthropods associated with pig carrions in oil rich Warri, Nigeria showed three insect orders, Diptera, Coleoptera and Hymenoptera. A total of 233 insects were collected during the fresh stage and 324 collected during the bloated stage, 328 during active stage, 405 during the advance stage and 158 during skeletonization stage. Dominance index was higher during dry decay stage and was lower during the bloated stage. Shannon–Weiner index showed that diversity was higher during the advanced decay stage (Iloba and Odo 2020). Three insect orders (Diptera, Coleoptera and Hymenoptera) were reported by Mabika et al. (2014) that spanned into Calliphoridae, Muscidae, Phoridae, Sarcophagidae, Drosophilidae, Histeridae, Cleridae, Dermestidae and Formicidae families. Succession and diversity of arthropods of domestic rabbit carcass in outdoor and indoor environments in Port Harcourt, Nigeria attracted 7 orders, 22 families and 33 species (Joshua and Noutcha 2019). Ndueze et al. (2013) recorded 6 arthropod orders, 9 families and 30 species on different mammalian carcasses in Omagwa, Nigeria. Arthropods of mammalian carcasses in Rivers State, Nigeria showed that out of

414 insects collected the order Diptera, has three families, Muscidae, Bombyliidae and Syrphidae, Coleoptera has one family Cleridae and Hemiptera also with one family Reduviidae (Okiwelu et al. 2008).

7.5 Efforts to Salvage Arthropod Biodiversity in Africa

The United Nation has launched a globally coordinated response to biological loss and degradation of habitats, with a content of building political willingness and capacity to restore interrelationship between nature and living organism. This programme is called a decade on ecosystem restoration (2021–2030) and is focused on the prevention, and reversion of the degradation of ecosystems over one hundred countries, including African countries that have endorsed the treaty on this global approach to halt biodiversity threats.

The UNEP is leading the decade on ecosystems restoration by ensuring that the science and best practices on ecosystems are gathered together and also encourage and collaborate with biodiversity-related conventions and scientific bodies. The UNEP through its organ, world conservation monitoring centre (UNEP-WCWC), collaborates with scientists and policy makers worldwide to put biodiversity at its front priority of the environment and development decision making.

In spite of the effort made by UN, no significant attention has been paid to address threats to arthropod biodiversity worldwide. Samways (2018) stated that it is only recently that arthropod (insect) biodiversity has been made to address threats to arthropod biodiversity through semi-cultivation practices of preferred edible insect species. The practice is devoted of consideration of arthropods particularly insects that bear relevance to ecological services, indicating that only those that are important on the rural people's livelihood are captured in the practice. In the practice, the insects habitat are manipulated, for instance, in Guinea, palm trees that produce small quantities of starch are reserved for palm weevil larvae production, and in Venezuela, *R. palmarum* is encouraged to grow on moriche palm (*Mauritia flexuosa*). For instance, larvae found on M. flexuosa palm after 4 weeks are collected and placed in a plastic container. Banana pseudostem, and vegetable refuse are used as rearing substrates for the larvae while they are fed with juice from fruits such as pineapple.

In Democratic Republic of Congo, caterpillars of *Cirina forda* are reared on Acacia trees near residential houses and harvested for food, while some are allowed to emerge to adult butterflies. In Togo, termites are reared using Canari (comprising plastered water storage recipients), dry sorghum stems or other cereals, water, jute bag piece and some moist soils. In Nigeria, *R. Phoenicis* has been reared using substrates, such as cereal shafts, water and honey all stored in air-free cages. In semi-cultivation practices, rearing of edible insects begins in the wild by falling of trees deliberately to stimulate the production of palm weevil larvae. It is clear that much has not been done on the avoidance of threats to arthropod biodiversity in Africa and the following suggestions may help:

1. Edible insects should be reared in artificial substrates and habitats.
2. The roles played by insects and mites, such as pollinators, herbivores, soil burrowers, nutrient suppliers, decomposition and parasitoids, should be understood and prioritized in conservation programmes.
3. There should be maintenance of the interactions between arthropods and other organisms, and physical and chemical parameters of the ecosystems. This should be understood and maintained.
4. In polluted ecosystem, arthropod biodiversity restoration programmes should be undertaken using formulated organics. This will restore impacted soil ecosystems, particularly arthropods abundance, nutrients and water-holding capacity.

7.6 Conclusion

Arthropods biodiversity in Africa is threatened mostly by habitat loss and fragmentation, over-exploitation of preferred edible insects, pollution and climate change. The ecological roles of anthophilous insects of Africa are glaring that their biodiversity and their inventory should be taken for conservation purpose. Edible insects truly have contributed meaningfully to the food security of Africa, but the crude methods of harvesting them are threats to insect diversity. Notes of insects as biological indicators for monitoring ecosystem health in Africa showed that only aquatic ecosystems have received minimal attention. Insects that are useful in forensic science are enormous and are beginning to attract the interests of entomologists in Africa to assist in mitigating crimes related to questionable deaths. The use of formulated organic substances for soil restoration and taking of an inventory of ecologically important arthropod species, are some of the prerequisites recommended to mitigate threats to arthropods biodiversity in Africa.

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Part III
Drivers of Biodiversity Loss in Africa

Chapter 8
Leaving No One Behind: Impact of Soil Pollution on Biodiversity in the Global South: A Global Call for Action

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Abstract Soil pollution, as one of the primary recipients of toxins, should not be a hidden secret anymore. There are many dangers associated with soil pollution, but its effects reach more than just the dimension of soil, as soil pollutants might negatively

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impact both human as well as ecological health. This review adds to increase in awareness of the problems faced by soil from pollution by bringing together a science-based approach to soil contamination as well as the interconnection with other global environmental challenges. As the Planetary Health and One Health initiatives stress, ecosystems and human health are inextricably linked, but none is isolated from one another. Toxins from polluted soil can affect all environmental compartments, including water, food, and air, as well as organisms, including humans. However, soil pollution cannot be effectively addressed without addressing pollution and its sources. As a result of soil pollution, ecosystem services can be lost, as well as serious economic losses and social injustices jeopardize the attainment of the 2030 Agenda at risk. Among the top contaminants sources resulting in soil contamination (order of significance) are mining, industrial operations, agriculture, waste treatment, extraction as well as processing of fossil fuels, as well as transportation emissions. However, there is not anything solid as well as comparable statistics on each sector's real emissions. Most contaminant releases to soil, with the exception of pesticide inputs, remain difficult to quantify and, as a result, continue to be highly unknown. Contaminants from industries continue to enter the environment at several phases of their whole life cycle, together with manufacture, contaminant manufacturing containing commodities, transportation, usage, as well as disposal are all factors to consider. Global yearly industrial chemical output has nearly quadrupled to over 2.3 billion tons in recent years, with an 85% rise expected by 2030. If production and consumption patterns do not change rapidly, environmental pollution and erosion are thus predicted to worsen unless there is a commitment towards true sustainable management of the environment that fully respects nature. Despite decades of research, there remain remarkable knowledge gaps and great uncertainty regarding the quantity and scope of affected locations, which is exacerbated by new contaminants contributing to the situation. There is a growing gap in knowledge regarding soils impacted through pollution diffusion as well as its influence on other environmental compartments has grown even wider.

Keywords Soil health · 2030 agenda · Political commitment · Planetary health · Gbarian garbage dump site · Pollution diffusion · Environmental pressures · Global South

8.1 Introduction

In a world marked by complicated and typically deteriorating global environmental concerns, how people feel and react about these difficulties is a significant and expanding field of study. Most people recall the health risks associated with extensive radioactive exposure in the aftermath of the 1986 Chernobyl disaster, resulting from a flawed reactor design that was operated with inadequately trained personnel. Human land use has been changing Earth's ecology for millennia. Increasingly intense human land use has influenced global patterns of soil biodiversity loss, ecosystem modifications, landforms, impoverishment, as well as food insecurity, including shifting climate, through poaching and foraging, land burning, farming, as well as industrial agriculture (Raimi and Sabinus 2017a; Raimi et al. 2018a, 2019a, 2021b, 2022; Ebuete et al. 2019; Olalekan et al. 2019a, 2021; Henry et al. 2019a; Suleiman et al. 2019; Ajayi et al. 2020; Okoyen et al. 2020; Morufu et al. 2021a, 2022). All terrestrial life depends on the soil, and it is also involved in the management as well as provision of several crucial ecosystem functions that remain critical towards human survival. As long as the earth is concerned, the soil plays a key role in the storage of carbon which also retains an estimated 2270 liters of water in 1 m^3 of soil that permits the flourishing of crops even in periods and areas of famines. Additionally, soil is responsible for the provision of an approximately 95% of the total food produced on earth and serves as the medium for literally all food-producing crops growth. Despite the fact that soils remain known for their contributions in areas such as providing enough quantities of nutritious food products, pharmaceuticals, and assisting in the development of the human immune system (Once crops are grown in nutrient-deficient soils or when people are exposed to unsafe pollution levels or pathogenic organisms via soil contact, adverse health impacts can occur). Soil species diversity, on the other hand, aids in the nutrient cycling as well as carbon, influences the emergence of pests as well as diseases, and also acts as a medications source that aids in human health improvement (Raimi and Sabinus 2017a; Okoyen et al. 2020; Olalekan et al. 2021). Soils also serve as a source of building materials, fibre, and fuel. They serve as the foundation for human infrastructure as well as help maintain our cultural legacy. Soils are still under a lot of pressure all around the world. In their 2015 study titled "the Status of the World's Soil Resources", the United Nations' Food and Agriculture Organization (FAO) as well as the Intergovernmental Technical Panel on Soil (ITPS) highlighted ten (10) major threats to the world's soils. Organic carbon loss in soil, erosion, as well as biodiversity, acidification and sodification, pollution, nitrogen imbalance, salinization, sealing, compaction, as well as waterlogging are all significant towards pressures on soil health (Morufu and Clinton 2017; Raimi and Sabinus 2017b; Olalekan et al. 2018, 2019a; Premoboere and Raimi 2018; Odipe et al. 2018; Raimi 2019; Odubo and Raimi 2019; Okoyen et al. 2020; Morufu et al. 2021b, c, d; Deinkuro et al. 2021; Afolabi and Raimi 2021; Raimi et al. 2021a), restricting its potential to provide these ecological benefits for human well-being (Isah et al. 2020a, 2020b; Olalekan et al. 2020a; Raimi et al. 2020a, 2022; Hussain et al. 2021a, b; Morufu et al. 2021d, 2022). Human health is influenced by soil in a number of ways, and soil health is linked to human health. The consequences of soil contamination on human health have been extensively studied, predominantly trace metals in urban regions, mining, industrial areas, and places affected by conflict activity. Agricultural lands have also been the subject of such studies (Morufu and Clinton 2017; Raimi and Sabinus 2017b; Olalekan et al. 2018, 2019a; Premoboere and Raimi 2018; Odipe et al. 2018; Raimi 2019; Okoyen et al. 2020; Morufu et al. 2021b, c, d, 2022; Deinkuro et al. 2021; Afolabi and Raimi 2021; Raimi et al. 2021a, 2022). The spread of illness by contact to soil-borne toxins like lead, arsenic, cadmium, as well as other trace metals; asbestos; or infectious agents like enteric bacteria, viruses, fungi, as well as parasites have all been found as having a detrimental influence on human health (Raimi et al. 2017, 2021a, 2022; Henry et al. 2019b; Olalekan et al. 2018; Morufu et al. 2021b, c, d, 2022). Hypothyroidism/ multinodular goitre, Keshan/Kashin–Beck illness, as well as anaemia are all conditions linked to selenium, iodine, as well as iron deficiency in the soil. Soil contamination, which is the result of a chemical decomposition process that depletes rich soils, may go unseen by the human eye, but it endangers our food, water, and air. A majority of pollutants continue to be discharged into the milieu as a consequence of inefficient manufacturing, use, and disposal practices (Koleayo et al. 2021; Omoyajowo et al. 2022). Pollutants have been migrating through the land, the air, and the water, infiltrating agri-food systems along with causing harm to public health and the milieu. The principal humanistic contributors to soil pollution include chemicals utilized in or created as byproducts of industrial operations, animal, home, including agrochemicals, municipal wastes (wastewater), as well as petroleum-derived products (Premoboere and Raimi 2018; Isah et al. 2020a, b; Olalekan et al. 2020a; Raimi et al. 2020a; Deinkuro et al. 2021; Hussain et al. 2021a, b; Morufu et al. 2021d; Lateefat et al. 2022a, b; Ademiluyi et al. 2009). These chemicals get released into the milieu perhaps accidentally (as in oil spills or landfill leaching) or inadvertently (e.g. as in the usage of pesticides and fertilizers, untreated wastewater irrigation, or sewage sludge land application). Smelting, pesticide spray drift, transportation, including incomplete combustion of different substances, along with deposition of radionuclides resulting from weapons testing atmosphere, as well as nuclear disasters, all contribute to soil contamination. Emerging pollutants, like endocrine disruptors, pharmacological hormones, as well as toxins, among others, are producing new problems, as are biological pollutants such as bacteria and viruses in soils. Soil pollution, according to scientific studies, has the potential to seriously harm soil's fundamental ecological functions. Soil contamination reduces food security by lowering crop yields as well as rendering crops cultivated in contaminated soils unsuitable for consumption by animals and humans. Most toxins (such as nitrogen as well as phosphorus) continue to be transferred from the soil to groundwater and surface water, creating significant environmental consequence as well as causing significant human health issues through eutrophication concerns from the consumption of contaminated water. Soil-dwelling microorganism and other species are not spared by the direct effects of these contaminants, reducing soil biodiversity and the benefits offered by these organisms. While the entire globe still pushes to attain the projected Sustainable Development Goals (SDGs) (Morufu et al. 2021d). Most of those SDGs were indeed directly or indirectly reliant on soil ecosystem services, for example, (a) guaranteeing the availability as well as sustainable water management and sanitation for all (SDG 6), especially for individuals living in rural locations, is directly reliant on soil provisioning services, which are in turn dependent on biogeochemical cycles, a sustaining ecosystem function; and (b) eliminating hunger, ensuring food security, boosting nutrition, as well as encouraging sustainable farming (SDG 2), which is directly reliant on soil provisioning services, which are in turn reliant on biogeochemical cycles, which is a crucial ecological service; it is obvious that many of the SDGs related to health remain linked to soil services in some way (Morufu et al. 2021d); malnutrition, which is attributed to poor food, lowers the immune system, rendering individuals more prone to infectious illnesses, like malaria. SDG 15 safeguard the milieu and biodiversity through incorporating sustainable development ideas into government programs and policies, as well as prevent environmental and resource loss, which is dependent on soils providing the ecosystem services necessary to achieve the SDGs. To continue supplying these vital ecosystem services to a rising population, major efforts in soil management and restoration would be required. As a result, the purpose of this review is to present critical features of our comprehension of soils in a contemporary sense pertinent to the core principle of ecological processes, and perhaps to sum up the recent advancements of soil pollution to understand the key pollutants as well as their sources influencing public health, with an emphasis on toxicants present in agricultural practices as well as reaching humans through the food chain. It then goes on to explain the most efficient ways for evaluating and remediating contaminated soils.

8.2 Soil Pollutants: Properties, Origins, and Health Consequences

Soils continue to be critical in the production of food, fibre, feed, and energy, as well as in influencing the quality of our environment. Plant through photosynthesis transform soil water, nutrients, CO_2 (carbon dioxide), and solar energy into a stored energy that nourish animals and people while also providing fibre and fuel. Soils collect rainwater and irrigation-generated "green water", as well as nutrients from mineral or organic sources, and release them at rates that encourage plant development (Falkenmark and Rockstrom 2004). The biota in the soil decomposes organic matter, cycles nutrients, as well as regulates gas fluxes into and out of the atmosphere. Clay surface adsorption and precipitation processes screen both non-hazardous as well as harmful substances in soils, determining the quality of surface waters. Ecosystem services are the soil processes that benefit humans (Millennium Ecosystem Assessment 2005; Olalekan et al. 2021). Provisioning, control, culture, as well as support are all ecological functions provided by soils. Food output from soil-grown crops and animals has climbed by 170%, timber production by 60%, and fuel (mainly for firewood) and fibre (flax, cotton, sisal, wool, jute, and hemp) production have all probably improved by roughly the same amount over the previous four decades (1961–2003) (Millennium Ecosystem Assessment 2005). As a result of these large increases in output, soil degradation and many of the regulating and supporting services that soils serve (Millennium Ecosystem Assessment 2005), for example, controlling hydrological as well as nutrient cycles, have suffered (Olalekan et al. 2021). Ecosystems' capacity to generate food, fibre, fuel, and water would be harmed as a result of these trade-offs between provisioning and regulating roles. Simultaneously, soil contamination initiates a chain reaction of degrading activity in soil, threatening its ability to deliver ecosystem services. Because soil pollutants have wide-ranging impacts on

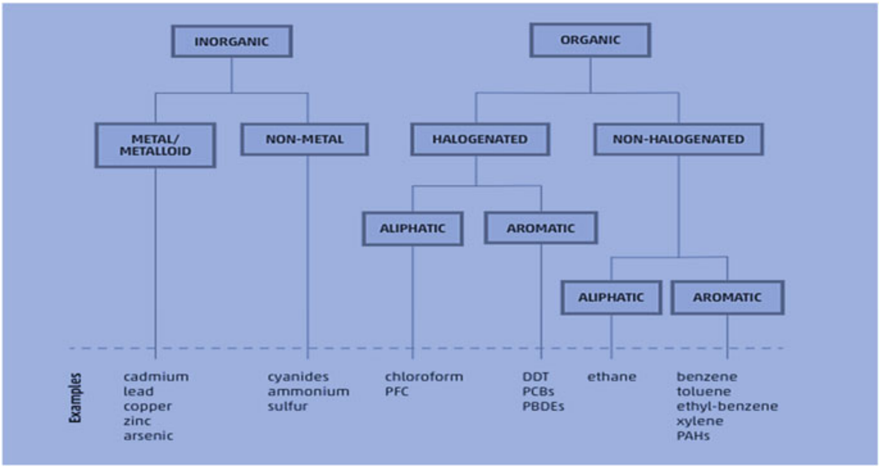

Fig. 8.1 IUPAC classification of the major contaminants in soil. Fluorinated, chlorinated, as well as brominated chemicals are examples of halogenated compounds. Source: Permission to reproduce from FAO and UNEP (2021)

animal organs as well as systems, they cause a wide range of health outcomes, from acute to chronic disorders, resulting in severe developmental difficulties, alterations in biological functioning, and early mortality. Contaminated plants as well as soil organisms cause potentially harmful accumulations in higher-level food web species like grazing animals and birds, which are transmitted to people. Swartjes (2011) stated that the discharge of contaminants into the milieu is usually the result of manmade activity. Regardless of the fact that some metals and chemicals exist naturally in soils, human activities continue to be the leading cause of pollution. Chemicals, both inorganic and organic, continue to act as environmental contaminants in soil, posing a risk to public health and the milieu. Swartjes developed a systematic pollutant categorization (Fig. 8.1) that may be effective in better understanding the most frequent contaminants in soils based on their chemical features (Swartjes 2011). The contaminant's intrinsic properties and local soil factors determine the contaminant's destiny in the soil (Fig. 8.2), which includes retention or migration into other environmental media, along with impacts on living species. Identifying the environmental sources of trace elements is critical for understanding their pollution patterns as well as making pollution remediation decisions.

8.3 Ecosystem Pollution in Soils and Its Impacts

Although soils appear to be exceedingly resilient, their effective functioning can remain extremely vulnerable. Soils and its biota are currently endangered by degradation induced by global changes, such as land use, changing climate, chemical

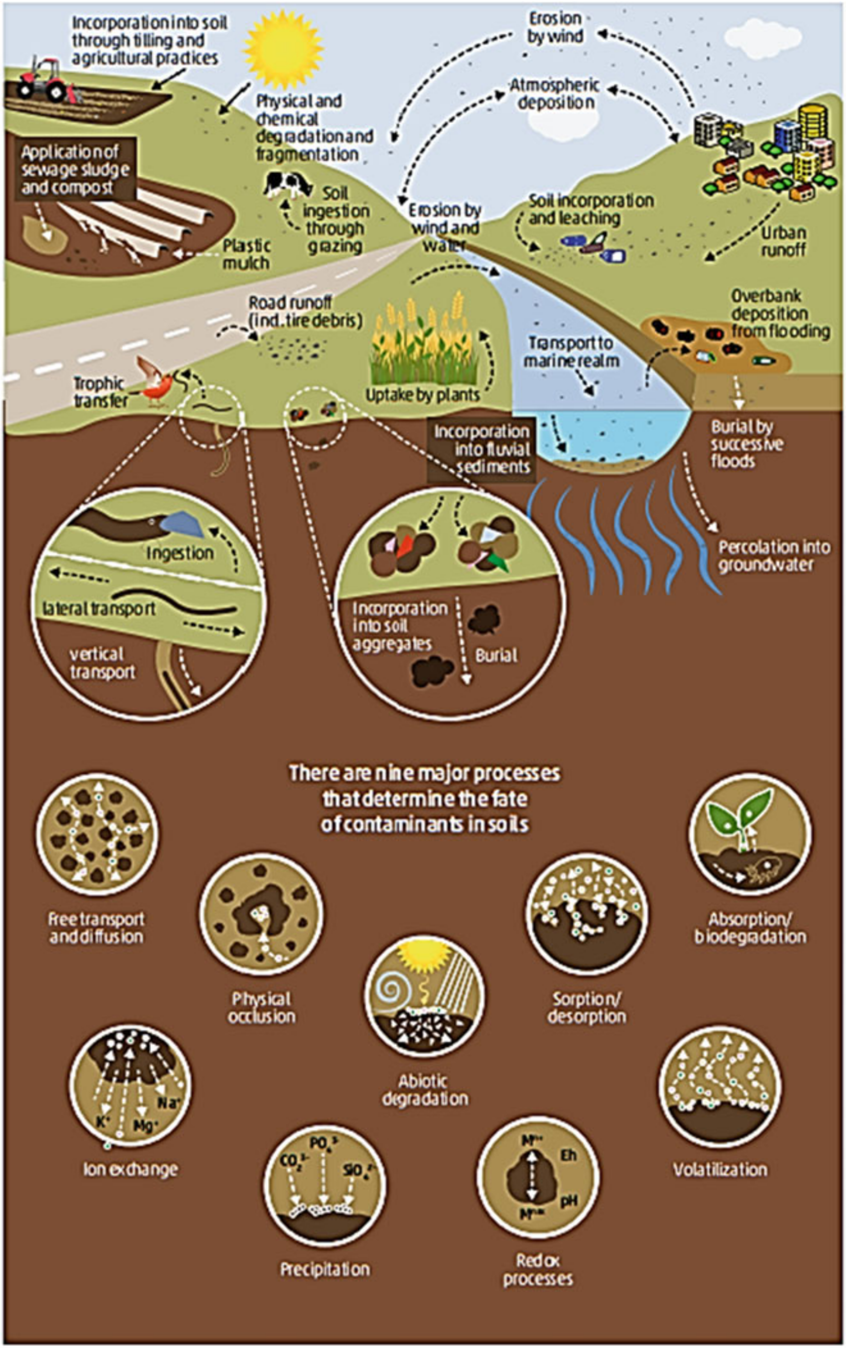

Fig. 8.2 Contaminant's entry points and their fate in soils. Permission to reproduce from FAO and UNEP (2021)

pollution, as well as new species invasions, which could have far-reaching consequences for Earth's ecosystems. Global climate change, in its broadest meaning, is regarded as the most serious threat to biodiversity protection, ecosystem function, as well as service delivery (Foley et al. 2005; Galloway et al. 2008). A considerable portion of the Earth's terrestrial surface area has indeed been transformed for human use (Millennium Ecosystem Assessment 2005), and over 15% of the world's soils are still considered deteriorated, with pollution wreaking havoc in numerous areas (Bridges and Oldeman 1998). Whereas arid to semiarid habitats represent well over 40% of the Earth's land surface area, and this proportion is expanding owing to desertification (Reynolds et al. 2007). These soil changes are focusing global attention on measures towards preserving soils as well as their life capital for the future. Thousands of years of human activity have left a legacy of poisoned soils all throughout the earth. Come 2050, the entire planet is predicted to surpass nine (9) billion individuals, necessitating the provision of adequate high-quality food as well as water (McBratney et al. 2014; Godfray et al. 2010; Raimi et al. 2019c; Olalekan et al. 2019b, 2020b; Oluwaseun et al. 2019; Gift and Olalekan 2020; Gift et al. 2020; Omotoso et al. 2021; Lateefat et al. 2022a, b). Food output would grow by 70% worldwide by 2050, and by 100% in impoverished countries (Dubois 2011). According to FAO's most current projections, world food production will rise by 60% between 2005/07 and 2050 if the benchmark scenario is followed. Based on existing facts and figures, this is a decrease from the 70% increase forecast for the same time in 2009 (http://www.fao.org/economic/esa/esag/en/). Food quantity as well as nutritional quality remain beneficial to human health, and soils produce 95% of all food (Oliver and Gregory 2015; FAO 2015). Only healthy soils can provide essential ecosystem services even while providing sufficient food and fibre. The supply of ecosystem services has gotten a lot of press, and it is still defined as "the ability of natural activity and its components to provide products and services that directly or indirectly meet human needs" (Groot 1992). "The availability, accessibility, consumption, and consistency of the food supply" is how food security is defined. Contamination of soil reduces food security by decreasing crop yields as well as making the products produced unfit for human consumption owing to excessive levels of contaminants in the soil (FAO and ITPS 2015). Since then, soil has evolved into a complex growth environment that can only be fruitful when properly cared for and maintained. Combating and mitigating soil contamination entails identifying and mitigating the threats to food security, human health, as well as the environment. As a result of the harmful effects of pollutants, soil contamination has impact on biodiversity, both on the surface and underground, reducing the number of organisms and causing changes in communities as more vulnerable species were replaced via further pollution-resistant ones. Changes in soil organisms' operations can likewise happen, impacting biogeochemical cycles. Furthermore, contaminated soils become an origin of groundwater pollution due to contaminant leaching, as well as a source of contamination aimed at fresh water as well as the marine milieu, because toxins can remain carried off-site by wind as well as water erosion. Altogether, these changes could occur gradually or abruptly until they reach an inflection point, at which time significant degeneration occurs (Raimi

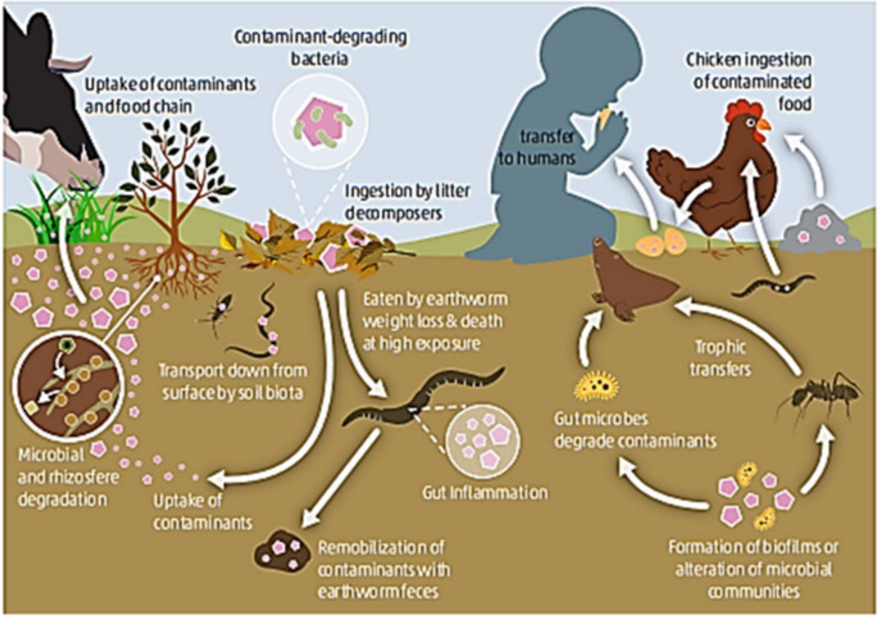

Fig. 8.3 Pollutants are transferred from soil towards pastures as well as crops, where they are devoured by humans, animals, and livestock, or they are carried from soil to invertebrates, where they are consumed via birds as well as poultry and subsequently passed on towards humans. Permission to reproduce from FAO and UNEP (2021)

et al. 2021a, 2022; Morufu et al. 2022). This sets off a chain reaction of degrading activity in terrestrial as well as aquatic ecosystems, resulting in ecosystem services loss (Fig. 8.3). Soil contamination is a transnational, often unseen issue whose existence and impacts can be found in every part of the world. Biodiversity loss affects soil organic carbon intake and modifies nutrient recycling through changing litter input, litter decomposition, and organic matter mineralization on the soil surface. Litter decomposition in significantly polluted soil might be reduced by 10–80% when in comparison to soil that has not been poisoned (Kozlov and Zvereva 2015). In heavily contaminated soils, physical property deterioration occurs owing to loss of soil organic matter, and decreased presence and soil organisms' activity (Korkina and Vorobeichik 2018). Clay discharge and irrevocable soil structure breakdown are also aided by some contaminants, like salts, as well as surfactants. Soil erodibility is a potential as a result of this physical degradation. Soil acidification (soil contamination) is one of the most underestimated hazards to soil health. Nonetheless, pH cushioning capacity is low, notably in soils that are sandy. Acidity of the soil is often generated through the use of nitrogen mineral fertilizers and animal urine, as well as plant biomass harvesting on a regular basis in agricultural regions. Acid deposition and nitrogen inputs are thought to have reduced soil pH by 0.26 globally (Tian and Niu 2015). Acidification of soil also increases trace element mobilization as well as bioavailability, endangering human health and restricting agricultural development. Nitrifying soil bacteria continue to break down nitrogen fertilizers into nitrite (NO_2^-) and nitrate (NO_3^-). In soils, nitrate and nitrite remain especially mobile and could leach into groundwater. Nitrous oxide and nitric oxide (N_2O and NO), both of which are very volatile and can leak from soils into the atmosphere, are converted to elemental nitrogen (N_2 gas, which is harmlessly returned to the environment) by denitrifying bacteria in the soil matrix. "N_2O is a major greenhouse gas with a 256-fold global warming potential of CO_2, making it a key player in climate change (IPCC 2014; Raimi et al. 2018a; Morufu et al. 2021a). Denitrifying bacteria were accountable for 80% of N_2O emissions, according to the Intergovernmental Panel on Climate Change (IPCC) research on Land and Climate Change" (IPCC 2019).

8.3.1 Negative Impact of Contaminated Soil on the Terrestrial Ecosystem and the Food Chain

The ecotoxicological reactions of terrestrial ecosystems to soil contamination remain highly diverse in relation to the pollution source, primary pollutants, exposure period, trophic level impacted, as well as climate. In general, trophic group performance is reduced in terms of body size and survival when pollution sources are close by, but primary consumers remain more robust towards pollution in relations to variety as well as abundance (Kozlov and Zvereva 2011; Okoyen et al. 2020). However, stress reactions remain site-specific, and generalizing local patterns to a global scale is fraught with uncertainty. Many contaminants are absorbed as well as "translocated to edible tissues via plant roots. Soil-dwelling creatures could store toxins in the soil. Plants and soil critters are at the bottom of the terrestrial food web, as well as when they're eaten through grazing animals, amphibians, birds, or mammals, pollutants go into the food web and build up in significant amounts in top-of-the-food-chain species" (Fig. 8.3) (Huerta-Lwanga et al. 2017; Baudrot et al. 2018). Wildlife is always exposed to small amounts of pollutants throughout their lives, unless there has been a substantial release of poisons (Olalekan et al. 2019a). Long-term low-dose exposure's health impacts, as well as the additive, cumulative, or antagonistic implications of such interactions, have largely gone unreported in terrestrial ecosystems. Soil contaminants can cause cancer, teratogenicity, neurotoxicity, and endocrine disruption in vertebrates. The contaminant nature and combination of pollutants towards the animals remain visible, the animal's dietary and living habits, which help assess exposure intensity, and the animal's development and immune status determine the consequences on animal well-being as well as behaviour; immature status or ill organisms remain far more particularly prone towards stress effects as well as have a harder time avoiding contaminated areas and food (Death et al. 2019; Lateefat et al. 2022a, b). In terms of contamination exposure, herbivores differ from omnivores in that the former collect higher quantities of trace elements or radionuclides, while the latter typically accumulate larger amounts of lipophilic pollutants like PFAS or PCBs (Kowalczyk et al. 2018). Hydrophilic and ionic pollutants remain especially dangerous to reptiles as well as amphibians because they can pass through their permeable egg membrane and come into interaction with them at different stages of their lives (Sparling et al. 2010).

8.3.2 The Effects of Soil Contamination on Aquatic Environments

Floods, rain, snow, and irrigation all increase the quantity of water in soil pores, resulting in waterlogging in flat regions and run-off on slopes once the soil is saturated. Run-off water delivers dissolved organic components, tiny particles, and sorbed toxins into the seas and oceans, where they may pollute nearby rivers, marshes, and lakes (Shi and Schulin 2018; Odubo and Raimi 2019). Changing climate exacerbates this activity, increasing the possibility of land-based activities contaminating the aquatic milieu (Fig. 8.4). More than 80% of marine contamination is still assumed to be caused by land-based activities (Cicin-Sain et al. 2011). "Every year, an approximately 35 billion tons of soil remain lost as well as mobilised as a result of erosion; around 12 billion tons of this total remain cultivated topsoil as well as topsoil tainted with nutrients and pollutants that are nonetheless released into the environment (Kok et al. 2009). Run-off contributes to eutrophication by increasing nutrient loading in rivers, transporting inorganic as well as organic pollutants that degrade quality of water and impair aquatic ecosystems, as well as transports soil particles that obscure the water and restrict the watercourses depth". The bulk of nutrients applied to soils are washed or leached away, eventually ending up in lakes, rivers, as well as, eventually, oceans and seas (Cosme et al. 2018). Excess nutrients concentrations in streams are still generated by soil nitrogen loss, that fosters eutrophication as well as the creation of cyanobacteria and algal blooms, which use a lot of oxygen and prevent other organisms from surviving. A majority of these cyanobacteria are still hazardous to both aquatic and terrestrial life (Lehnert et al. 2015). Several of the world's largest water bodies, including the Bay of Bengal, the Gulf of Mexico, San Francisco Bay, the Hudson River, the Mediterranean Sea, and the Baltic Sea, have generated "dead zones" as a result of eutrophication cycles (FAO and UNEP 2021). Corrupt and inept garbage discarding in coastal nations are to blame for about 4.8–12.7 million metric tons of plastic flowing into the deep sea via waterways, wastewater, and wind erosion, while on-land activities still discharge 75,000 to 1.1 million tons into rivers. Microplastics concentrations in agricultural fields are expected to range from 63,000 to 430,000 tons in Europe and 44,000 to 300,000 tons in North America, correspondingly (Nizzetto et al. 2016). Micro- as well as nanoplastics could induce a variety of impacts in aquatic species, ranging from physiological changes in primary producers to endocrine disruption, limited growth, and even digestive system collapse in higher primates, resulting in death. Furthermore, plastics collect additional contaminants onto their surfaces, like trace

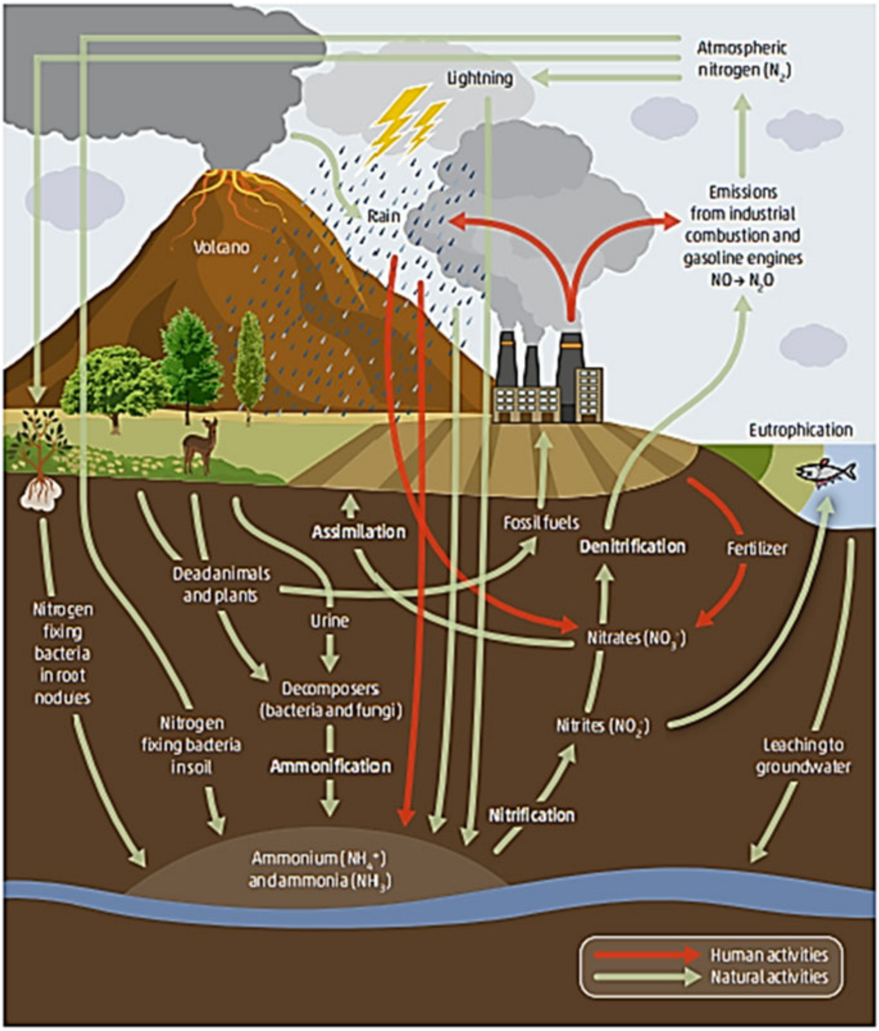

Fig. 8.4 The soil pollution impact on aquatic ecosystem has increased as a result of changing climate, which has exacerbated processes in the terrestrial milieu. Source: Permission to reproduce from FAO and UNEP (2021)

metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), as well as other organic pollutants, adding up their transit into the food chain and generating further health concerns for aquatic organisms (Alimi et al. 2018; Koleayo et al. 2021; Omoyajowo et al. 2022).

8.3.3 Socioeconomic Consequences of Soil Pollution

As a result of human pillage of nature, the world is now on the edge of crumbling. The well-being of the greatest susceptible population groups, like pregnant women, children, as well as expectant moms, is the most affected by soil contamination. Pollution tends to have a negative influence on the well-being as well as health of society's poorest and most vulnerable citizens (Landrigan et al. 2018). Even though there are substantial inequalities in health status within a country, environmental-related mortality and disease burden are highest in middle- as well as low-income nations. The poorest countries and places have the slightest access towards clean technology and pollution remediation options, putting their food security at risk, and environmental regulations are typically slack (Mackie and Haščič 2019; Suleiman et al. 2019). The key socioeconomic drivers impacting the unequal circulation of disease burden credited towards the milieu remain access towards clean green areas, health insurance or public sanitation, nutritious food, environmental and urban development rules, as well as clean technology are only a few examples (Pasetto et al. 2019). A large number of emerging nations demonstrated their ability to quickly implement regulations as well as procedures towards decreasing pollutant release into the soil, but they require knowledge as well as transfer of technology from more wealthy nations (Hilton 2006). Repairing and managing soil pollution can cost hundreds to thousands of millions dollars each year. The remediation cost varies according to the site attributes, like the affected area size, the contaminants concentration, the remediated environmental compartments (vadose zone, topsoil, surface water, and groundwater), the precautions to remain taken towards protecting the public throughout the restoration process, the tolerable standard to be obtained based on the land use after environmental clean-up, and the utilized technology (Darmendrail et al. 2004). Other indirect costs are sometimes disregarded, leading to an underestimating of soil pollution's impacts. Soil pollution impairs several ecosystem services, reducing production as well as the ability to withstand long-term challenging conditions (Fig. 8.5). As a result of high pollution concentrations, biodiversity loss, increased insect incidence, poor water quality, as well as marine environment eutrophication, soil contamination reduces agricultural yields and increases food waste. As a result, the monetary burden of diseases due to soil contamination, several of which are chronic as well as have long-term implications, along with lost human output, is typically understated (Attina and Trasande 2013).

8.4 Worldwide Status and Trends of Soil Contamination: Global South

Despite the substantial environmental stresses that exist, identifying the scale and complexity of existing contaminated soils is critical for both recognizing the magnitude of the problem and establishing the urgency with which it should be treated.

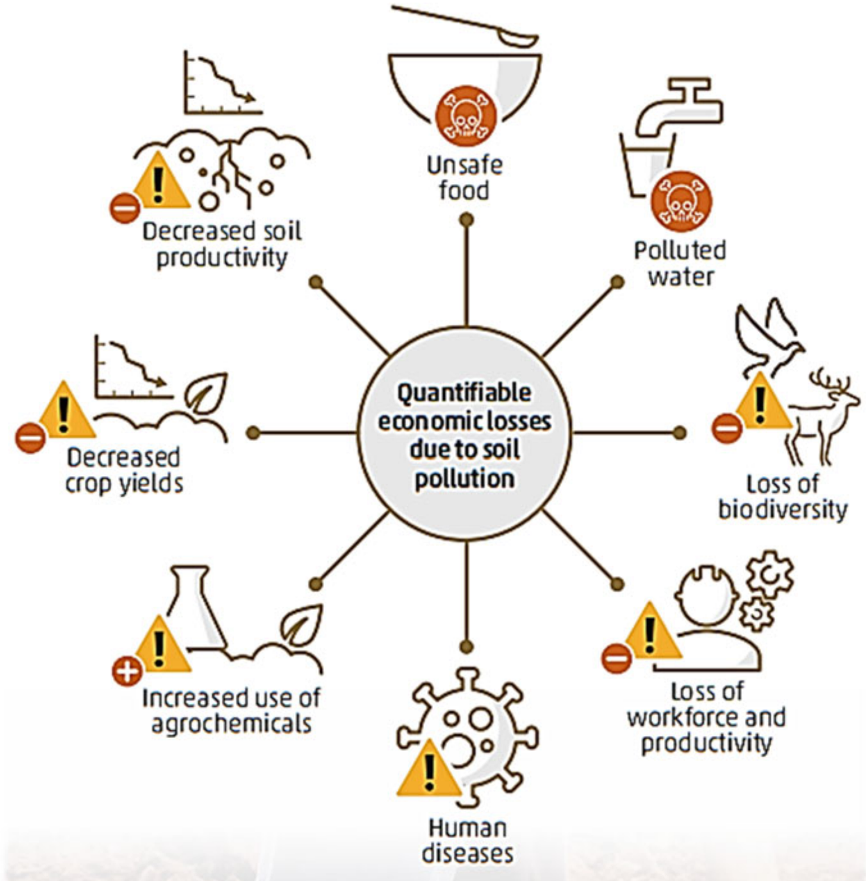

Fig. 8.5 Quantifiable economic losses related to soil degradation. Permission to reproduce from FAO and UNEP (2021)

Whereas a majority of soil pollutants are present all over the world, their distribution and key sources differ by nation. The regulatory structures in place to avoid soil pollution range significantly as well. The Global South, on the other hand, consists of 48 African nations that are either south of the Maghreb or the Sahara Desert, or have a piece of it in their northern areas. “From a population of 227 million in 1960 to 1.08 billion in 2018”, the region’s population has grown significantly. Between 1950 and 2015, the urban population of Africa expanded over 2000%. Individuals frequently settled in locations precisely adjacent to industrialized zones, agricultural processing facilities or mines, in order to remain near to places with job prospects, in contrast to industrialized as well as emerging nations, where urban sprawl has resulted in an apparent lack of indigenous land zoning. This poses significant health hazards in areas with contaminated soils. The practice of geophagy is a special risk factor in the Global South (deliberate ingestion of soil). In the Global South, there has yet to be a large-scale regional evaluation of soil contamination. Research on trace metals contamination as well as pollution dominates the information available regarding known and new contaminants, but insecticides, hydrocarbons, as well as PCBs are also major pollutants. The primary sources of soil contamination in the Global South as well as their distribution throughout remain addressed in more detail below:

8.4.1 Transport of Waste and Its Management

Around "81 million tonnes of municipal solid waste (MSW) were produced in the Global South in 2012. By 2025, MSW output is predicted to reach 244 million tons. An increase in electronic waste is caused by increased demand for electrical as well as electronic equipment (sometimes with a limited lifespan), like obsolete digital waste. E-waste from Asia as well as Europe is being sent in significant numbers to Nigeria. In addition to garbage created locally, the region gets end-of-life automobiles, old tyres, as well as technical waste from all over the world". In Africa, around 4% of MSW trash is recycled. Waste transport from other areas, in addition to rubbish creation in the Global South, resulted in a high environmental load associated with waste in the Global South. The harmful public health consequences of e-waste sites were emphasized in a research correlating pollutants concentrations in current blood levels of 245 individuals towards the import as well as e-waste processing in 16 African nations. Western and Central Africa provided the majority of sub-Saharan African responses. People, especially children, who reside in locations where processing of e-waste is a top priority are visible to high quantities of trace metals, like vanadium, arsenic, aluminium, mercury, chromium, as well as lead, all of which are dangerous to their health. E-waste hotspots have been discovered as causes of soil pollution, such as the Gbarian rubbish dump site in Yenagoa, Bayelsa State, Nigeria. One of the most significant types of soil pollution connected with transportation in the past was lead poisoning of roadside soil due to the use of leaded gasoline. Despite the fact that the phase-out of leaded fuels began over four decades ago, progress in the Global South has lagged behind Europe, the United States, and many other developed countries. Since leaded fuels are no longer used in the Global South, high-traffic regions' car emissions have now been linked to elevated trace concentration of heavy metals in urban soils, notably antimony as well as cadmium (Henry et al. 2019a).

8.4.2 Industrial Activities

One of the pillars of long-term economic prosperity is industrialization. Industrialization has become a development priority for the Global South due to its ability to create jobs, strengthen structural economic reforms, and further spur the growth of other sectors via linkage (Raimi et al. 2019a; Suleiman et al. 2019; Raimi 2019; Olalekan et al. 2019a). Pure Earth/Blacksmith Institute has found trace element polluted locations in the Global South via the Toxic Sites Investigation Program. Lead, uranium, mercury, cadmium, arsenic, and chromium (both hexavalent and total) are among them. The most common trace element polluted sites remain those with dangerous lead concentrations. According to the TSIP, lead pollution has been identified in Tanzania, Kenya, Rwanda, Ghana, Uganda, Senegal, Madagascar, and Nigeria, among other nations. Higher lead concentrations in soil are caused by a variety of factors. Lead battery recycling, transportation, wastewater treatment facilities, tanneries, coal or oil-fired power plants, mining as well as ore processing, smelters, and auto repair shops, including medical waste management, are among these enterprises. In residential neighbourhoods, a range of small industrial firms, oscillating from dry cleaning towards recycling lead battery, as well as vehicle repair shops, may be found. Trace element levels have been shown to be high in the soil as well as biota surrounding metal smelters (Sawyerr et al. 2018; Henry et al. 2019a). Although each operation is minor in and of itself, collectively they provide a significant soil pollution source. “The casual recycling of spent discarded lead-acid batteries has a substantial impact on the amount of lead present in soil. At a typical informal recycler, the plastic box containing the battery mechanisms is broken apart with a hand axe or machete, as well as the sulphuric acid solution inside is spilled on the ground or into a storm drain. The lead plates are taken out and buried in a pit before being filled with charcoal and burnt. After cooling, the molten lead is poured into ingot moulds and supplied to battery producers”. In most cases, the activity is directed out without the use of any pollution control devices or regulatory monitoring.

8.4.3 Mining

Global South possesses substantial mineral resources as well as deposits of oil; extraction as well as processing may promote economic activity as well as also providing livelihoods for inhabitants (Okoyen et al. 2020). Nonetheless, large-scale, artisanal, and small-scale mining and processing of natural resources have resulted in significant environmental degradation and soil pollution in the region. In the Global South, mining and quarrying are still important causes of trace metal contamination as well as pollution sources (Raimi et al. 2017, 2021a, 2022; Henry et al. 2019b; Olalekan et al. 2018; Sawyerr et al. 2018; Morufu et al. 2021b, c, d, 2022). Dust from mines and ore smelters can contaminate neighbouring soil, as well as residential and agricultural regions, with trace element levels in the region posing a threat to public health and the milieu. At mining sites, trace elements are typically coupled with other organic pollutants, culminating in more complicated structures that need more extensive clean-up processes. Suppression of dust is a technique used in extensive mining to limit the harmful effects of dust emissions resulting from bare-surface transport highways to move ore from the mine. However, this approach has the potential to introduce toxins into the soil where it is utilized. Soil acidification in mining locations is exacerbated by acid mine drainage from tailings storage facilities. Lower pH values in both soil as well as tailings increase trace element and radionuclide mobility. Extracting the mineral from the ore, artisanal as well as small-scale mining rely heavily on human labour and crude extraction technology. "Even though the precise number of individuals in the Global South who rely on this type of mining is unknown, it is thought to make a substantial contribution to at least 23 regional economies. Burkina Faso, Mali, Sierra Leone, Tanzania, as well as the Democratic Republic of the Congo are among the countries where artisanal as well as small-scale gold mining provides support for rural livelihoods. Mercury and cyanide are the two most common pollutants connected with artisanal as well as small-scale gold mining. Elemental mercury is utilized to extract gold from silt via generating a mercury-gold amalgam, which is then heated to extract gold". Mercury is deposited in the tailings during the washing process, and it eventually enters the soil or nearby water sources. In Mozambique, the United Republic of Tanzania, Burkina Faso, as well as Zimbabwe, small-scale and artisanal miners are now using cyanide to recover gold. "According to studies, artisanal as well as small-scale mining is the world's greatest source of mercury, with Burkina Faso providing 35 tons of the predicted 1400 tons each year. According to the International Institute for Environment and Development, 75 locations in the Global South have been recognised as mercury-polluted, as assessed by Pure Earth". These changes are projected to effect around 2.4 million individuals. In seven of the region's countries, sites polluted by elemental mercury have been recorded (Guinea, Ghana, Mozambique, Kenya, Uganda, Senegal, and the United Republic of Tanzania). Aside from mineral extraction, the extraction and fossil fuels processing add towards soil contamination in the area. Nigeria and Angola have been reported to have the greatest levels of soil pollution caused by trace metals and hydrocarbons as a consequence of petroleum sector (Premoboere and Raimi 2018; Olalekan et al. 2018; Deinkuro et al. 2021; Morufu et al. 2021c). Between 1960 and 2010, Nigeria saw over 4000 oil spills, with total amounts anticipated to be available at more than 2 million barrels (320,000 m^3), with sabotage being the primary reason. Since 2009, the oil and gas business in Angola has been responsible for oil pipe breaches and spills in the provinces of Cabinda and Zaire, polluting sediment in riverine as well as coastal areas with minimum of 15 PAHs (Okoyen et al. 2020).

8.4.4 Agriculture

Agriculture's history has been continually overcoming restrictions and boosting food production by increasing the quantity of farmed land as well as intensifying cultivation through the adoption of novel agricultural technologies. Agricultural production quantity and nutritional quality, on the other hand, remain ultimately determined by a dynamic balance of adequate biophysical resources, such as water availability, soil quality, CO_2, sunlight, temperature suitability, and, in certain situations, pollinator abundance. Production is reduced by some weather extremes, as well as pests, diseases, and air pollution (e.g. tropospheric ozone) (Adeolu et al. 2018; Raimi et al. 2018b, 2020b, 2021c). Agricultural operations in the region, on the other hand, have become a cause of soil contamination. Persistent organic pollutants, toxic pesticides, as well as commodities encompassing trace metal, like mercury and lead, remain employed in the region, putting human and environmental health at risk. Whereas the usage of such dangerous substances is forbidden or regulated in affluent nations, their illicit disposal creates a significant pollution control concern in Africa. Pesticide use in agriculture is widely acknowledged as the most major source of soil pollutants. Organochlorine pesticides, endosulfan and DDT, have been found in soils in Kano State, Nigeria, and have been linked to prior agricultural practices in the area. In the soil of cotton-growing areas in Northern Nigeria, endosulfan and profenofos, an organophosphate insecticide, are still existing (Suleiman et al. 2019; Isah et al. 2020a, b; Olalekan et al. 2020a; Raimi et al. 2020a; Hussain et al. 2021b; Morufu et al. 2021d). Despite the fact that DDT for agricultural use was outlawed in the Global South, the Stockholm Convention has given several countries exemptions to continue with DDT for control of malaria vector. Regrettably, DDT from malaria control can occasionally find its way into the agriculture sector through local markets. Past pesticide burial is another sort of soil contamination that might potentially remain a diffuse groundwater pollution source via leakage. According to World Bank, 50,000 tons of outmoded pesticides were detected across Africa in 2013. The Africa Stockpiles Program (ASP) of the FAO calculated the degree of pesticide contamination in Africa, including persistent organic pollutants (POPs) which are "chemical substances that persist in the environment, bioaccumulate in the food chain, and harm human health and the environment (FAO and UNEP 2021). POPs are numerous in number and origin, having been used in agriculture, disease control, manufacturing, as well as a variety of industrial processes. POPs encompass chlorinated and brominated aromatics, like polychlorinated biphenyls (PCBs), which have been useful in a variety of industrial applications, such as electrical transformers and large capacitors, hydraulic as well as heat exchange fluids, and additives to paints and lubricants; and organochlorine pesticides, such as DDT and its metabolites, which are still used to control mosquitoes that carry malaria in some parts of the world. Other unintentionally produced chemicals include dioxins (polychlorinated dibenzo-p-dioxins and –furans), which are produced by some industrial processes and combustion (municipal and medical waste incineration and backyard burning of household waste)". Tanzania, Tunisia, and Mali continue to be among the nations having over 1000 tons of obsolete pesticides. Four of the regional countries have pesticide stocks in excess of 400 tons. Côte d'Ivoire, Rwanda, Benin and the Democratic Republic of the Congo are among them. Pesticide-polluted soils have also been found by the TSIP. Cameroon, Benin, Ethiopia, Kenya, Somalia, Ghana, Senegal, and the United Republic of Tanzania are among in a number of nations where these locations have been found.

8.5 Efforts to Combat Soil Pollution

8.5.1 Governmental and Legal Structures to Address Soil Pollution

"Apart from international treaties and agreements, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 and became effective in May 1992 (Basel Convention 2011); the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade is a multilateral treaty that fosters collective responsibilities in relation to hazardous chemical importation (Rotterdam Convention 2010); the Stockholm Convention on Persistent Organic Pollutants (signed in 2001 and effective from May 2004); the Minamata Convention on Mercury is a global treaty to protect human health and the environment from the adverse effects of mercury (Millennium Ecosystem Assessment 2005); the Global Soil Partnership (GSP) was established in 2012 as a mechanism to develop a strong interactive partnership and enhanced collaboration and synergy of efforts between all stakeholders (GSP 2017); the Voluntary Guidelines for Sustainable Soil Management (VGSSM), endorsed by FAO Council in 2016, provide technical and policy recommendations for achieving sustainable soil management (FAO 2017); the International Code of Conduct for the Sustainable Use and Management of Fertilizers (Fertilizer Code), endorsed by FAO Conference in 2019, provides a set of voluntary practices that promote the judicious use of synthetic and organic fertilizers (FAO 2019); and the International Code of Conduct for the Sustainable Use and Management of Pesticide (Pesticide Code), adopted by FAO Member Nations in 2013, establishes voluntary standards of conduct for the various stakeholders involved with pesticide use to ensure the judicious use of pesticides (FAO and WHO 2014); the Codex Alimentarius establishes international food standards, guidelines, and codes of practice to contribute to the safety and quality of international food trade (WHO and FAO 2018); and the International Nitrogen Initiative (INI) is a science-policy platform for responding to the global nitrogen crisis (INI 2017)". INI's goal is to "optimize nitrogen's beneficial role in sustainable food production while minimizing nitrogen's negative effects on human health along with the milieu resulting from food as well as energy production"; the Bamako Convention on the Ban of Import into Africa, Control of Transboundary Movements, and Management of Hazardous Wastes in Africa was adopted". Nonetheless, all of these international and regional agreements should be taken into consideration because they focus explicitly on a set of binding conventions that support the prevention along with management of some of the most serious causes of pollution. As a result, the presence of legal frameworks and the distribution of obligations varies across country. Limited nations have legislation in place to manage, prevent, as well as remedy soil pollution. On the contrary, many nations incorporate soil management concerns in environmental law, which is frequently extremely broad and does not provide a proper dealing with many sources of soil contamination. Soil contamination control is a top issue in most countries' legislation and policymaking (Raimi et al. 2019d, 2020c; Omidiji and Raimi 2019; Olalekan et al. 2020c, d; Adedoyin et al. 2020). However, because contaminating sources vary, soil contamination is not legally defined or regulated, as an alternative, most nations have legislation linked towards urban as well as agricultural inputs and methods, as well as industrial waste management. Because they persist to be the dominant causes of pollutants, these techniques appear ineffective to avert soil contamination. In the lack of clearly specified soil contaminating activities, the options for developing best practices, compliance, monitoring plans, and enforcement actions remain inadequate.

8.5.2 Strengthened Monitoring, Reporting, and Knowledge

Given the abundance of information available, there are a lot of knowledge gaps that need to be filled. More collaborative studies coupled with data collection on pollutant emissions into the milieu, their fate in soil, and beyond also the geographic distribution of contaminated places are still needed, with an emphasis on hotspots that represent the greatest treat or harm to the environment and human health. All stakeholders, alongside with the general public, need better ways to communicate the causes, consequences, and preventative actions of soil contamination. Subsequently, the 2018 Global Symposium on Soil Pollution and World Soil Day, the Global Soil Partnership's activities, has shown great interest in the subject.

8.5.3 Contamination and Pollution of Soil Management

The management of contaminated soil sites (which represent a danger to human health and the environment) differs dramatically from those of non-contaminated sites. Contaminants must be reduced to levels that do not harm non-target organisms, and polluted regions must remain kept separate from human and animal interaction. Soil remediation is the process of reducing the level of pollution in the soil. The budgets of protecting and eradicating a concentrated pollutant before it spills remain orders of magnitude cheaper than the costs of remediating the soil after it has spilled. Contaminated places would only be rectified on rare occasions; instead, the site's management would need to be changed to limit the danger of harm towards organisms (Cachada et al. 2018). The inaction cost of removing global soil contamination stockpiles is too high. Given the prospect of irreversible land deterioration, the risks to public health as well as the milieu, as well as the cost and difficulty of restoration, avoiding contamination appear to be a top priority.

8.5.4 Risk Assessment and Identification

The first step in site evaluation is to identify potential polluted areas. Sites can be chosen based on historical analysis (for earlier activities) or accident site information. Given a basic study into the site's former usage, a preliminary evaluation is carried out to see if pollutants are still present and, if so, if they constitute a hazard to the environment or human health—in other words, to differentiate among pollution as well as contamination of a place. Soil screening values (SSVs) remain often employed. These are national standards for soil quality that have been established to detect polluted soils based on common exposure patterns and situations (Carlon et al. 2007). To measure the quantity of pollution as well as its harm potential, a risk assessment approach is applied. Risk analysis decisions for soils and sediments are still focused on finding relevant exposure routes that are harmful to the environment or human health and adopting suitable remedial activities. These may entail eliminating or treating sources, blocking exposure routes, or a combination of the two. Risk assessment techniques are still in use across the world as instruments for making science-based political and technical decisions. These distinguish polluted sites from contaminated ones, making it simpler to select appropriate management options.

8.6 Management of Contaminated Sites

Contamination of soil is frequently caused by contaminants spread from sites that are polluted through water erosion or wind, soils irrigation with contaminated surface or ground water, sewage sludge, or land spreading of manures that are contaminated; all these remain well thought-out through diffuse pollution sources. It can also arise as a result of toxins being dispersed by wind from a point source, such as a waste incinerator or smelter. The soil might remain polluted near the epicentre, but further downwind, pollutant levels remain lower than those known to affect non-target creatures. To measure the quantity of pollution and its potential for harm, a risk assessment approach is applied. Risk analysis decisions for soils and sediments are still focused on finding relevant exposure routes that are harmful to the environment or human health and adopting suitable remedial activities. These may entail eliminating or treating sources, blocking exposure routes, or a combination of the two. Risk assessment techniques are still in use across the world as instruments for making science-based political and technical decisions. Another key methodology adopted by management is to implement soil conservation measures on the contaminated site in order to reduce or eliminate contamination spread caused by wind or water erosion. To reduce or eliminate pollution leakage into groundwater, similar strategies, such as growing deep-rooted plants that use a lot of water, can be used.

8.7 Contaminated Soils Management

Overall, hazardous soil must be separated if it is identified to avoid harming humans, animals, or aquatic systems (that is, when the contaminants level cause harm towards non-target organisms). "Soil remediation (the reduction of a pollutant's concentration in the soil) is a long-term pollution control strategy. Point-source contamination is remedied using a site-specific method that includes assessment, risk evaluation, characterization, and technology selection (Fig. 8.6). If pollution is discovered and clean-up is required, the first line of defence must be to keep individuals as well as animals away from such site by erecting fences or other physical barriers, as well as warning signs". This move must remain accompanied through communication campaigns to educate the public and the local residents about the dangers of entering the site for themselves and their animals. Following that, a thorough investigation must be conducted to assess the scope of the problem and potential remediation solutions. Following that, risk management and/or remediation measures remain established and implemented. There are two types of remediation techniques: ex situ (moving of contaminated soil from its original location for treatment elsewhere) and in situ. Physical, chemical, besides biological therapies (e.g. phytoremediation) remain available as remediation substitutions, and these treatments have the potential to provide methodical answers to the majority of soil contamination. The net effect on the pollutants for both ex situ and in situ measures can remain classified as (1) lowering the concentration, (2) lowering bioavailability without lowering concentrations, or (3) encasing contaminated soil in an inert matrix, (4) containment, and (5) elimination. Following clean-up, efforts must be taken towards ensuring that the danger has been decreased as well as the pollution source has been controlled. The management of risk can remain accomplished in a variety of ways when restoration is not possible (due to financial, logistical, or political restrictions). If the risk of groundwater pollution is limited, capping the contaminated soils alongside with pristine soil, a hard surface, or other confinement material is one option. Is there a risk to pollution of groundwater? Because of the high level of pollution, an impermeable barrier beneath the polluted soil may be necessary.

8.7.1 Soils Management as a Pollution Source

Finally, reducing or eliminating water pollution caused by chemicals transferring from the soil through groundwater and surface water, notably synthetic pesticides, is an essential facet of pollution control. This agrochemical migration is a major source of water contamination in many parts of the world, affecting both marine and freshwater ecosystems. Specific methods can be used to confirm that synthetic pesticides are incorporated into the soil system in a safe and sustainable manner, preventing off-site pollution, according to the "Voluntary Guidelines for Sustainable

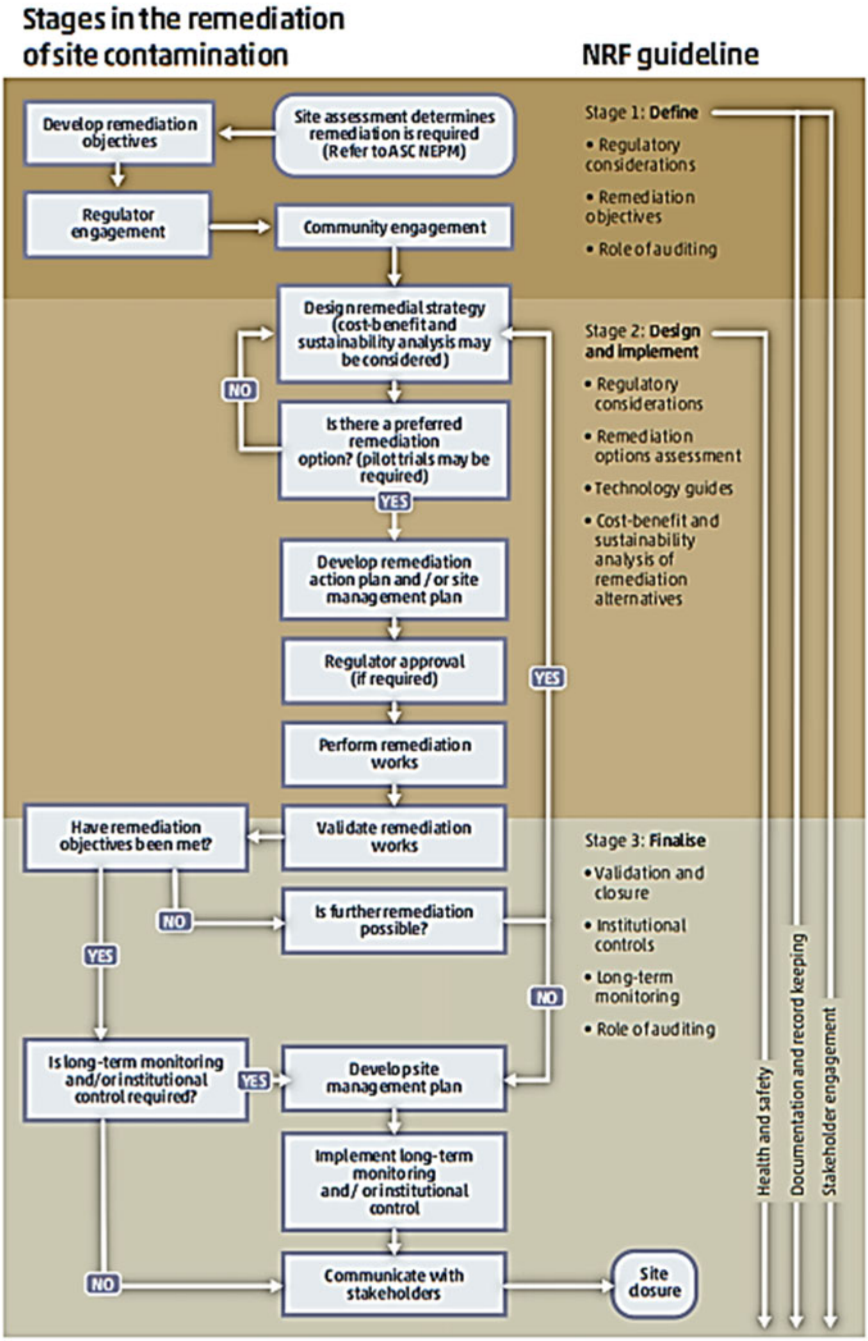

Fig. 8.6 National Remediation Framework Guideline on the stages in the remediation contaminated sites. Source: Permission to reproduce from FAO and UNEP (2021)

Soil Management (FAO 2017) and the International Code of Conduct for the Sustainable Use and Management of Fertilizers" (FAO 2019).

8.8 Priority Actions Towards Preventing and Halting Soil Contamination and Polluted Soils Clean-Up

The first and most important step in combating soil contamination is to prevent it. All parties must act urgently action towards preventing soil contamination, beginning with simple changes in people's consumption habits as well as progressing towards the implementation of severe rules and incentives to encourage industrial innovation as well as the use of environmentally and sound sustainable technologies.

- Knowledge Gaps

  From Evaluation to Monitoring

  - Increase funding in targeted research on new emerging pollutants, including detection, risk assessment, environmental destiny, as well as remediation.
  - Prepare periodic public reports on the state of the soil in various area.
  - Encourage the inclusion of soil pollution data and information in national and worldwide soil information systems, as well as the inclusion of soil pollution data and information in conventional soil surveys.
  - Create standardized soil pollution threshold levels and standard operating methods for laboratory soil pollutants analysis.
  - Create standardized soil contamination threshold values and standard operating procedures for laboratory analysis of soil pollutants.
  - Support the creation of a global soil pollution monitoring and information system.
  - Develop as well as improve national biomonitoring as well as epidemiological surveillance systems towards identifying, assessing, and monitoring soil pollution-related damage as well as diseases, and to fund preventive efforts.
  - Develop and enhance national, regional, and global point source and diffuse soil contamination inventories as well as monitoring.

  From Strategies to Technical Implementation

  - Create an incentives system as well as acknowledgement for efforts towards reducing soil pollution, such as eco-labelling or schemes compliance, like the Voluntary Guidelines for Sustainable Soil Management by labelling agricultural products that use those schemes/tools.
  - Ascertain that general pollution, chemical, persistent organic pollutant, and soil management guidelines are followed (including the voluntary guidelines for sustainable soil management, as well as the International Codes of Conducts for the Sustainable Use and Management of Fertilizers and Pesticides).

- Disincentivize as well as decrease single-use items, notably in material as well as food packaging.
- Create as well as promote rules, along with de-incentivize manufactured materials of planned obsolescence in order to reduce waste, especially e-waste.
- As part of the zero contamination/towards a pollution-free planet objective, advocate for a worldwide commitment to avoiding, stopping, and resolving soil contamination, building on regional initiatives and goals, like the European Green Deal.
- Strengthen national as well as international legislation governing emissions from mining and industry, as well as encourage industrial practices that are environmentally friendly.
- Increase the scale of nature-based, environmentally sound, long-term management as well as remediation solutions (e.g. bioremediation).
- Strengthen the capacity of Department of Environmental Impact Assessment in the Ministry of Environment to further strengthen the EIA/SEA/HIA process so as to ensure that sector policies, plan, and programmes are subject to ESIA/SEA.
- Implement policies targeted at sustainable agricultural soil management, with a particular emphasis on minimizing reliance on agrochemicals as well as managing the irrigation water quality as well as organic wastes.
- Adopt trash collection as well as green management strategies that encourage recycling or otherwise ensure proper waste treatment within and across countries.
- Create and incorporate soil pollution targets as well as indicators connecting SDGs achievement into national reporting processes.
- Encourage and reward the usage of environmentally friendly transportation.
- Ensure that all significant development projects are subjected to environmental impact assessment.
- Strengthen the Department of Planning Research and Statistics (DPRS) of the Ministry of Agriculture to support the Minister in his oversight role in soil policy formulation to monitor the implementation of the policy in relation to other sectoral policies and report to the National Council on Environment.

• Awareness Raising and Communication

- Ensure teaching and speak up to include soil health as well as soil pollution education in primary and secondary schools.
- Encourage citizen science as well as citizen observatories in order to advance early warning systems as well as soil pollution monitoring in the community.
- Raise public awareness of rational and ecologically sustainable shopping, as well as trash separation and the waste hierarchy, or the 4R technique (reduce, reuse, recycle, and recover).
- Establish and strengthen environmental education resource centres at all levels.
- Implement innovative public environmental education programmes.

  - Launch a global soil pollution education campaign targeted at the general population to help explain why soil contamination is a problem that affects everyone and what they can do to help.

- Regional Cooperation
  - Create a global training program towards building capacity in the complete soil pollution cycle.
  - Provide guidelines for environmentally sound master plans for urban development, industrial, and rural settlement.
  - Develop and implement an integrated soil policy that embraces environment issues/challenges by creating job opportunities for the teeming populace.
  - Promote technology transfer as well as capacity building from nations with extensive expertise and experience throughout the entire soil pollution cycle, from preventative measures to detection, surveillance, control, and remediation, in the topic of those with little or no expertise.
  - Establish and strengthen transboundary monitoring networks for the prevention, management, and remediation of diffuse pollution.
  - Require environmental management plans from all industrial production companies.
  - Document, disseminate, and encourage the use of indigenous knowledge in soil protection and conservation.
  - Encourage the publication of materials in open access repositories and the exchange of scientific information through international conferences.

8.9 Future Directions and Conclusions

Direct clean-up and management expenses for soil contamination range from thousands to billions of dollars each year, depending on the extent and kind of contaminants. The “Be the Solution to Soil Contamination” campaign drew attention to the worldwide problem of soil contamination and the vital need to increase community activities to enhance human health, food safety, and ecosystem services. To enhance productivity, nutrition, the environment, and everyone's level of life, society must conform to as well as minimize these shifts while upgrading our agro-based systems to become more comprehensive, productive, robust, and viable. A transformative approach that aims to accomplish socioeconomic growth while also safeguarding the environment, in accordance with the 2030 Agenda for Sustainable Progress. Polluting our soils is polluting our future, based on a recent joint report produced through the United Nations Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP), because deepening soil pollution and waste dispersal endangers worldwide food security, public health, and perhaps even the milieu, necessitating immediate global action. Not forgetting the overall impact of pollution of this nature and magnitude incident on our ecosystem and human health is far more difficult to predict. Consequently, the complete recovery of the ecosystem may be prolonged for up to 20 years or more if immediate action is not taken. Meanwhile, if OBD-PLUS Microbial Consortium is used to bioremediate the hydrocarbon polluted soil, it could take less than 20 years. Oil spill locations must be restored under international oil industry laws. This implies that the soil and water at certain places should be treated to mitigate the effects of pollution and restore them as close to their natural form as feasible. Thus, soil pollution prevention, control, and repair remain crucial if the 2030 Agenda for Sustainable Development is to be met. Furthermore, in order to achieve the UN's SDGs, a collaborative coordinated response to addressing soil contamination and improving soil health is required, as "soil protection is critical to the success of our future agri-food systems, ecosystem restoration, and all lives on Earth". As society seeks more nutrient-dense, pathogen-free foods, "tougher enforcement of universal environmental conventions, as well as long-term monitoring to prevent industrial pollution and sustainable agricultural practices that supported the use of environmentally friendly pesticides toward helping to restore balance and protecting it for future generations". The task must be met if the SDGs remain to be realized, and especially if we are to build a milieu in which these services can be provided in the future. Because countless of these ecosystem services rely on soils, reversing ecosystem degradation must begin with soil restoration. Our knowledge of the relationships between individual soil qualities, processes, as well as ecosystem services is insufficient to address this task. Soil scientists must link soil properties to processes, ecosystem ecologists must link soil processes to ecosystem services, and landscape ecologists and agronomists must place these practices in a broader and more prominent frame of reference for strategic planning decision-making, as well as direct efforts and collaborative partnerships, in order to renew.

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Chapter 9
The Impact of Unsustainable Exploitation of Forest and Aquatic Resources of the Niger Delta, Nigeria

Aroloye O. Numbere and Eberechukwu M. Maduike

Abstract Overexploitation of forest and aquatic resources in the Niger Delta has become a recurring decimal and has led to the decline in species population. Many species have become vulnerable to extinction due to unregulated exploitation. Lack of monitoring and regulation has increased the rate of overexploitation. In addition, poverty is a critical factor that has made some local people exclusively depend on the resources in their environment as sources of food and income. Continuous exploitation can lead to the loss of species. Forest destruction has a domino effect on other species that depend on forests for survival. For instance, the use of mangrove stem as fuelwood (i.e., firewood) has decimated 25% of the mangrove population. The rate of decline is increasing yearly, and if nothing is done to protect and conserve them, they will become endangered in a few years. Overfishing has been going on in the Niger Delta for decades because of a lack of regulation and control, and most of the fish in the river are caught unsustainably. The fish stock is getting depleted daily, and there is a dearth of information on fish population models that map out aquatic regions and show the level of fish stock in the area. This situation will make coastal management of fisheries resources a nightmare and difficult. This chapter thus recommends that the best way to preserve the forest and aquatic resources is to foster partnership with the local community members as equal stakeholders in monitoring and controlling overexploitation. Then the government should also fulfill its social responsibilities by providing good social amenities and employing the teeming unemployed to create another source of livelihood.

Keywords Aquatic resources · Forest resources · Unsustainable practices · Biodiversity depletion

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9.1 Introduction

Sustainable exploitation is the harvesting and utilizing of natural resources sustainably (Sutherland 2001). It is the use of resources presently to preserve them for future generations. For example, the fishing industry has been a typical example of where sustainable management of natural resources is practiced and demonstrated (Fréon et al. 2005). In contrast, unsustainable exploitation is the present use of natural resources in a manner that will deplete and drive them to extinction, which deprives future generations of the use of those same resources for their benefit. It is the exploitation of resources outside a safe biological limit (Dulvy et al. 2005). The exploitation for the benefit of present generations is not a problem. Still, the overexploitation of the resources that lead to steady decline, degradation, and loss without the thought of replenishment or replacement is terrible for the ecosystem. Forest resources overexploited are numerous, but some include timber (logging), wildlife (animals are monkey, bush rat, civet, antelope, etc.), and plants e.g., mangrove, date palm, neem, obeche, Mansonia, and abura.

Aquatic exploitation is the utilization of marine resources such as fisheries, water plants, and the water body. Unsustainable exploitation of aquatic resources involves harvesting fishery resources from seas, rivers, oceans, and estuaries in a way that will lead to a drastic decline in species population. Unsustainable exploitation consists of harmful exploitation such as dynamite fishing, bottom trawlers that collect fingerlings and the use of nets with small mesh sizes not acceptable for the target fish species. Sustainable exploitation of aquatic resources is the use of recommended fishing methods that meets international regulations and is not detrimental to marine organisms' survival is a method that will not lead to population decline. For instance, in sustainable harvesting of fishery resources, the point at which harvesting stops is at the level of constant equilibrium, not at the end of the carrying capacity (K), which will lead to a drastic decline in population. This is technically called the maximum sustainable yield (MSY) and is used globally (Mesnil 2012) to monitor the fishing industry in local and international waters. The MSY is a system that enables harvesting to stop and allows the fish stock to recuperate to its maximum target population for increased food and species population (McClanahan 2022). Here the target population to be harvested is the adults and not the fingerlings. Two factors that can lead to the depletion of natural resources are artificial and natural. Artificial factors that cause the decline of forest resources include pollution, deforestation, desertification, habitat fragmentation, and eutrophication. At the same time, factors that lead to the depletion of aquatic resources include overfishing, pollution, harmful waste disposal, etc.

Natural factors include agents of environmental degradation such as flooding, erosion, earthquake, tsunami, and hurricane. Overfishing is a significant factor that depletes aquatic resources in many coastal areas in the Niger Delta (Raza et al. 2022). According to Kelleher et al. (2009), illegal fishing is a major contributing factor to the collapse of the fishing industry, which has led to the loss of billions of dollars. The local people are primarily involved in fishing as a source of livelihood

(Simmance et al. 2022). They do not have any other income source; that is why they embark on continuous fishing to ensure their survival from hunger and poverty. Forest resources face the same problem of overexploitation because forest and non-forest products are harvested for financial and subsistence purposes (Chand et al. 2022). If this type of uncontrolled harvesting occurs regularly, it will gradually lead to the decline in species population resulting in a small population susceptible to extinction.

9.2 Anthropogenic Activities That Impact Species Population in the Niger Delta

Human activities are the primary cause of species population decline in terrestrial and aquatic environments. Human activities have a more significant effect on the environment compared to natural events such as volcanoes, earthquakes, tsunamis, flooding, and erosion. especially in the Niger Delta region. In the Niger Delta, many human activities contribute to the loss and decline of the species population. Some of these activities include

1. Urbanization (e.g., Numbere 2018)
2. Sand dredging/mining
3. Coastal development
4. Industrialization
5. Overexploitation of resources
6. Pollution
7. Invasive palm species

9.2.1 Urbanization

This leads to the clearing of forests to make way for the construction of houses, industrial complexes, schools, and other social amenities. An area can be converted from a rural to an urban setting by establishing more infrastructural development, leading to massive deforestation of mangrove forests due to limited land space and the loss of agricultural land (Yang et al. 2022). The existing cities in the Niger Delta area are already congested due to the growing population trend. Therefore, to expand the city limits, marine and forests areas are reclaimed through land reclamation and converted to bare land to accommodate infrastructure (Numbere 2020). Marine areas are sand-filled and consolidated with concrete to create a solid platform for erecting buildings. In addition, some coastal areas are used as a platform to bury pillars that hold connecting bridges. During the construction of the bridges, some sections of the water body are converted to land through the sand filling. Poor land management and improper planning of urban areas have resulted in wastage of land space leading to

Fig. 9.1 An underground corridor at Saint Louis, MO that allows animals to migrate across a highway to other parts of the forest

the conversion of aquatic to terrestrial areas. Many land areas are lying waste because they are situated in a flood and erosion belt caused by removing the vegetation cover, which acted as the land barrier. There is also a problem of building houses haphazardly without good architectural design and urban planning, resulting in the wastage of the land that should be used to erect more structures to accommodate more persons and create fields and green areas to improve the esthetic value of the city. The construction of new roads and bridges take up more pristine forest areas.

The fragmentation of the forest areas leads to habitat loss, which leads to the disappearance of species. Animals flee the construction site and migrate to other areas to seek for shelter but eventually meet their doom in the hands of the hunter (Altizer et al. 2011). The partitioning of the forest because of constructing a road across the forest also results in the separation of male and female animals, making reproduction difficult to achieve. In developed countries, allowance is created in the form of an underground corridor to aid the migration and escape of wild animals from one part of the forest to another. An example is an underground corridor at Highway 64 in Saint Louis, Missouri, USA (Fig. 9.1). The loss of forest spaces to urban development negatively impacts species populations. Thus, the more forest areas cleared for the establishment of projects, the higher the tendency for species loss.

During the construction of bridges across rivers, many aquatic organisms are killed or smothered to death by the dumping of concrete during the construction of the foundation of the pillars. The constant transportation of tools and equipment across the sea to industries situated along the coast can create rough tidal waves, which erodes the seas shore leading to increased water turbidity. This situation will affect the marine organisms living in that area.

9.2.2 Sand Dredging and Mining

sand dredging is the opening of the coastal environment by removing bottom sediments to allow large ocean-going ships to berth. This action affects pelagic and benthic organisms in the marine and estuarine environments resulting in the depletion of their populations (Mynott et al. 2022). The organisms are directly injured or killed by the blades of the dredger. The removal of the bottom sediments also carries along some benthos that plays a critical role in the marine trophic system. The loss of the bottom invertebrates affects the other aquatic organisms up the food chain leading to a cascading trophic effect on fishery population and productivity.

Sand mining, on the other hand, is the removal of sand from the sea bottom manually or mechanically and the deposition on the land surface to be used for building and construction work. This activity over the years has led to collateral damage to the aquatic system. Merchants of this damage will stop at nothing if their financial need is not achieved at a particular sand-mining site; they move on to the next river to begin another mining activity (Aliu et al. 2022). In the last 10 years, thousands of new sand-mining sites have been established across the Niger Delta region with little or no restriction by the authorities responsible for checking and controlling this adverse environmental activity. Many small inland rivers have been plundered and abandoned, resulting in the collapse of the mangrove and the fishery population in that environment. To make things worse, abandoned sand mines are never restored or remediated, allowing foreign species (e.g., grasses and Nypa palm) to colonize such areas to the detriment of the native species resulting in the loss of thousands of organisms that depends on the mangroves for survival. Many mangrove trees have been cut down, and the ecosystem so perturbed that invasive Nypa palms come in to colonize the area without resistance from the mangroves (Numbere 2018).

People are encouraged to sand fill rivers and swamps because of the unrestricted sale of such areas to private individuals who later sand fill and build on them. Sand filling of rivers and creeks has become the practice of private individuals and government agents to recover more land to build houses, hotels, and filling stations. Because of the caliber of individuals involved in the sand filling business, the regulatory agencies are helpless in calling them to order. The conversion of an aquatic environment to a terrestrial one has some consequences on the environment, which include the following:

1. Reduction in the size of the water body leads to a decline in the fishery population
2. Increased flooding and erosion
3. Removal of the carbon sequestration role by the sea and the mangrove vegetation
4. Migration or death of aquatic organisms
5. The loss of the water body leads to the loss of the ecosystem service it renders
6. Loss of rare and endangered aquatic species that have not been identified and classified for the benefit of science
7. Destruction of coastal vegetation, e.g., mangrove
8. Change in the ecosystem from aquatic to the terrestrial system
9. The introduction of pollutants and foreign species into the marine system from land-based soils may lead to the collapse of the food chain

Sand-filling activity is one of the worst ways of eliminating an aquatic environment because of the conversion to a terrestrial area. Sand filling the water body destroys the water body and gives no chance for species to survive. All organisms from micro to macro and invertebrates to vertebrates in the different layers of the water body are buried alive under the sand. Sand filling is a significant way of forming coastal areas to accommodate more houses and buildings as the population increases. Many coastal towns (e.g., Buguma, Okrika, Port Harcourt, etc.) in the Niger Delta were sand-filled to create more land for development. But after the sand filling, those areas are abandoned because of the difficulty of building. For instance, after the sand filling in Buguma was done 40 years ago, 70% of the site is still bare without any development even after allocating the land to people to build their houses.

9.2.3 Coastal Development

The development of coastal areas for housing projects, hotel resorts, filling station, and industrial centers has led to the destruction of thousands of hectares of mangrove forest (Numbere et al. 2021; Numbere 2022). These destructive activities have been going on for decades without any meaningful action to stop it because people in high authority buy off the coastal lands to establish their businesses. This attitude shows that they are less concerned about the loss of mangroves. The loss of mangroves has a ripple effect on other organisms because they serve as home to numerous species. Using the coastal environment for human projects could lead to the loss of thousands and millions of species, most of which are yet to be discovered, identified, and taxonomically classified. In the Niger Delta, years of coastal destructions have eliminated mangrove trees and fishery populations (i.e., shellfish, finfish). The collapse of the coastal environment makes it vulnerable to other disturbances such as destructive fishing, hydrocarbon pollution, and toxic waste deposition from industrial and commercial activities.

Furthermore, the use of the coasts for port and harbor activities has also contributed to the destruction of this vital environment. Due to increased human actions of shipping, exporting, importing of goods, marine transportation, and movement of light and heavy sea crafts that bring in and take out goods to and from the country. Most mangrove vegetation around the harbor had been destroyed because of constant pollution from diesel discharge from sea-going vessels and ballast water. The major ports in the country have been over labored because of the continuous inflow and outflow of goods, which has increased pollutant and waste discharges into the coast, thus impacting neighboring areas and causing an increase in the biological oxygen demand of aquatic organism. For instance, the Lagos Port is a majornt sea entry point where imported cars and other machinery are brought into the country. This coastal route serves as an international trade route that receives an inflow and outflow of many seacrafts. While berthed at the port, the ship and other marine vessels expel liquid, gaseous, and solid waste, leading to severe water pollution. Pollutants from this location are then transferred to other connecting rivers and tributaries. A significant problem in international maritime activity is the introduction of invasive species such as Nypa palms (*Nypa fruticans*), barnacles, and mussels from the ships' ballast. These foreign species antagonize the native species leading to a drop in native population. Similarly, the changes in the physico-chemistry of the sea impact the fishery population leading to their decline and extinction. The pollution of the water body from numerous industrial and anthropogenic activities leads to the migration of economically beneficial organisms harvested for subsistence and commercial purposes into the Atlantic Ocean far away from the reach of local fisherfolks.

The narrowing of the coastal environment because of sand filling and other encroaching human activities creates negative feedback leading to a surge in tidal energy, which washes away the coastal boundaries and terrestrial mudflat areas. The washing out of the intertidal mudflats leads to the loss of intertidal species such as ghosts' crabs, which die or migrate upland into more dangerous areas where they are easily captured and killed. Furthermore, an increase in tidal surges leads to a rise in sea splash and battering, resulting in flooding and erosion of coastal communities. Anthropogenic activities also lead to the hardening of the swamps, making them unhabitable by roots of mangroves and other ground-dwelling organisms of the forests. Hardening of the swamp makes it more accessible to local people who enter to plunder its resources (e.g., periwinkles, mudskipper, barnacles, etc.). All coastal activities have collateral damage on species population by leading to habitat loss, which lead to species loss.

9.2.4 Industrialization

The proliferation of industries along the coast is a disaster for biodiversity globally. It affects species directly and indirectly. Species are directly affected when removed to make way for the construction of industries. Usually, the existing trees will be cut

Table 9.1 Ways by which industries pollute the aquatic environment in the Niger Delta, Nigeria

Activities	Environment	Impact	Organisms affected
Turbines/ machinery operations	Intertidal fringe and open sea	Release of pollutants and hot water	Fishery, aquatic plants, and mangroves
Construction of landing jetty for ships	Intertidal fringe and open sea	Increase turbidity and perturbations	Pelagic and benthic organisms
Construction of bridges	Intertidal fringe and open sea and deforestation of mangroves	Increase turbidity and perturbations	Pelagic and benthic organisms
Boat transportation services	Intertidal region and all water columns	Release of spent fuel, diesel, and other pollutants	Fish, crabs, periwinkles, etc.
Gas flaring	Acid rain and defoliation of mangrove leaves	Impact coastal swamps and intertidal region	Shell and fin fishes
Crude oil transportation via ocean liner and pipelines	Entire water body is affected: coast, shores, and mangrove ecosystem	Leaf defoliation, clogging of pneumatophores of mangroves by oil slick, all aquatic organisms	Fish population (shell fish) including pelagic and benthic organisms
Building of industrial complex	Onshore and offshore plant and animal communities, deforestation of mangrove forest	Increase in biological oxygen demand (BOD), decrease in dissolved oxygen (DO)	Onshore and offshore organisms, e.g., crabs, fish, periwinkles, barnacles, etc.

down, chopped into logs, and sent away to the sawmill to be used by the building industry. In swampy or aquatic areas, unconsolidated soils removed from the ground will be carried away and dumped in a different location, taking along some aquatic species which cannot survive the new environment. Then small rivers are completely sand-filled and consolidated to enable construction work to be done. These actions eliminate large quantities of biodiversity and cannot be recovered even when the area is restored. The establishment of industries can also indirectly affect species when the industries begin operation by releasing smoke, heat, and oil and emitting loud noise that scares away organisms such as birds and other terrestrial and aquatic organisms. Coastally situated industries also discharge waste and other harmful chemicals into the sea rather than treating or recycling the waste products. And since the rivers and oceans are connected, their water circulates to other aquatic systems. Any pollutants deposited at one point are carried thousands of kilometers to other parts of the world. Thus, local pollution in each country leads to trans-boundary and international transfers to other neighboring countries. A typical example is the transfer of invasive Nypa palm from Nigeria to neighboring Cameroon. The transfer of pollutants across the sea is not suitable for the wellbeing of aquatic organisms. Ways by which industries cause species population loss are shown in Table 9.1.

Massive deforestation of mangrove forests is carried out to set up industries in coastal areas and create space for buildings such as industrial complexes, housing for staff, hotels, and seaside resorts. Many other species are also eliminated from the

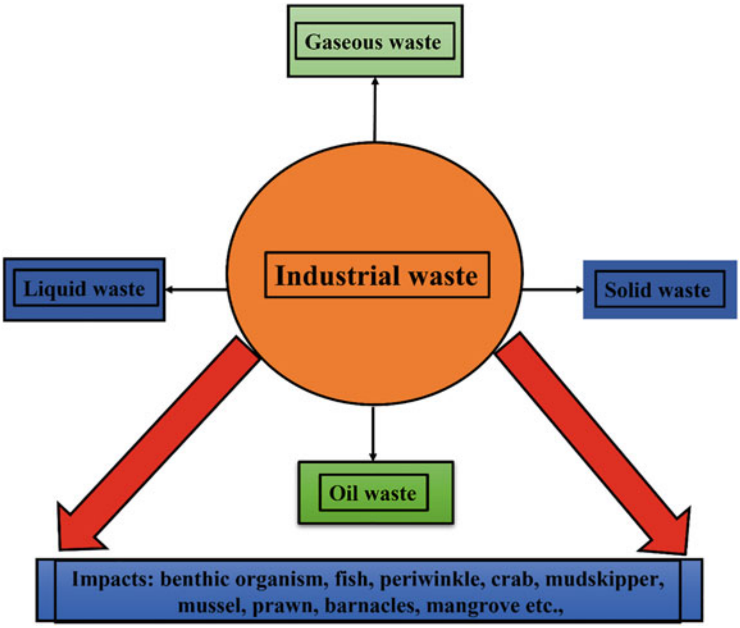

Fig. 9.2 Impact of industrial waste on aquatic organisms in some communities in the Niger Delta, Nigeria

shorelines because of construction activities and land reclamation to make way for the projects. More forest areas are cleared for oil industries to create a right-of-way (ROW) passage for pipelines conveying the crude oil to and from the refinery. Coastal and aquatic routes are also cleared to construct pillars carrying pipes coming from offshore oil rigs to refineries. The pipe-laying work disturbs the benthic and pelagic fishery community through increases in turbidity, which blocks the entry of sunlight into benthic regions of the sea. Industries set up jetties where oil tankers berth and offload their products from and into the ships. During the transfers of the products of the tankers, some quantities are expelled into the sea, causing damage to the aquatic community. Oil spillage is detrimental to sea organisms because it suffocates them and causes mutation and eventual death. Hazardous substances like PCBs, hydrocarbons, and heavy metals accumulate in the body of seafood and, when consumed by humans, can cause diseases such as cancer, food poisoning, etc. Industries generate and release all kinds of waste ranging from liquid, semi-liquid, solid, and gaseous into the environment, as shown in Fig. 9.2.

9.2.5 Overexploitation of Resources

Overexploitation is the act of harvesting and utilizing a given material in excess. Therefore, the overexploitation of natural resources is the harvesting and use of natural resources beyond the safe level that will lead to a drastic drop in their population, which is detrimental to their continuous existence. Almost all consumable and non-consumable resources in the Niger Delta had been overexploited for economic and subsistence purposes. Resources harvested for food have the highest form of overexploitation because of poverty and hunger. Aquatic resources harvested in the Niger Delta include marine organisms such as tilapia, catfish, swimming crabs, and periwinkles, while land organisms include bush rats, antelope, etc. Plant-based resources overexploited are the red mangroves (*Rhizophora* spp.), which are used for firewood production. The problem of overexploitation of resources is that it gradually leads to the decline of species population, making it susceptible to unpredictable events that may drive it to extinction. The low population of organisms such as animals can lead to a low rate of mating and, thus, low reproduction, leading to a small population. A small population is vulnerable to stochastic events that may ultimately drive the species to zero. The loss of a species can also lead to the loss of other species that depend on the host species. For example, a mangrove is a host to other biodiversity, so when eliminated will have a chain reaction that will eventually lead to the loss of other species. Mangroves serve as the spawning ground of fingerlings of fishes, so when the mangrove forest in each location is cut down, it will lead to the loss of those dependent species leading to more collateral losses in the environment. It would lead to the loss of other ecosystem services rendered by mangroves, such as carbon sequestration, air purification, and the manufacture of local materials like baskets, hats, and their use as food. Loss of natural resources through overexploitation can make such resources not to be available for future generations.

9.2.6 Pollution

Pollution is the addition of harmful substances into the environment, detrimental to life. Pollution can lead to population decline through the death of aquatic and terrestrial organisms. A key source of pollution in the Niger Delta is oil and gas exploration and exploitation, which in the last 50 years has emitted millions of barrels of crude oil into the environment (Numbere 2018; Sam et al. 2022). Spillage from broken pipelines is caused by sabotage, mechanical failure, corrosion, and theft (Adelana et al. 2011; Guo et al. 2018). The release of crude into the water body leads to the death of mangroves and fishes by cutting off oxygen and leading to the suffocation and death of these species. Crude oil is also harmful to humans when they consume seafood that has absorbed pollutants. Hydrocarbon pollution in the aquatic environment increases the death of marine organisms, which is a loss to the entire fishery population. Pollution also causes a loss of livelihood opportunities, especially for those whose profession is fishing. The proliferation of coastal fossil fuel industries has multiplied over the years, which has compounded the effect of aquatic pollution because of the fuel transportation across the sea to the fuel depot of these industries. Some amount enters the water body and contaminates marine organisms. The dumping of harmful waste further increases the pollutant load into the water body by individuals and companies that find it as their dumping ground and an easy way to dispose of their waste products. Offshore oil rig also contributes to marine pollution when drill cuttings, drill oil, and drilling mud are released into the water body. These pollutants travel thousands of kilometers to contaminate marine organisms in other locations around the Niger Delta. The entry of contaminants into the marine environment can come through two sources, namely point and non-point sources. The point source is when the oil is directly released from a particular source into the water body, for instance, from oil tankers involved in accidents such as the Mobil oil spill in international waters that polluted many parts of the global seas. The non-point source is the most difficult to detect and control because it occurs without notice. It is the release of pollutants into the environment through undetectable sources, such as the release of pollutants into the sea from land seepage from oil tank farms and agricultural farms. The release of chemicals from the soil into the water body from erosion and land runoff contaminates the aquatic environment and is difficult to detect or control. The proliferation of artisanal refineries has also escalated the pollution index in the marine, land, and atmospheric environments of the Niger Delta. For instance, the crude pattern of burning the oil to refine and recover petrol has increased the atmospheric soot within the urban and rural areas of the region. The black soot contaminates the land and water body when washed down by rainfall. The detection and estimation of the atmospheric pollutants are problematic because it occurs all over the terrestrial and aquatic surfaces. The deposition of soot on the water body changes the chemistry of the water by decreasing the pH and making the water more acidic, which affects sea organisms that need neutral to alkaline pH to survive. Other aspects of the water quality are also negatively impacted, such as the metallic contents, salinity, temperature, total dissolved solids, and carbon content. A preliminary study at the Eagle Island mangrove forest detected black soot on the water body's surface.

9.2.7 Invasive Species

Invasive species are foreign species that are brought in directly or indirectly from a different location into another country. They can be brought intentionally as a pet for some esthetic or economic purposes and later become a threat to the native species. They can also be brought in unintentionally, especially when they hitchhike into transport vessels such as ships, airplanes, or vehicles and transport from one part of the world. They can also get stuck to the bodies and clothing of humans and animals and transported to foreign land from their native country. Not all alien species are invasive, i.e., they can invade new areas and wreak havoc, but all invasive species are foreign. When brought into a foreign land, some species may not survive because the local species will resist their presence due to biotic resistance. However, if they can fight back and survive, they may become evasive and invasive by overpowering the native species. Alien species survive their new environment when they come along with innate good qualities from their home country. Their escape from intense competition from their native land can free them up and provide them with better quality to overcome the native species, which probably has not experienced such competition in their lifetime. Invasive species attack the local species by different means. Plant invasives (e.g., Nypa palm) produce allelopathic chemicals that impede the growth of other neighboring plants along a specific diameter around their roots. The invasive plants also change the soil's chemical composition, making it difficult for the native species to survive the new soil environment, leading to their gradual death and disappearance from that area. Nypa palm is the major invasive species in the coastal areas of the Niger Delta. They were brought in from Indonesia a century ago to serve as erosion control for coastal communities. They failed as erosion control because they instead spread wildly to colonize mangrove areas leading to the decline in the population of mangroves in many districts of the Niger Delta. The mangroves, which are the native species, cannot put up a fight with the palms, which studies have shown have a better quality in surviving anthropogenically disturbed soils. The mangroves, for centuries, had stayed in swampy wetland soils. However, human activities of emitting oil and dumping waste have converted the swamp to muddy brownish soils that are not typically the swampy soil mangrove thrives in. The change in the soil is a key-deciding factor leading to the elimination of the mangroves from the Niger Delta environment (Numbere 2018). Thus, the mangroves need a century or more to adapt to the muddy soils fully. It will take further studies to determine how mangrove can survive in muddy soils. Reducing human intrusion into the mangrove forest can save the mangroves from extinction.

Similarly, polluted and perturbed mangrove areas can be remediated and restored to guarantee the growth of mangrove seedlings and complete restoration of the mangrove forest, which may take 20–30 years to grow to maturity. The loss of mangroves will affect the people's economy because they depend on it for their livelihood. For example, many ecosystem services are derived from the mangrove forest, such as firewood, food, fishery, aquaculture practice, basket, hats, roofs, weaving products, hatchery, and human and animal feed. As for the Nypa palm, not many use has been identified compared to the mangroves. However, they are used for weaving brooms and baskets and making thatched roofs. But in terms of habitat for other animals, it is not as prominent as the mangroves which sometimes serve as spawning ground for fishes. There is ongoing research to detect the food value of the Nypa palm seed. There are reports of people eating the embryo in some locations. The study will do a proximate analysis and physiological test using rats to detect if the fruit is good for human consumption. Apart from hydrocarbon pollution, the palms are the primary threat to mangrove forest survival because they are aggressive and have taken over 25% of mangrove areas (Yang et al. 2022). They will continue to encroach if nothing is done except the palms are stopped on their tracks. The palm may not be completely removed from the Niger Delta because of the future potential of their use to manufacture human and animal food. Still, they can be removed from the areas occupied by the native mangrove forest to prevent further encroachment.

9.3 Causes of Overexploitation of Aquatic and Forestry Resources

Overexploitation is the continuous and deliberate harvesting and utilization of natural resources without regard to their long-term survival. This form of exploitation is unsustainable because there is no consideration for allowing the species to survive for the benefit of future generations. This eventually leads to the elimination of a large population of the species, resulting in local extinction. In the Niger Delta, the factors that lead to resource exploitation are listed as follows.

1. Ignorance
2. Poverty
3. Lack of regulation of resource exploitation
4. Unemployment
5. Pollution

9.3.1 Ignorance

Overexploitation of environmental resources is done out of ignorance of the ecosystem importance of the species that is being plundered or its role in the wellbeing of humanity (Eichhorn 2022). Illiteracy has made the locals who understand one language: what to eat and not what to leave behind for future generations. Most rural people who hunt or fish or cut trees don't know that they are eliminating the source of their future livelihood and their children's survival, and those yet unborn because of lack of education. Who will blame them because they overexploit to feed and earn their living? Thus, the solution to overexploitation is employment for the growing population which will take away people's attention from the resources in their environment. A well-educated person will not have time to hunt or fish when there are other better jobs to earn a living except as a hobby. An adequate enlightenment campaign is essential to help educate the people about the importance of having trees around us. The enlightenment will help counter overexploitation by rural dwellers who have no schools in their community or the funds to get the necessary education. They will be trained on how to exploit their resources sustainably.

9.3.2 Poverty

Poverty is the hallmark of many African societies because of the lousy governance system present in the area, the wastage of resources on frivolities, and the government's abandonment of the less privileged in society. Poverty is the primary cause of poor environmental practice in Africa (Farouk and Widowaty 2022). Poverty is a crucial factor that influences every poor decision to exploit and use scarce natural resources. The need for survival is a significant factor that pushes people to overexploit aquatic and forest resources. Lack of money in the pocket of rural dwellers has made the people over harvest and hunt for forbidden animals to satisfy their feeding needs so as not to die of starvation. People are ready to use grasses for cooking to stay alive and feed their families. For instance, the reckless cutting of mangrove trees to provide firewood is for both cooking and economic needs. Cutting mangrove trees has led to the decimation of mangroves to the barest minimum. The mangrove trees have been wiped out in some locations, making the environment susceptible to flood and erosion. Poverty is a curse in Africa because it limits people from realizing their dreams of getting educated and achieving their aims and objectives. Poverty also makes people embark on a dangerous mission to retrieve resources from the forest or river in crude ways. Many persons have lost their lives in thick woods or in the sea while trying to get some resource to feed on or sell to make money. The high poverty level in Africa is caused by the government, who are less concerned about alleviating the people's suffering by providing jobs and social amenities. In this situation, it would be tough for the government to sell the idea of conserving the natural resource or establishing conservation laws in rural areas that the people will obey. These policies would not work out since there is no alternative way of earning a living. People now utilize almost every type of plant–animal found for subsistence or commercial purposes. Some persons have lost their lives by eating poisonous plants or animals. In some communities, till date, they eat any wild animal captured or stray into the community. Using any organism for food can lead to a decline in the biodiversity population. In the past, animals like whales, dolphins, and swordfish that are washed ashore by tidal currents were butchered and taken home for cooking by community members. Members of the community go into a frenzy to get a piece of the unfortunate animal without thinking of rescuing it or sending it back to the sea. This scenario shows a lot of poverty in the land, and people will go to any length to put food on their table irrespective of any actions damaging the species' wellbeing.

9.3.3 Lack of Regulation of Resource Overexploitation

There are no checks and balances on the exploitation of natural resources. This is because any person who wants to harvest any plant or hunt any animal will just go into the forest to get these organisms or go to the sea to catch any aquatic organism

Table 9.2 Some species used as food or sold by rural dwellers in the Niger Delta, Nigeria

Organisms	Category of utilization		State of conservation	Conservation effort
	Subsistence	Commercial		
Forest resources				
Snake	Yes	No	Threatened	None
Termite	Yes	Yes	Common and threatened	None
Birds (dove)	Yes	Yes	Threatened	None
Crocodile	Yes	Yes	Endangered and rare	Yes
Bush rat	Yes	Yes	Common	None
Antelope	Yes	Yes	Endangered and rare	None
Alligator	Yes	Yes	Endangered and rare	None
Monkey	Yes	N/A	Endangered and rare	None
Civet cat	Yes	Yes	Endangered and rare	Yes
Pangolin	Yes	No	Endangered and rare	Yes
Whale	Yes	No	Endangered and rare	None
Elephant	Yes	No	Endangered and rare	Yes
Timber	No	Yes	Endangered	Yes
Aquatic resources				
Crabs	Yes	Yes	Common	Unsustainably caught
Periwinkle	Yes	Yes	Common	Unsustainably caught
Mussel	Yes	Yes	Common	Unsustainably caught
Croaker	Yes	Yes	Common	Unsustainably caught
Tilapia	Yes	Yes	Common	Unsustainably caught
Catfish	Yes	Yes	Common	Unsustainably caught

without restriction or control. Many rural areas have been abandoned by mainstream society without any government presence. It thus becomes difficult to monitor resource exploitation and the activities of people whose aim is to plunder the natural resources in their community. Environmental monitors from the ministry of environment and natural resources do not go into these communities because of insecurity and the fear for their lives. Even when they are sent on an official errand to these communities, they do not go; they instead get their information from a third party. Similarly, those whose jobs are to monitor resource exploitation activities in local communities do not go but sit in their offices doing administrative jobs (Glaviano et al. 2022). Three fundamental problems causing poor resource management are

1. Lack of implementation of resource exploitation laws
2. Lack of compliance with conservation laws by the people
3. Lack of enforcement of environmental regulations by the authorities concerned

The above problems have made the effective management of resources a mirage for decades, which has resulted in the natural resources of the communities being left at the mercy of the people who exploit them recklessly without regard to the negative impact on the environment. In many communities in the Niger Delta, many persons have never seen a monitoring team for resource exploitation. Members of the monitoring teams stay back in their offices in the state capital, allowing people to capture any animal or plant they can find and convert them to food. In many communities, people eat termites, snakes, birds, and other wild animals, which lead to the decline and extinction of rare and endangered species (Table 9.2).

Table 9.2 shows that 100% of the species found in the Niger Delta community in both marine and terrestrial areas are used as food to derive protein from the local people. People in this region have eaten almost all known animals. Probably it may be bat that people regard as devilish that people might not have consumed. About 60% of the animals captured are sold to the public for consumption or scientific work. The most common animal captured in the Niger Delta is the bush rat, which is popularly displayed or carried by hand and sold along major highways.

9.3.4 Unemployment

Unemployment is one of the key factors resulting to the over exploitation of natural resources by members of the community. Since most members of the community are unskilled and have no jobs, they resort to exploiting the resources at their disposal. Even the educated ones in these communities embark on unsustainable exploitation because they have nowhere to work with their certificate unless they migrate into the cities to search for greener pastures. There is a saying that "an idle mind is the devil's workshop." Persons that cannot take to crime because of lack of employment are engaged in deforestation, hunting, or fishing to earn a living. Another factor that encourages over exploitation of resources is that most rural areas have no meaningful government presence in terms of infrastructural development that will be an avenue for employment. Based on the unavailability of a means of earning a living through the acquisition of jobs, many persons are taking to their traditional profession of hunting, fishing, and farming to earn their livelihood. And this they do with impunity to ensure their survival from starvation. Those that cannot migrate to urban areas to secure good jobs remain in the village and embark on unsustainable exploitation of the natural resources they can find. Over the years, overexploitation will put much pressure on the available resources and driving them to extinction.

9.3.5 Pollution

Pollution is the addition of harmful substances to the air, land, and water, which is detrimental to public health. Pollution is one of the causes of overexploitation because it destroys farming activity, which is the main traditional occupation of the people by messing up the land on which they farm. The loss of land to oil and gas exploration had made many to resort to other unconventional means of survival that are environmentally unfriendly such as tree cutting and excessive hunting to earn a living. Constant oil spill had destroyed the fertility of the soil and had impoverished the quality of the farm products produced by farmers thereby pushing many out of the farming business. Most farmers have now changed their occupation to logging to produce firewood. Logging is an occupation that had decimated the mangrove forest in the Niger Delta region. Furthermore, fishing which is a long-time traditional occupation of the people who live in coastal communities had been devastated by water pollution from industrial activities. Many fisher folks are now jobless because they do not have the kind of fish catches, they use to have because after spending hours casting their nets and getting little result, they get tired fishing which make them go into other environmentally harmful activities to survive. People now hunt for any wild animal to use as meat to sell and feed their families. People also scrape and scour the bottom of the sea during low tides picking shelled organisms such as periwinkles and oysters to be sold or consumed.

9.4 Environmental Factors That Lead to Population Decline

The population is the number of species that occupy a specific area at a given time. These species interbreed and compete among themselves for survival. The study of population is critical because it provides an idea of the number of organisms that exist at a particular place and time, which will provide data for researchers to know whether the population is dwindling, declining, or growing. Knowledge of the population of organisms enables the proper management of the species by providing information on the type of protection or conservation needed. It would also provide information on whether the species are threatened, endangered, or extinct. A small population is at risk because it can easily be wiped out. The danger of a small population can affect the overall health of the species in the following ways:

1. Inbreeding depression
2. Outbreeding depression
3. Loss of genetic variation
4. Demographic stochasticity
5. Environmental stochasticity
6. Allee effect

9.4.1 Inbreeding Depression

It is a cross between closely related species. Here similar species mate between themselves because of the difficulty in finding partners from other species due to the small population size (Allendorf et al. 2022). Inbreeding depression is harmful to the population because there will be a low genetic variation due to the similarity of their genes. The consequence of inbreeding is that any disease will affect all the species since they are all made up of the same genetic makeup.

9.4.2 Outbreeding Depression

It is the opposite of inbreeding depression. It is the mating by distantly related species. Here the lack of similarity of the genes may make their gamete non-compatible or non-viable, leading to a lack of reproduction, which will continuously cause a decline in the overall population (Van Rossum and Hardy 2022) leading to a negative effect on the population (Escobar et al. 2008).

9.4.3 Loss of Genetic Variation

Many similar species in a confined location can lead to the reduction in genetic variation, and reduced genetic variation results in an increase in diseases that cause the death of species, leading to further reduction in population (Wahl and Tanaka 2022). The key to genetic stability is diversity, and once there is a monotony of genes there will be a high chance of extinction.

9.4.4 Demographic Stochasticity

Demography has to do with the ratio of male to female species in each area and the number of organisms in each location reproducing. It also has to do with the habitat type, which increases the chances of fertilization and the generation of new species (Melbourne and Hastings 2008).

9.4.5 Environmental Stochasticity

Environment plays a key role in the survival and breeding of species (Engen et al. 2005). Most natural disasters are uncontrollable and can occur suddenly without warning. For instance, temperature determines the production of males or females in turtles. The turtle eggs hatch to form females in high temperatures, while the eggs hatch to develop males in cold temperatures. In a situation where there is a high temperature because of global warming, all the eggs of the turtle will form females leading to the problem of reproduction of new species leading to a drop in population and eventually extinction. Furthermore, other adverse environmental effects such as volcanoes, hurricanes, and tsunamis can lead to the death of many species, leading to a small population.

9.4.6 Allee Effect

This is the change in a population caused by the fitness of the reproducing or non-reproducing females, which may have a ripple effect and thus influence the fitness of other species (Andrén et al. 2022).

Many natural and artificial factors lead to population decline, some of which have been mentioned earlier in this chapter. Other factors that influence population growth are a favorable environment and the availability of abundant food and mates. Therefore, factors that eliminate the increase in population will ultimately lead to a drop in population. The level of environmental unfavourability will accelerate the decrease in population and is dependent on the level of anthropogenic activity in that area at a given point in time. Competition and the fight for survival can impact the population size.

1. Natural Factors: These are events that occur without human effort. They occur spontaneously or stochastically and leave severe environmental destruction to plants and animals. Luckily, in the Niger Delta, natural factors cause little destruction of ecological resources compared to anthropogenic factors. The Niger Delta do not experience volcano, hurricane, tsunami, and El Nino wind that cause massive and complete destruction in other parts of the world. Naturally caused devastation in the Niger Delta is caused by flooding and erosion, which in most cases are triggered by human activities. Global warming and sea-level rise are a worldwide phenomenon that is not location-specific but is wreaking havoc in the Niger Delta area through the migration of water upland because of the constriction of the tributaries because of human development. Water from the river causes the submerging of many coastal areas. Increased temperature leads to sunburn of plant leaves, causing wilting and death. Although it is at the small-scale level, it is a sign that crops will be affected if the temperature rises, leading to food scarcity and starvation.
2. Human-mediated Factors: The humans are the main culprit of environmental destruction, resulting in population decline. In the Niger Delta, the following factors contribute to the fall of species population from oil and gas exploration: (1) hydrocarbon pollution, (2) invasive Nypa palm species, (3) urbanization leading to habitat loss, and (4) industrialization leading to habitat fragmentation.

The Niger Delta is rich in natural resources, especially crude oil, which has made a lot of oil prospecting industries search for crude oil in the region. These industries carry out onshore and offshore drilling to locate oil. During the search for oil on land, economic trees and other vegetation are cut down, which reduced population. The first oil well in Nigeria was struck in a Niger Delta community called Oloibiri in 1956 (Numbere 2018). The site where the Oloibiri oil well was first found has never been the same over 50 years after the discovery because of the mass destruction of trees and vegetation and the effect of spilled crude oil on the aquatic environment. The oil spill has resulted in the death of many organisms from micro to macro and from invertebrates to the vertebrate organism. Oil pollution causes species devastation on both water and land because most oil companies do not abide with the rules and regulations of oil prospecting operations (e.g., Hu et al. 2022).

Invasive Nypa palm (*Nypa fruticans*) species is a major threat to the mangrove forest in the Niger Delta because they have crept into areas exclusively occupied by the mangroves. The palms produce allelopathic chemicals which prevent the mangroves from growing around them. Any area colonized by the palms soon has no mangrove trees. Human activities have complicated the situation by converting the swamp to dirty mud, providing the preparatory ground for the palms to invade successfully (Numbere 2020). Nypa palms have wholly taken over many communities' rich mangrove forests, e.g., Bonny, Opobo, Andoni, and Ogoni areas. If the palms are allowed to continue to spread, the mangrove forest will go extinct in the next few years. The loss in mangroves will affect man because it will lead to the loss of species that depend on mangroves for survival, which are beneficial to humans. Many industries are established near the coast because of the ease of transporting raw materials by sea. Coastal vegetation is cleared to set up these industries, leading to the drop in their population. The aquatic environment also suffer from pollutant and waste discharge and waste disposal from the adjoining industries (Denny and Jacob 2022). Some examples of coastal industries and their impact in the Niger Delta are listed in Table 9.3.

Urbanization goes together with industrialization. Urbanization is the creation of new urban centers through the sitting of infrastructural development. It involves the expansion of the city limits into the suburb and hinterland. Urbanization leads to clearing the vegetation and sand filling of rivers to create more land space for site projects. To construct a bridge across a coastal area, the foot of the bridge is usually constructed inside the water. Urban mangrove trees surrounding the city are cut to make way for roads and other social amenities (e.g., schools, hospitals, event centers, and restaurants).

9.5 Socioeconomic Factors That Lead to Population Decline

Socioeconomics deals with society and how it survives. It is the interaction between the social system and how it influences the economy. Socioeconomic factors can influence the populations of plants and animals, especially when humans see them as the only source of survival (Agbonifo 2022). A community with a 70–80% unemployment rate will be poor, and thus poverty will lead to the overexploitation of the natural resources that can be freely obtained from the environment. There will be overhunting to capture endangered species and rare animals to be used for food and to generate income. There will also be overfishing in the coastal community to derive protein for consumption. These actions will occur because of poor agricultural yield

Table 9.3 Impact of coastal industries on the aquatic environment in the Niger Delta, Nigeria

Types of industries	Waste discharged	Impacted areas	Causes
Oil companies	Crude oil, solid waste, abandoned rig	Fishery, mangrove, benthic fauna and flora	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Cement industry	Sewage, hot water	Increase turbidity, BOD	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Logging and sawmill industry	Wood particles, sawdust	Eutrophication, water quality	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Bottling company	Solid, liquid waste e.g., sewage, got water, broken bottles	Eutrophication, high BOD, low DO	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Confectionary and food company, e.g., bakery	Solis and liquid waste	Eutrophication, high BOD, low DO	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Shipping industry	Ballast water, solid waste, discharged oil	Invasive species, eutrophication, high BOD, low DO	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Fishing industry	Solid and liquid waste	Eutrophication, high BOD, low DO, smell	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Water company	Liquid waste	Hot water, sewage	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Sewage company	Liquid waste	Eutrophication, poor water quality	Lack of regulation, non-compliance to environmental of laws, lack of enforcement
Auto-mechanic industry	Solid, liquid, and gaseous waste	Pollution, spent fuel, eutrophication, high BOD, low DO	Lack of regulation, non-compliance to environmental of laws, lack of enforcement

from farmers as a result of polluted soil and water from oil spillages by industries sited around the community. For the aquatic community, scarcity of seafood will lead to the capture of marine organisms not previously consumed by community members. For example, there are forbidden aquatic and coastal organisms such as the fiddler crabs (*Uca tangeri*). Formerly, this species of crabs were not eaten, but

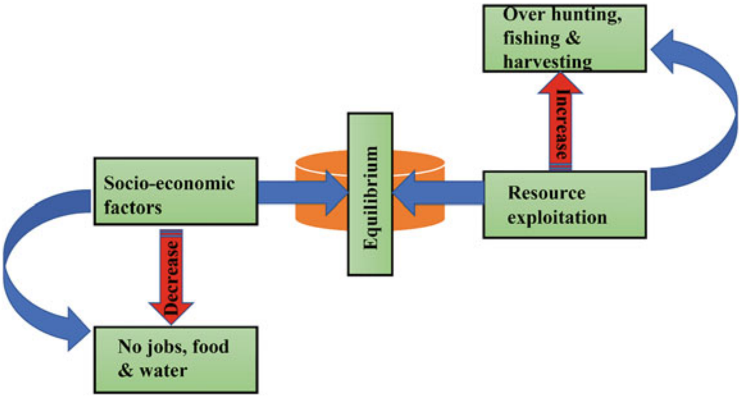

Fig. 9.3 The influence of socioeconomic factors on resource exploitation in the Niger Delta, Nigeria

now, because of poverty and the scarcity of the ones eaten, e.g., land crab (*Cardisoma armatum*) they have become a delicacy for most people. But before now, it was used as part of a fish meal (Sese et al. 2013). Another species not previously consumed is the mudskipper because of its habit of feeding on human waste, but now due to poverty, people do not care if it will provide for their protein needs, they consume it. The iguana lizard is another species whose killing is forbidden in some communities, but now it is used as food. Based on the effect of poverty and the quickly changing social system, people have started doing what was not obtainable in the past. This shows that socioeconomic situation influences the attitude of people to the conservation of their natural resources. Thus, socio-economy affects resource exploitation, which can be mathematically expressed as follows:

$$\mathrm{Se} \infty \frac{1}{\mathrm{Re}} \tag{9.1}$$

This means socio-economy (S_e) is inversely proportional to resource exploitation (R_e). This means the higher the standard of living, the less the overexploitation of the natural resources (Fig. 9.3).

Equation (9.1) shows that the higher the poverty level, the higher the tendency to exploit natural resources. Figure 9.3 shows that as the economic condition decreases, the poverty level increases, leading to more resource exploitation for survival. To balance the effect and promote resource conservation in rural areas endowed with numerous resources, an alternate source of livelihood needs to be provided to prevent community members from the destructive exploitation of the natural resources. Lack of money in the people's pockets can influence their behavior and move them to exploit resources unsustainable. To counter the overexploitation of resources, there should be a provision of jobs to reduce the unemployment rate. Social amenities (pipe borne water, hospitals, good roads, and schools) should be upgraded to meet the demand of the people to reduce self-help and extra cost to the people. The provision of amenities will help reduce the suffering of the people. The people can be made employable by providing free education that will give them the necessary skills to acquire meaningful jobs to cater for their families. Education provides the requisite knowledge of conserving natural resources and the need to exploit sustainably.

9.6 Regulation and Monitoring of Resource Exploitation

The best way to stop or reduce resource overexploitation is to partner with the people in the local community in a win-win fashion (Sircely et al. 2022). A win-win conservation method regards community members as joint stakeholders in preserving their natural wealth. In the past, authorities ignored the feelings and needs of the people and just went ahead to implement resource protection laws without a human face. Ignoring community members led to the resistance of the community members, leading to the unwarranted killing of wild animals, and plundering of forest resources. The partnership of the government with the people makes them feel as though they are equal stakeholders in conserving environmental resources. The local people should be appointed or employed as forest guards and monitors to help stop the overexploitation of the natural resources because of their native knowledge of the length and breadth of the forests (Chandra et al. 2022). The monitors and guards would be placed on a monthly salary to help them cater for their families. This financial incentive will motivate them to take their job more seriously and protect the forest and aquatic resources. Forest guards can efficiently perform their jobs well because they speak the same language, which has often been a barrier to the authorities of the exploiters. They can talk them out of such behavior. Environmental regulators are to be sent to the various communities by the state ministry of ecological and natural resources.

Regular monitoring of forests and waterways will help check the reckless exploitation of their resources. Any person caught exploiting the resource should be sanctioned by paying heavy fines or serving jail terms to deter would-be offenders. Regulatory laws should be enacted to provide legal background for any court case (Haas et al. 2022). Limits should be placed on the number of animals and fish to be caught at a given time. The government can sign the resource regulation act into law with the full backing of the state House of Assembly.

Similarly, there should be an open and closed season for hunting and fishing to prevent overexploitation of resources. If there are no limits, some people will be hunting and fishing every day, which may drive the population of organisms down. Incessant tree felling to manufacture firewood and for logging should also be checked to prevent deforestation, which is a major cause of the decline of the tree population. Firewood production is a lucrative business in the Niger Delta. The log used in making the firewood is derived from the mangrove forest without restriction and chopped into bits before being sold. Sustainable logging can be practiced saving the mangrove from extinction by selectively harvesting mature trees only while leaving the young ones to grow to maturity. The young ones can be reinforced through aggressive afforestation to plant more new seedlings to replace the cut ones. This will help to prevent population decline and help boost the replenishment of the existing trees.

9.7 Mapping of Aquatic and Forest Resources

Mapping uses geographic information systems (GIS) and remote sensing technology to study the forest and its resources. Here species-rich maps and ecological niche models (ENM) can be drawn to properly take stock of the range of forest and aquatic resources in the Niger Delta (Numbere 2022). This project will be an ambitious one because of the area covered by forest and water bodies. Sophisticated technologies would be needed to achieve this aim. It would be necessary to use Landsat and satellite imagery to construct the actual size of the forest and rivers in the region to provide data for proper management of their resources. The use of GIS is also essential to take good ground control points across the zone to carry out on the spot assessment or “ground-truthing” to give accurate results of the extent and kinds of resources available for protection, conservation, and sustainable harvesting.

The purpose of the species map and the ENM is to determine areas of the forest that have been removed over the years based on historical data derived from Landsat imagery in the last 40 years. Species map will also help determine the extent of encroachment of mangrove forests by invasive Nypa palm. Using the species map, the rate at which the invasive species is moving can be calculated to know the best management strategy to use to stop the spread. The species map will help to identify the direction of invasion and establish restoration sites where more native mangrove species will be planted to stop further encroachment. It will determine the number of seedlings needed, the species of mangrove to be planted, and the area of space to use for the planting. Knowledge of the species map will help manage the forest and aquatic resources. For instance, a study was carried out to sustainably utilize the Tunisian endemic *Marrubium aschersonii* (Lamiaceae) using GIS systems and open-source data (Pipinis et al. 2022).

9.8 Conclusion and Recommendation

The destruction of the coastal zones through unsustainable fishing will have negative feedback on species population because humans derive a large percentage of their protein from fish and fish products. The loss of the coastal forest system, such as mangroves aimed at accommodating human developmental projects, is detrimental to the wellbeing of humans and the environment. The loss of coastal vegetation will take away the ecosystem services rendered, such as preventing coastal erosion, air purification, and the habitat for beneficial species, including humans, because half of the world's population live along the coast. The aquatic zones have become the recipient of all kinds of pollutants and waste products from point and non-point sources from industries operating along the sea in offshore and onshore locations. Most of the damages done to the coastal areas are non-reversible and will take thousands of years before such damages will be reversed, if at all it will. Therefore, the solution is to stop the unsustainable exploitation of natural resources in aquatic and forest areas. The government alone cannot achieve that, instead making members of the local community equal stakeholders will help to facilitate any protective measures that will be put in place in the sustenance of these resources for the benefit of present and future generations.

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Chapter 10
Advantages and Potential Threats of Agrochemicals on Biodiversity Conservation

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Abstract The use of agrochemicals in agriculture as a tool for generating increase in agricultural production per unit of inputs has both its merits and demerits. Agrochemicals have been a useful tool in the intensive development of agriculture over the centuries. While agricultural intensification is necessary for meeting the food needs of the world's ever-increasing population, it has undoubtedly resulted in the loss of biodiversity and ecosystem services. Changes in agricultural management practices and intensities of production, and changes in the vegetative diversity in an agroecosystem are issues that are closely linked to one another. The development and use of agrochemicals have greatly helped in keeping up with world food demands, but the effects they have on plant and animal life, the integrity of our soil and water, as well as the health of the environment as a whole should not be overlooked. Mankind cannot do without farming the land for his food and livelihood, but in tackling the problems of hunger and nutrition, attention must not only be paid to boosting food production, improving livelihoods and creating resilient food systems, but also to protecting and sustaining our natural ecosystem and resources. Activities such as plowing, harrowing, as well as the use of chemical fertilizers, herbicides, and insecticides have been shown to have significant effects on the environment. Structure of modern agriculture gradually and continually eliminates biological diversity which is the foundation of any stable and productive ecosystem.

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This situation pushes forward the question of if technological progress (with a major focus on the use of chemicals for plant protection and increased yield) without due respect to biodiversity principles can bring about the environmentally friendly agriculture that is necessary for sustainable development. It is therefore necessary to examine the threats that exists as a result of the use (and misuse) of agrochemicals, and what exactly these existing threats portend for biodiversity. In this light, this chapter will examine in great depth, the advantages and threats of agrochemicals on biodiversity conservation.

Keywords Agrochemicals · Biodiversity · Agriculture · Ecosystem · Environment · Conservation

10.1 Introduction

Conserving the ecosystem biodiversity is extremely important as the Blue Planet is currently faced with economic, social, cultural, and political menace through climate change which is caused by diverse factors such as the population depletion of micro- and macro-organisms that are keeping the ecosystem at a balance. Agrobiodiversity, which is the variability and variation of microorganisms, plants, and animals that are explicitly or implicitly used for agriculture and food, is of ultimate importance to mankind. It is an agglutination of the diversities of species that are used as food, fiber, fodder, pharmaceutical and fuel, and genetic resources (breeds and varieties) and which may include fisheries, livestock, crops, and forestry. It also involves the diversities of species, such as pollinators, predators, and soil microorganisms, and the species in more extensive environments that promote agroecosystems such as forest, livestock, aquatic, and agricultural farming.

Agrochemicals have been a useful tool in the intensive development of agriculture over the centuries. But the use of agrochemicals in agriculture as a tool for generating increase in agricultural production per unit of inputs has both its merits and demerits. The environmental impact of agrochemicals (pesticides and herbicides) reveals that some organochlorines, which are a vast group of pesticides, and other agrochemicals are persistently high in the environment. Wildlife is threatened by fungicides (used for the treatment of seeds), insecticides (used for controlling insect pests), rodenticides (for a cultural control of rodent pests), and all other more toxic herbicides. Some agrochemicals result in direct species poisoning which can cause major population shrinkage especially in vulnerable and endangered species. Other agrochemicals gradually get deposited and accumulate in the food chain, which is of a great concern particularly to top predators, like raptors and mammals, and other vertebrates. Predatory mammals, such as foxes and dogs, and raptors that are non-targeted by the agrochemicals frequently get attacked by secondary poisoning when they eat mice poisoned by rodenticides.

Agrochemicals have a vast effect (both negatively and positively) on biological diversity, climate change, and loss of habitat. They exert toxic short-term effects on exposed organisms as well as long-term effects which can result from alteration in organism's food chain and their respective habitats. Although there is a need to increase production of crops and livestock for the world population, measures should be put in place to ensure that our production does not degrade the natural environment. Agricultural practices that are sustainable, like mixed cropping and organic farming, should be employed (as against intensive cropping and inorganic farming) to cater to the needs of the environment and reduce the use of pesticides and fertilizers.

This chapter elaborates on the ecological micro- and macro-organism interactions in the ecosystem, advantages of agrochemicals in agriculture, threats of agrochemicals to agriculture and the ecosystem at large, and the laws guiding the usage of agrochemicals in agriculture. It looks into agricultural intervention to curbing the negative effects on biodiversity in our ecosystem through an exposition on sustainable solutions to the use of agrochemicals on farmlands.

10.2 The Ecosystem

The ecosystem is the building block of the environment. It comprises both the living (biotic) and non-living (abiotic) components as well as the interaction that happens among them. The biotic components of the ecosystem are plants, animals, and microorganisms, while the abiotic components are soil, water, air, and land. An ecosystem is classified into two, namely the artificial and natural ecosystems.

Artificial ecosystem This is a manmade ecosystem where the biotic and the abiotic components interact with each other for one reason or the other. This reason may be economical or commercial. The system can be terrestrial or aquatic. Examples of an artificial ecosystem are aquariums, dams, and gardens (vegetables or flowers).

Natural ecosystem This is a naturally occurring community depicting the interaction between living and non-living things. The two components interact freely and together without any external influence from human activities. The different factors of the ecosystem are related either directly or indirectly, and this means that a disruption or fluctuation in one will have an effect on another factor. The natural ecosystem can also be categorized into two. These are the aquatic and terrestrial ecosystems.

Aquatic ecosystem This ecosystem is only found in water bodies. All the organisms relate and live in the aquatic environment. There are two major types of the aquatic ecosystem: the marine and freshwater ecosystems. Marine ecosystem is majorly found in seas and oceans. Intertidal zones, salt marshes, mangroves, deep seas, lagoons, estuaries, coral reefs, and the sea floor are all part of this ecosystem. The flora and fauna of the marine ecosystem are unique, and it supports a huge kingdom of species. Both the marine and terrestrial environments rely on these ecosystems to function properly. The most productive ecosystems are seagrass meadows, mangrove forests, and salt marshes. Reefs (corals) give food and shelter to the world's largest population of aquatic life. Biodiversity is abundant in the marine ecosystem.

The freshwater ecosystem is found in pounds, rivers, lakes, and streams. Plants and algae are essential components of the freshwater environment because they provide oxygen and food to the creatures in that ecosystem. Estuaries are home to plant life that has evolved to thrive in both fresh and saline conditions. Plants found in estuaries include mangroves and pickleweed. People rely on freshwater ecosystems for water, electricity, transportation, recreation, and other purposes.

Terrestrial ecosystem This type of ecosystem is found on land. Forest ecosystems, desert ecosystems, grassland ecosystems, and mountain ecosystems are examples of these ecosystems. The decreased supply of water in terrestrial ecosystems, as well as the role of water as a limiting element, distinguishes them from aquatic ecosystems. Temperature changes are stronger on a diurnal and seasonal basis in these habitats than in aquatic environments with similar temperatures. Differences in temperature and light reflect a completely diverse flora and fauna in terrestrial environments.

10.2.1 Components of the Ecosystem

The components of an ecosystem are majorly classified into two, the biotic and abiotic components.

Biotic components of an ecosystem The biotic components of an ecosystem comprise the living components of such an ecosystem. These living components have an impact on an ecosystem or the other species that live in it. They range from the smallest microorganisms like viruses, bacteria, fungi, and nematodes to plants and animals. An ecosystem's habitat is shaped by the interactions of its animals. Fish, aquatic plants, algae, and amphibians are examples of biotic factors in a river or sea. Because the living components are active, there is a basic requirement for energy; the surroundings provide them with energy and sustenance. It is common in an ecosystem for one biotic element to rely on another biotic factor for survival. A zebra, for instance, is a biotic factor for lions and other predators, but also relies on plants (trees and shrubs) for survival.

The living factors are grouped into three classes based on their energy requirement. They are producers, consumers, and decomposers.

Producers Producers are also referred to as autotrophs. These organisms produce their own food from inorganic materials and energy sources. The major member of this group is the plants which produce their own food through photosynthesis. They use carbon dioxide (CO_2) for food production, which they get from natural sources such as air and from animals that breathe it out during expiration (respiration). Abiotic energy is stored by producers by transforming it into complex molecules. Although some plants exhibit carnivorous behaviors obtaining food by capturing their preys such as insects by using a special organ to trap such preys, they still make their own food through photosynthesis. Many creatures flourish in settings rich in plants because plants function as producers in an ecosystem.

Consumers They are also referred to as heterotrophs and they rely on other living species for energy and survival. They are unable to produce their own food and must rely on plants or other animals for nourishment. Bacteria, fungi, and parasitic plants are all examples of consumers. Consumers are divided into three categories: main, secondary, and tertiary. Herbivores are plant-eating consumers who fall under the major consumer category. Sheep, goats, zebra, cattle, and other herbivores are examples of herbivore consumers. Carnivores are animals that eat herbivores or grass-eating animals and are classified as secondary consumers. Lions, cats, tigers, hyenas, and other carnivores are examples. Omnivores are those who eat both plants and animals, and they might be secondary or tertiary consumers. Tertiary consumers are creatures that eat the secondary consumers. Humans, bears, crows, and other omnivores are examples. For example, a rabbit is the major consumer, a snake that eats rabbits is the secondary consumer, and an owl that eats snakes is the tertiary consumer. Unlike autotrophs, which create complex products, such as carbohydrates, fats, lipids, and other organic compounds, heterotrophs may break down these complex organic compounds. Carbohydrates are turned to glucose, proteins are transformed to amino acids, and fats are converted to glycerol and fatty acid. Water, carbon dioxide, and energy are the end products of the breakdown.

Decomposers They are also called as detritivores. Decomposers are biotic factors that break down plants, animals, and animal feces in the environment. They obtain their nutrients and energy by decomposing these complicated molecules. Decomposers have a role in the breakdown and recycling of nutrients as biotic factors (nutrient cycles). They are vital to the ecosystem because they help break down complicated compounds into simpler ones that may be utilized by other creatures, especially producers. Fungi, soil bacteria, flies, worms, and other species are examples of detritivores.

Abiotic components of an ecosystem The non-living parts of the ecosystem are the abiotic components of the ecosystem. Examples of abiotic components are climate elements, such as temperature, light, humidity, precipitation, gases, wind, water, soil, and salinity. Non-living components of the ecosystem put the operation of the ecosystem in motion because each ecosystem on the planet depends on nutrient/ water cycle and the flow of energy.

Abiotic influences differ among ecosystems. Water, pH, sunshine, turbidity, water depth, salinity, accessible nutrients, and dissolved oxygen are some of the abiotic elements that can affect an aquatic environment. In terrestrial ecosystems, abiotic influences might include temperature, soil, rain, wind, nutrients, and solar radiation, among others.

10.2.2 Ecological Interactions in the Ecosystem

There are numerous interactions between the abiotic and the biotic components in an ecosystem. These interactions occur naturally and are necessary for the development and evolution of ecosystems. Some of the interactions between biotic components of an ecosystem are as follows:

Competition: For this type of interaction, the two species are in a state of disharmony with each other. There is an identical need for food or space between the two competing species. This poses a threat and the two species are equally negatively affected by this action.

Commensalism: In this type of interaction, it happens between two organisms or species where one is benefiting while the other is seemingly unaffected.

Parasitic: For this type of interaction, one of the species (the host) is affected by the association, while the other is enjoying optimum benefits.

Mutualism: In this interaction, the two species benefit from the interaction.

10.2.3 Relationship Between Ecosystem and Human activities

Human activities have a big impact on the ecosystem. Some of the environmental problems brought about by human activities on the ecosystem include overpopulation, pollution, soil degradation, natural resources depletion, deforestation, loss of biodiversity, and climate change. The implications of these problems include, but is not limited to, rise in sea level by melting glaciers, increased flooding, and freshwater shortage.

10.3 Agricultural Intensification and the Environment

Agricultural intensification is the process that brings about an increase in agricultural production volume resulting from an increase in inputs. It is the process of increasing the input of agricultural resources in order to improve the yield per unit of agricultural land or pasture. Agricultural intensification can take many forms, be it the introduction of new pesticides in intensive agriculture or increased use of chemicals in form of fertilizers to improve yield. It always entails increasing the intensity of some types of agricultural inputs in order to raise production levels.

Agricultural intensification arises as a need to provide food for the world's ever-increasing population. The impact of agricultural production on the environment is both positive and negative. The positive influence has been found to be on the short-run basis, while the negative impacts are for both short run and long run. Agriculture can sustain the environment as well as degrade the environment. The positive effect of agriculture on the environment is possible when production is controlled and managed according to the environment. Increased production or intensification of production may lead to all the positivity changing to negatives. Some of the negative influences of Agricultural intensification on the environment include as follows:

Increased greenhouse gases emission: Agriculture has been reported to contribute a significant percentage of global greenhouse gas emissions. This percentage can be further increased through increased production of livestock. Modern farming practices advocate for increased usage of fertilizers to increase production and yield. These fertilizers are known to be made from inorganic chemicals containing sulfur, nitrogen, and other elements which naturally exist in little amount in the environment. Increase in the use of fertilizers increases the concentration of these chemicals which constitute the greenhouse gases.

The disruption of the nutrient balance: Increased production of crops leads to some mineral nutrient being depleted faster than the environment can replenish them. This result in unavailability of some nutrient in the soil. Fertilizers are used to replenish those nutrients that depleted but because most fertilizers are made from inorganic materials, their decomposition takes a long period of time and this later causes an imbalance in the nutrient scale of the soil.

Soil erosion: Intensive agriculture is majorly practiced in intensified production programs, and this make the soil porous and susceptible to wash off by rain. The topsoil is mostly washed away and this leaves the soil bare and useless.

Loss of vegetation: In order to increase agricultural land which is suitable for crop and animal production, there is a need to cut down trees (deforestation). This is necessary because most times, economic crops cannot survive under trees because the tree canopies will not allow light to penetrate to reach the crops and they need light to grow and produce food (photosynthesis). The loss of vegetation will also lead to a loss of biodiversity because the animals and plants that are predominant in that area will be displaced and some might even be lost to extinction.

Pollution: Pesticides, fungicides, herbicides, and insecticides used in control of pests, fungi, weeds, and insects, respectively, constitute pollution to the environment. These chemicals are toxic and can affect both lower and higher organisms even human. The buildup of these chemicals in rivers and streams can kill fishes and can also accumulate and kill humans that feed on those fishes.

Soil degradation: Erosion of the topsoil degrades the soil. Erosion can be brought about by intensive cultivation of farmland over a period of time.

The release of harmful chemicals and pathogens: Undecomposed elements of fertilizers, like phosphorus and nitrogen, tend to be leached during rainfall to rivers, streams, and other water sources. This then leads to increased nutrients in the water bodies and this further leads to an increase in algal and phytoplankton growth (eutrophication). The increased growth will disrupt the normal ecosystem of water bodies. The disruption can be in the form of oxygen reduction, and this results in death of many aquatic organisms that need oxygen to thrive.

Reduced water quality: Run-off from farmlands and wastes from livestock farm eventually find their way into water bodies and these pollutants eventually reduce the water quality through either an increase in acidity or alkalinity or an increase in mineral deposits of the water.

10.4 Advantages and Potential Threats of Agrochemicals in Agriculture

Of all the innovations in agriculture, the most notable is the invention of synthetic fertilizers for improving crop yield. The use of fertilizers and other chemicals has become quite influential in modern agriculture and has been attributed with contributing the lion's share of the world's food demands over the past century. Chemical fertilizers which are produced using a method that converts nitrogen in the atmosphere into a form (ammonia) that can be applied to crops were initially introduced in the early 1900s, and have since become a hallmark of industrial agriculture. This invention, however, is not without consequences.

Agricultural chemicals, otherwise known as "agrochemicals" are needed to manage pests and improve farm productivity. Agrochemicals such as ammonia are used to enhance growth and improve yield, while herbicides help deal with unwanted plants. Insecticides and pesticides also find a wide range of use on farmlands for their usefulness in eradicating insects and pests. The use of chemical substances, however, poses direct risk and indirect risk on humans and the environment. Some of these risks are real, while some are merely perceived with no solid evidences to back up their claims. Amidst the speculations concerning the adverse impacts of agrochemicals on man and the environment, their use still remains inevitable as the world's high demand for food and other agricultural produce continues to be on the high. Ever since the beginning of the Green Revolution, the production, market demand, and agrochemical utilization have increased exponentially. This has brought about another concern which is that of improper and discriminate use of agrochemicals in agricultural production. Efforts have been made to assess the level of environmental toxicity brought about by the use of agrochemicals, and also to study the biomagnification and bioaccumulation of their remnant across various trophic stages of the agroecosystem, as well as their effect on essential environmental components such as soil, water, and air (Dhananjayan et al. 2020).

While agrochemicals are known to pose environmental risks, they also avert food loses to pests, help control diseases, and increase crop yields. It is why advocates of the use of agrochemicals argue that abandoning their use to preserve the environment would lead to food insecurity and shortages. Nevertheless, pesticides and fertilizers have been recognized as one of the primary drivers of the widespread decline of biodiversity that farms have experienced (Andrade et al. 2020). The following sections points out in more details the advantages and disadvantages of agrochemicals in agriculture.

10.4.1 Advantages of Agrochemicals in Agriculture

Undeniably, modern agriculture has recorded various advantages associated with the use of agrochemicals. These advantages include increase in yield of agricultural crops, soil fertility, pest management, and crop protection (Majeed 2018). Several biotic and abiotic stresses are managed through the use of various chemicals in form of fertilizers, pesticides, etc. The application of agrochemical has brought about significant improvement in fertility of soil as well as pest management over the past 40 years (Lamichhane et al. 2016). Fertilizer containing nitrogen and potassium help plants blossom and grow. Without pesticides, food production would drop and food prices would soar. Several other benefits can be attributed to the use of agrochemicals and these include increased yield, protection from pest-induced losses, improved food security, etc.

10.4.2 Negative Impacts of Agrochemicals on Humans, Animals, and the Environment

According to Adu et al. (2019), the utilization of agrochemicals was prompted by the need to improve crop yields and agricultural productivity on a massive scale. The extensive use of pesticides pollutes, air, land, and water, causing great damage to the ecosystem and posing a serious health hazard for living organisms in the environment. Aside the harm to the environment, it also hinders the absorption of important mineral nutrients by plants (van der Werf 1996).

Agrochemicals, such as pesticides and fertilizers, are quite pervasive and ubiquitous. They increase the value of crop yield, thereby saving money for both consumers and farmers. However, the long-term destructive impacts of application of agrochemicals should not be overlooked. Pesticides are considered as one of the main factors contributing to environmental contamination of today's world. Pesticides (e.g., insecticides, herbicides, fungicides) are designed to be toxic to pest and vectors of diseases (Mostafalou and Abdollahi 2013) and the number and diversity of these chemicals in current use have greatly expanded during the past 50 years. Also, the utilization of compound fertilizers has expanded enormously since the 1960s and has prompted vastly expanded crop yield, but the big challenge with the utilization of synthetic fertilizers is groundwater pollution, conglomeration in crops, and long-term impacts of heavy metal pollution (Valcke et al. 2017; Jallow et al. 2017). There have been recorded effect of pesticides on fishes, amphibians, birds, earthworms, predators, pollinators, and humans. It is, therefore, necessary to consider risks and challenges posed by agrochemical application in agriculture for safeguarding human health, ecosystem, and environment. Highlighted below are some of the negative impacts of agrochemicals.

Human health Humans are the top predators of the agroecosystems and with a linkage between the improper and indiscriminate use of agrochemicals and occurrence of acute ailment. Many agrochemicals, especially in their concentrated forms, are known to be highly dangerous to humans and animals. Ammonia, for example, in low concentrations is generally harmless to humans, but high concentrations of the gaseous fertilizer anhydrous ammonia can prove fatal to human.

Due to the detrimental impacts of agrochemicals and especially its overuse, efforts have been made to assess its toxicity to environmental components (Dhananjayan et al. 2020). Toxicity, which is the potential of any substance to impair the structure or functions of an organism, can cause harmful biological effects in exposed individuals in the short and long term. Pesticides are an example of toxic substances that can cause damage to immunological, nervous, endocrine, and reproductive systems of an organism. DNA damage, which can lead to abortions, cancer, and degenerative diseases, has been linked to pesticides exposure (Arévalo-Jaramillo et al. 2019). Prolonged pesticides pollution will definitely have a harmful effect on human's health and affect the functionality of different body organs, including cardiovascular, nervous, immune, endocrine, renal, respiratory, and reproductive systems. Amyotrophic lateral sclerosis (ALS), certain reproductive disorders and birth defects, chronic kidney failure, cardiovascular diseases, chronic respiratory diseases, coronary artery disease, acute nephropathies, immune system diseases, such as rheumatoid arthritis and fundamental lupus erythematous, persistent fatigue condition, Parkinson disease, and Alzheimer's disease are examples of diseases that have been linked to exposure to agrochemicals. There have also been different evidences on the relationship between exposure to pesticides and the incidence of chronic human ailments like cancer and diabetes (Mostafalou and Abdollahi 2013). Vast number of cancer cases and non-deadly poisonings every year are associated to pesticides. Individuals who work consistently with pesticides, such as farm workers, are most vulnerable to diseases. Furthermore, few pesticides instigate immunotoxicity in people which might prompt immunosuppression, inflammation, immune system illnesses, and extreme allergies.

A study carried out by Adu et al. (2019) which sampled 144 participants consisting of 83 agricultural workers and 61 indigenes with no patent exposure to agrochemicals, revealed that long-term use of some types of agrochemicals may be related with adverse health impact. The review examined renal function, hematological indices, bioaccumulation of heavy metal in farmers, and their utilization of personal protective equipment (PPE). It inferred that disregard of the utilization of PPE might be inclining the agrochemical laborers and local community bioaccumulation of lead and arsenic with a subsequent decreased renal and hematological function.

Classes of pesticide (such as carbamate, triazine, organochlorine, organophosphate, pyrethroid insecticides, and chlorophenoxy herbicides) have been proven as causal agents of dysfunction and renal damage in animals, and the definite effect of prolonged exposure to such pesticides on human kidney functionality remains a contemporary area of research as well (Sobel et al. 2005). However, high amount of organochlorine pesticides was found in severe kidney disease patients together with a substantial reduction in glomerular filtration rate and an increased oxidative stress in few epidemiological researches (Jallow et al. 2017).

In addition, environmental and occupational pesticide exposure has been linked to thyroid dysfunction. A study by Requena et al. (2019) assessed the relationship between environmental exposure to pesticides and the danger of developing thyroid diseases. The study was carried out among Spanish populations living in areas categorized (according to agronomic criteria) as of high or low pesticide use and consisted of 79,431 individuals diagnosed with goiter, thyrotoxicosis, hypothyroidism, and thyroiditis. Data collected from hospital records for the period of 18 years revealed that risks of thyroid diseases were substantially higher in areas with higher pesticide use, with a 49% greater risk for hypothyroidism, 45% for thyrotoxicosis, 20% for thyroiditis, and 5% for goiter (Requena et al. 2019).

Risks to animals Organisms that have suffered harm due to pesticide usage include microbes, insects, fungi, plants, fishes, birds, and rodents. Pesticides could disrupt the physiology of specific taxonomic groups and thus should only be specifically toxic to the organisms in question, but unfortunately, that is not always the case as most pesticides are quite non-specific and may destroy other non-harmless and ecological useful organisms (Gill and Garg 2014).

Environment Regarding the implications of leading crop production practices on environmental quality, agricultural management practices, which includes an increased use of agricultural chemicals or fertilizers, are often assessed according to their benefits for economic efficiencies in production. Little consideration is usually given to their potential environmental effects and more attention is given to benefits derived from reduction in total production costs and increased production yield (Udeigwe et al. 2015). Carriger et al. (2006) reported that only about 0.1% of the pesticides get to the targeted organisms, while the remaining only contaminates and pollutes other plants and the surrounding environment. Consequently, the utilization of non-biodegradable and persistent pesticides has contaminated various water bodies, soil, and air ecosystem, thereby contaminating the ecological food chain and bioaccumulation in higher tropic level (Mostafalou and Abdollahi 2012).

Additionally, tens of thousands of chemical contaminants, in the form of pesticides, petroleum hydrocarbons, metals, plasticizers, pharmaceuticals, personal-care products, and emerging industrial agents, regularly enter lakes, rivers, estuaries, and nearshore marine environments and have significant effects that can aggregate to the level of populations, species, communities, and ecosystems. The movement of these toxic chemical contaminants within aquatic ecosystems is quite complex and therefore often challenging to detect and expensive to monitor (Scholz et al. 2012). Dhananjayan et al. (2020) opined that to understand the effect and impact of agrochemicals on the environment, biomonitoring studies, through which the risks posed by agrochemicals can be assessed, become imperative. By observing or assessing the state and ongoing changes in ecosystems, components of biodiversity, and landscape, pollution may be suspected or inferred.

10.4.3 Potential Threats of Agrochemicals in Agriculture

Not only is the fertility of soil affected by the death or damage to microorganisms caused by pesticides, but the loss of natural antagonists to pests, pesticide resistance, honeybees and pollination decline, and losses to adjacent crops are also real threats to agriculture.

Pest resistance A challenge with the utilization of agrochemicals is the resistance of the pests to the chemical which leads to further destruction of crops despite adding the agrochemicals in the right proportion (De Bon et al. 2014). Whitefly, for example, has developed resistance to pyrethroids and organophosphates (Houndete et al. 2010).

Pest resistance is the condition whereby pests, such as insects, mites, weeds, and small animals, are able to resist pesticides. These creatures are said to be pest resistant when they do not get affected by pesticides and there is a clear failure of an item designated at any pest species to accomplish the normal degree of control in any event, when utilized by mark recommendation. Although resistant individuals will generally tend to breed a normal population, the promiscuous utilization of agrochemicals can dispense vulnerable populaces, thereby giving the resistant ones a specific benefit in the presence of a pesticide. These resistant individuals then, at that point, keep on increasing without any rivalry and in the long run become the predominant piece of the populace over ages.

Intense use of chemicals in form of pesticides has encouraged the development of resistance in various designated pest species all over the world. For instance, the quantity of resistant mite species and insects had risen to 600 by the end of 1990, and by the end of 2001, had expanded to over 700 (Gill and Garg 2014). Resistance has likewise been found in various insecticide groups. As indicated by Dhaliwal et al. (2006), 291 species have developed resistance to cyclodiene, 263 species to dichlorodiphenyltrichloroethane (DDT), 260 species to organophosphates, and 85 species to carbamates. While many factors like biology or ecology, control operation, and hereditary control the development of resistance to pesticide, significant plant pests, animal parasites, vectors of disease, etc., have created resistance "to such a degree that their control has become really challenging" (Gill and Garg 2014).

Pest resurgence Indiscriminate use of pesticides can induce pest outbreaks due to insecticide resistance. The term "Pest resurgence" is used to describe the phenomenon of reappearance of a pest population in invidious numbers following pesticide utilization. Use of consistent and/or persistent and broad-spectrum pesticides which kills non-target species that are oftentimes beneficial biological enemies of pest populations is thought to be the pace-setting cause of rapid reappearance of pests. However, pest resurgence has been observed to also occur because of numerous reasons, such as reproductive rates of insect pests, increment in feeding, and application of sublethal doses of pesticides, and occasionally, the removal of a fundamental pest which enables favorable atmosphere for the secondary pests to become key pests (Dhaliwal et al. 2006).

10.4.4 Potential Threats of Agrochemicals to Biodiversity Conservation

While agricultural intensification is necessary for meeting the food needs of the world's ever-increasing population, it has undoubtedly resulted in the loss of biodiversity and ecosystem services. There have been concerns about the indirect negative effects of pesticides which are operating through the ecological food chain as a potent causal factor in the depletion of bird species. Boatman et al. (2004) examined evidences for the indirect effects of pesticides on farmland birds. The substantial declines which were observed to have occurred in both the range and abundance of bird species are linked to increased use of pesticides. According to Boatman and colleagues, evidence for this (such as pesticide impacts on food resources that is sufficiently adequate to lessen survival or reproduction and hence to influence the pace of population change) is accessible for one animal species, the Gray Partridge perdix. Information showing impacts of pesticides on food resources and connections between food resources and reproduction are available for a few animal species.

A considerable portion of pesticides applied on land eventually enters aquatic systems as well. Fishes being an important entity of aquatic ecosystem interact closely with physical, chemical, and biological environment and form an integral entity of marine food web. Several reports have outlined that aquatic and terrestrial ecosystems are at emergent risks due to the application of fertilizer and pesticides (Jayasumana et al. 2015; Parks et al. 2016). From numerous researches carried out, the decline in fish population worldwide has been directly linked to the effect of pesticides. Although it is improbable that any single pesticide is the only driving factor behind the decline of species of fish, this does not suggest that pesticides have no impacts on the fish population. Fish kills, for example, do not necessarily reflect the comprehensive effects of toxics on ecosystems. Focus in toxicological research should be directed toward sublethal health effects, which includes disruption to endocrine system, reproductive and immune function impairment, decreased growth, and abnormal development (Scholz et al. 2012).

With regard to amphibians, the vast reduction in amphibian populace globally has become an environmental and natural concern. This class of organisms are tetrapod vertebrates, ectothermic of class Amphibia and they occupy a wide range of environments, with most species living inside arboreal, freshwater aquatic ecosystem, and fossorial environment. Impact of pesticides on terrestrial life phases of amphibian, for example, adult and juvenile frogs, newts, and toads, is less understood. Also, specific hazard evaluation for pesticide exposure, obligatory for other vertebrates, is presently not researched on them. However, a study by Bruhl et al. (2013) examined the impacts of seven pesticide items on juvenile European normal frogs (*Rana temporaria*) in an agricultural overspray situation. Mortality went from 100% following 1 h to 40% following 7 days at the suggested name pace of enlisted items. The examined toxicity was quite alarming and a huge scope adverse consequence of terrestrial pesticide exposure on amphibian populaces appears likely.

According to the researchers, “exposure to terrestrial pesticide may be undervalued as a driver of their decline which is requesting for more consideration in preservation efforts and the danger appraisal techniques set up do not secure this extincting creature group” (Bruhl et al. 2013).

In a study by Kittusamy et al. (2014), pesticides buildups were evaluated in 109 frogs involving two species, namely *Fejervarya limnocharis* and *Hoplobatrachus crassus*. These species were from conventional and organic paddy farms in Kerala, India. Results from the study revealed that seven frogs from the conventional group had distortions, while none from the organic farms exhibited such disabilities. Levels of absolute/total Organochlorines and Synthetic Pyrethroid, Fenvalerate II in twisted and deformed *F. limnocharis* and *H. crassus* were essentially more than in the healthy and undeformed frogs. The information shows that the undeniable degree of pesticides might have added to the deformation of frogs.

10.5 Legislation and Laws Regarding the Use of Agrochemicals in Agriculture

10.5.1 Use of Agrochemicals in Agriculture

The function of agrochemicals is to control crop loss from pest infestation by the application of various chemicals. In the last century, industrial and agricultural sectors of the world have employed the use of agriculture-based chemicals which often cause a negative impact on the environment due to their high toxicity. The bioaccumulation properties of these chemicals also have future repercussions on health and environment (UNEP 2007). In recent times, the application of synthetic chemicals is the most preferred method of crop protection for increased yield. Most of the pesticides used are of synthetic nature and can be absorbed by the soil through the characteristic of the substance, surface run-off, techniques of irrigation, and climatic factors (Agnihotri 2000). Pesticides like DDT, aldrin, dieldrin, endrin, and hexachlorobenzene are examples of pesticides that may alter the functions in living organisms and the environment (Taylor et al. 2002). Residues from these chemicals on land can percolate into the soil and contaminate ground water and in turn the quality of agricultural produce. The soil has a strong affinity for these chemicals and are attracted to its absorption either directly by application in agricultural practices or domestic activities or indirectly from airborne contaminants which are deposited from other areas (Pereira et al. 2010).

10.5.2 The Laws and Legislation on Usage of Agrochemicals in Africa

Africa is a continent with about 59% of its inhabitants largely dependent on agriculture and makes a living from the activity. The continent has a global market share of 2–4% of pesticide contribution, and it is the lowest in the world (Abate et al. 2000). Food demand has been projected to increase over the coming years and this is due to increasing human population, thereby increasing the demand and utilization of agrochemicals (Snyder et al. 2015) which has become a necessity in agricultural production (De Bon et al. 2014).

In the 1970s, the government encouraged pesticide use on agricultural lands and policies were amended in 1990s which led input subsidies being reduced and government monitoring was also reduced. This led to an increase in import of pesticide by 261% from year 2000 to 2010 and most imports were from channels that were not legalized which enhanced the increased use of pesticides. Other factors such as inadequate knowledge on the utilization of pesticides by farmers and the lack of inadequate mechanisms for regulation of pesticide have caused the increased use of agrochemicals.

The procedure in the registration of pesticides in West Africa is a multi-national process called Comité Sahélien des Pesticides (CSP) (Jepson et al. 2014). Van der Valk (2003) reported that about 44% of pesticide dealers in Niger are unlicensed and it is majorly because of the limited capacity of CSP in the state; registered chemicals were 8%, and 38% had incomplete labels and 6% unlabeled. Thirty percent of chemicals tested by CSP were of poor quality, and 27% did not contain the active ingredients that were declared on the labels. CSP was unable to implement its policies in several parts of Africa, thereby giving importers and distributors, who were not certified, power to import chemicals (Jepson et al. 2014). To this end, Africa markets can be labeled unregulated and the code of conduct by Food and Agricultural Organization is not followed and risks emanates from these effects.

10.5.3 Framework for Analyzing Implementation of Policies on Agrochemicals

A framework based on contextual interaction theory (CIT) can be derived from literature on policy implementation (Fimyar 2014). This theory indicates the social process of defining output and outcome by the actor's interaction (Bressers 2007). It evaluates the practice of policy, if the state (authorities that register agrochemicals) and non-state actors (farmers and dealers of pesticides) are functioning and if the said objectives are achieved. The framework basically presents if an outcome that is desired with the utilization of the specified agrochemical can be achieved or not.

The approach of governance focuses on the relationship between actors with information, motivation, and various resources, and these three components influence one another (Mengistie et al. 2014). These three components can shape actors and actors can shape the interactive patterns which assumes there are both links and actors. The policy evaluation framework realizes the interaction in actors which tells on the output. The major information to be considered in policy formulation are as follows:

- **Policy input and objectives**: This asks questions about the policy and objectives of the pesticide and how the output will be administered. The resources may be finance, pesticide registration documents, state and non-state actors of pesticides in relation to health safety, and sustainability of the environment
- **Policy implementation process:** This basically describes the roles of companies, authorities, and individuals. Questions on why, how, and what the actors are involved in during the implementation of policy are important. Identification of actors, stakeholders, and their relationship with registration, use, and distribution of pesticide is important. Also, extension workers, agricultural officers, importers, retailers, wholesalers, and farmers' association should be included in such process of implementation.
- **Policy output:** This harnesses all the challenges which farmers may encounter during the usage of a certain product or brand of agrochemical. The effects of implementation of agrochemicals are observed in this group.

10.5.4 World Health Organization Classification of Agrochemicals

A major setback in Africa about pesticides is the lack of knowledge about its usage and most chemicals used fall under WHO risk classification system (Kwakye et al. 2019). Highlighted are some agrochemicals, their registration status in the country, and WHO risk classification levels (Table 10.1).

10.5.4.1 Ethiopia

In Ethiopia, out of 302 pesticides that are registered, 160 pesticides contained the active ingredients classified as WHO class II chemicals, which indicates moderately hazardous status (Sharma et al. 2019).

Table 10.1 WHO levels of risk classification

Level	WHO classification	Examples
Ia	Extremely hazardous	Parathion
Ib	Highly hazardous	Methomyl, demeton-S-methyl, dichlorvos
II	Moderately hazardous	Malathion, copper sulfate, lindane
III	Slightly hazardous	Atrazine, metolachlor, glyphosate

10.5.4.2 Botswana

In Botswana, malathion and cypermethrin, which are pesticides classified as WHO class II chemicals, are used by over 50% of farmers: 7.1% use methomyl, 2.7% use demeton-S-methyl, and 1.8% use dichlorvos all of which are classified under WHO Class 1b pesticides, which indicates highly hazardous (Obopile et al. 2008).

10.5.4.3 Nigeria

It was established that 78% of farmers use monocrotophos which is a WHO class Ib chemical. Atrazine and metolachlor were also used, which are categorized under WHO class III chemicals which implied slightly hazardous (Oluwole and Cheke 2009) and copper sulfate, as well as lindane and paraquat categorized as WHO class II chemicals.

10.5.4.4 Zambia

A total of 41% of the farmers were reported to use monocrotophos, which is classified under WHO class 1b and very hazardous (Nyirenda et al. 2011).

10.5.4.5 Malawi

Parathion is used by over 25% of farmers in Malawi and as a WHO class Ia pesticide, which is classified as extremely hazardous (Sharma et al. 2019).

10.5.4.6 Benin, Ethiopia, Ghana, and Senegal

Agrochemicals, such as profenofos, fenitrothion, dimethoate, endosulfan, deltamethrin, chlorpyrifos, cypermethrin which are under WHO class II pesticide, and glyphosate and malathion which are classified under WHO class III, are frequently used in these countries (Williamson et al. 2008).

10.6 Conventional and Organic Farming Practice

Challenges in agricultural practices range from inadequate plant nutrition, pest infestation, increasing weed population, and microorganisms (fungi, nematodes, virus, bacterial) among others. Both conventional and organic methods of control are effective but with a price. Excessive and/or inadequate application of any or both

Table 10.2 Selected differences in conventional and organic practices relating to plant

Activity	Conventional	Organic
Microbial activity	Quick and higher rate	Slower rate
Nutrient availability	Fast	Faster
Nutrient sustainability	Lower	Higher
Nutrition	Sustains crop, productivity is faster	Sustains crop, productivity at a slower rate
Nitrogen level	Decrease	Increase
Soil carbon	Little net gain in carbon	Accumulated carbon

at a particular point has a lasting influence on the plant and the entire ecosystem. Changes in agricultural management practices and intensities of production, and changes in the vegetative diversity in an agroecosystem are issues that are closely linked to one another. Numerous researchers have reported that the utilization of high input conventional farming techniques, such as chemical/synthetic fertilizers, genetically modified microorganisms (GMO), toxic pesticides, herbicides, growth regulators, and other agrochemicals, has not only affected health and contributed to environmental hazards but also impacted soil fertility, while some have hyped organic farming as a sustainable and renewable alternative to conventional farming strategies (Table 10.2). Report has it that organic farming focuses on the conservation of soil health, natural resources, and biodiversity by using sustainable agriculture techniques (Drinkwater et al. 1998; Franke-Snyder et al. 2001; and Yadav et al. 2013). In addition, it has an essential role to play in nutrient leaching (nitrate and phosphorous), decrease soil erosion, as well as in improving water retention capacity of earth materials (soil) and greenhouse gas emission. Agriculture is more of land management covering about 40% of terrestrial land area (Foley et al. 2005). The role of agriculture cannot be over emphasized as the practice encapsulates many practices from pre-planting operations, planting operations, and post-planting operations till it gets to the final consumer. Agricultural practices are either organic or conventional and there are abundant species of so many taxa in organic systems than in conventional systems (Marja et al. 2014; Schneider et al. 2014).

10.6.1 Microbial Activity

Several reports revealed that apart from seasons and temperature, type of nutrition/practice (organic or conventional) affects microbial activity. Organic practice allows natural release of residues into the soil system, thereby increasing the natural N in relatively high amount. It is believed that the process of decomposition is higher under warm conditions likewise consistent soil disturbances and type of crop grown. Franke-Snyder et al. (2001) also stated that microbial ecosystem increased and decreased geometrically through different seasons depending on soil temperatures and activity on the soil irrespective of whether the soil had just been tilled or cultivated.

10.6.2 Plant Nutrient and Nutrition

All living things need water and nutrients to survive. Plants are not an exception. Studies have it that maintaining optimum crop yields depends greatly on nutrient supply in adequate amount and at the best time to support both the vegetative and productive growth of plants (Jeff et al. 2017). To achieve high crop yields, conventional agriculture has relied heavily on fertilizers to provide essential nutrients needed for plant growth, such as nitrogen. The use of commercial fertilizers comes at a price ranging from environmental problems like acid rain to greenhouse effects (Lal 2003). On the other hand, supplying of nitrogen needed by plant through Farm Yard Manure maintains the productivity of crops compared to the usage of conventional N fertilizers. This is comparable as the estimation of N, P, and K rate from organic source is measured on the total nutrient content. However, the ability of organic sources to efficiently provide the nutrient requirement of crops is not as secured as in conventional or synthetic fertilizers (Yadav et al. 2013). The joint utilization of chemical manure, alongside different natural sources, is suggested for supporting higher crop efficiency and productivity, further developing soil quality and long-term sustainability (Chhonkar 2002). These natural sources other than providing N, P, and K likewise make inaccessible sources of basic nitrogen, micronutrients, bound phosphates, and disintegrated plant residues into an accessible structure to work with the plants. The use of organic materials as nutrient supports the development and action of mycorrhizae and other advantageous organisms in the soil and is likewise useful in lightening the expanding rate or lack of auxiliary and micronutrients and is fit for supporting high crop efficiency, productivity, and soil health (Altieri and Uphoff 2001).

10.6.3 Nitrogen Levels

Reports from Hepperly et al. (2007) revealed that changes in total soil nitrogen occurred slowly in either conventional or organic practices. Report showed that after continuous practice of both conventional and organic for up to 15 years, organic farming systems led to an increase in soil nitrogen, while a decrease in nitrogen levels was observed in the conventional system.

10.6.4 Soil Carbon

In relation to soil carbon accumulation, the use of sole organic nutrient in combination with conventional (also referred to as organic systems) when compared with sole conventional resulted in better carbon accumulation in the soil, despite the higher biological activity operating within the soil environment after nutrient application (Drinkwater et al. 1998).

10.7 Sustainable Solutions to Agrochemicals

The principle of sustainable agriculture has been germane in guiding all political and economic sectors of the country since the United Nations Conference on Environment in Rio in 1992. It is seen as a tool for global sustainable development and very essential in generating revenue; the need for this system of production is widely known as well (Trabelsi et al. 2016). Sustainable agriculture encompasses numerous approaches and procedure, which makes it an important tool for economic development (Velten et al. 2015). It is important to understand the distinguishing differences between goal-prescribing and system-describing concepts because it determines how this form of agriculture is understood, the method to be applied, and approaches taken for its assessment. The goal-prescribing concept understands sustainability as a management approach and when standards are met, sustainability is believed to be achieved (Deytieux et al. 2016). The major advantage is the straightforwardness in its implementation. The system-describing concept views sustainability as the ability to achieve set of conflicting goals and continuation over time with major focus on balancing economic, social, and ecological goals. The goals of sustainable agriculture are numerous and it has to cut across all social, economic, and environmental issues for viability. It is important to reduce or remove obstacles which may hinder the implementation gap for sustainable agriculture processes.

10.8 Biodiversity and the Development of Sustainable Organic Farming

Biodiversity envelopes all the various forms of life on earth, including different genes, species, ecosystems, and ecological processes (Agapow 2004; Rathoure and Patel 2020). Biodiversity is one of the major key concepts in ecology and environmental protection that sustainable development depends on for efficient conservation (Wunder and Wertz Kanounnikoff 2009). It is evident that farming practices for different plant/crop species have structured effect on biodiversity, making it tasking to decide under what conditions designated practices could pose comparative advantages to organic cultivation (Hole et al. 2005; Schneider et al. 2014).

Recently, a study by Winqvist et al. (2012) reveals that organic farming generally enhances abundance of species. Organic cultivation can therefore be an essential tool to conserve biodiversity. Many practices in organic farming, including use of cover crops, crop rotation, and reduced pesticide use, are related to supporting soil biodiversity. As a result, organic systems are seen to have potential to enhance food web structure, promote soil biodiversity, and preserve the environment (Nielsen et al. 2015). Organic farming practice provides quality food with no adverse effect on the soil's health and the ecology. On this note, there is need to intensify the organic practice by identifying suitable crops/produce on location specific for organic production that has international market recognition. This will provide more opportunity for employment and bring prosperity and enhance biodiversity. There is, however, little or no consensus on the best practices to conserve and preserve biodiversity in relation to agriculture.

10.8.1 Mycorrhiza: A Study Sample

Mycorrhiza is an important soil fungus that lives in a mutual association (symbiosis) with roots of plants. In this type of association, the fungus as well as the plant benefits from the interaction. The plant derives nutrients/food from the fungus, while the fungus absorbs nutrients from the plant too. Although the symbiosis property of Mycorrhizae can find expression in all given types of soils, not all crops are symbiotic with this particular fungus. Some of the important roles Mycorrhizae plays are stated as follows:

1. Enlarging the root zone of plants which permits them to bore into small pores of soil.
2. Dissolving nutrients/foods and conveying them to the crop root and shoot systems.
3. Making the soil particles more stable, however, improving and making the soil structure stronger.
4. Preserving the moisture content of the soil, thus improving water supplied to the plants.

The formation of mycorrhiza depends on the crops that are grown, soil conditions, and the management practices. For example, soil culturing and burning of biomass extremely harm the mycorrhizae. Also, the presence of high levels of chemical pesticides as well as certain nutrients, such as phosphorus, suppresses symbiosis. On the other hand, crop rotation, mixed cropping, and the cultivation of perennial plants promote the activity of mycorrhizae in the soil. Mulching also help stabilize soil temperature and moisture, thereby encouraging mycorrhiza development.

Of all the naturally occurring species of mycorrhizae, not all of them show the same efficiency to deriving phosphorus from the soil and that is the reason artificial inoculation of specific mycorrhiza varieties can enhance their utilization.

Inoculation, however, does not reduce the essentiality of giving adequate living conditions for these organisms.

10.9 Conclusion

The importance of agrochemicals cannot be dismissed. They increase crop yield, improve soil fertility, and are effective in pest management and crop protection. Despite their benefits, the natural environment is greatly affected when they are misused and the aquatic and terrestrial ecosystems can be modified in extreme cases. The producers, consumers, decomposers, and their processes are affected by excessive use of agrochemicals. It is imperative to understand the threats of agrochemicals because it affects agricultural processes most especially in the areas of pest resistance and resurgence. The development and use of agrochemicals have greatly helped in keeping up with world food demands, but the effects they have on plant and animal life, the integrity of our soil and water, as well as the health of the environment as a whole should not be overlooked. Mankind cannot do without farming the land for his food and livelihood, but in tackling the problems of hunger and nutrition, attention must not only be paid to boosting food production, improving livelihoods and creating resilient food systems, but also to protecting and sustaining our natural ecosystem and resources.

Biodiversity is connected with the natural environment and human activities play an important role in biodiversity conservation. The output from these activities pollute the air, land, and water and causes serious damage to the ecosystem and health hazards to organisms in the environment. Human-related issues, such as pollution, soil degradation, over population, climate change, and deforestation, are some of the negative impacts impeding the preservation and conservation of the environment. Africa is an agricultural-dependent continent and is, thus, prone to the negative impacts of the excessive use of agrochemicals on the environment. Therefore, it is vital to understand the risk and challenges of application of agrochemicals in order to safeguard biodiversity and preserve the environment. Also, laws and regulations on the use of agrochemicals must be strictly adhered to. There must be proper registration and labeling of products to provide adequate information about the nature of the agrochemicals. Policy framework approaches must be developed and expected to incorporate optimal interaction between stakeholders, actors, farmers, and all connected with the value chain. This framework is expected to generate interaction, predict outputs, and comprise policy input and objectives, implementation processes, and output sections.

Lastly, the advocacy on a safer and more sustainable alternative to agrochemicals is the use of biopesticides, sustainable agriculture approach, and organic farming. These approaches incorporate the use of plant materials and excludes the use of synthetic chemicals for agricultural activities. Although the results from these processes may be slow when compared with the use of chemicals, they help protect the environment. Sustainable organic farming which incorporates ecology and environmental protection in its practice is a holistic way for optimal protection of the environment. It produces quality food without adverse effect on the health of human, soil, and ecology. Essentially, there is a dire need to intensify sustainable practices that help preserve the environment and protect biodiversity by identifying and implementing sustainable solutions. This will enhance biodiversity conservation and eliminate externalities from the intense use of agrochemicals.

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Chapter 11
Fish Production and Biodiversity Conservation: An Interplay for Life Sustenance

Omoniyi Michael Popoola

Abstract Biodiversity conservation is one of the vital concerns towards ensuring the longstanding viability required for natural resource utilisation. The diverse nature of both flora and fauna contributes to each of the key elements of food security, namely availability, access, usage, and stability. Globally, a few million species have been recognised, but the true number of species is believed to reach 30 million on average. This vast and valuable biodiversity is a vital source of ecosystem goods and services for humanity. Nigeria's aquatic germplasm resources include a diverse range of organisms from both fauna and floristic origin, although it is mostly species of finfish and shellfish with existing and prospective importance in both capture and aquaculture fisheries. These aquatic resources offer enormous promise for enhancing the genetics of farmed aquatic species and contributing to the nation's economic well-being. Regardless of how vital biodiversity is in our everyday lives, all of the species that make up biodiversity are in grave danger as a result of anthropogenic influences. This review evaluates technology, sophisticated genetic techniques, and operational strategies relevant to aquatic biodiversity preservation, as well as future research potential for sustainable fish production to fulfil national food demands.

Keywords Nigeria · Food security · Aquatic resources · Biodiversity · Sustainable fish production

11.1 Introduction

Fish production has a vital role in assuring a consistent supply of food fish, generating revenue and employment, earning foreign cash, and providing recreational advantages. The most critical component that is directly connected to food security challenges is the dependability of the fish supply. Production prospects are

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taken into account as a key factor in addressing food security issues, but the problem of production sustainability is given special attention. The function of fish in food security may be defined as a situation in which all homes have physical and economic access to sufficient quantities of fish for all members of the family, and where this access is not threatened. Pressures on the aquatic environment have resulted in resource deterioration and a negative influence on the ecosystem during the past three decades. How to limit negative impacts on resources, the environment, and fisheries sustainability will be a big problem. To make fish production cheap, sustainable capture fisheries and aquaculture development strategies are required.

11.1.1 Fish Production and Food Security

Fisheries are an important part of the global food economy, as well as a source of employment for approximately 200 million people who rely on ocean fishing for a living (Gareth 2001). Poverty and socioeconomically disadvantaged homes are unable to obtain enough nutritious food to maintain their health and well-being. Food is frequently made or acquired in the form of grains or low-cost staple items, as budgets do not allow for meat or fresh fruits and vegetables. Apart from the substantially greater protein levels, and several other critical minerals and vitamins, fish produced by aquaculture is usually thought to be cheaper than other animal flesh. Increased availability of fish can imply improve health and a more variety diet for many disadvantaged households as a method of giving more nutrition. Fish is the primary source of high-quality protein for 950 million people throughout the world, and it is an essential element of the diet of many more. For the period from 1970 to 2010, research has revealed that there is a link between population expansion and total fish consumption (FAO 2000; Delgado et al. 2002; Tacon 2003). The world's average per capita intake of fish has nearly doubled in less than 50 years (The WorldFish Center 2003). Fish is a significant source of minerals and vital fatty acids and contributes around 16% of the animal protein consumed by people globally. In the human diet, fish is the principal source of omega-3 fatty acids which are essential nutrients for baby brain and eye development, as well as for the prevention of a variety of human disorders such as cardiovascular disease, lupus, depression, and other mental illnesses (Crawford and March 1989).

Industrial aquaculture indirectly contributes to greater food security by providing local populations with options for employment and revenue generating. According to reports, more than 500 million people in the third world rely on fisheries and aquaculture for their survival. Because aquaculture is mostly produced in underdeveloped countries, increased wealth leads to increased food purchasing power and, more crucially, diversification. Non-staple food intake, such as fish and vegetables, has a positive relationship with income development, implying increased food security and nutritious richness in diets.

11.2 Threats and Weaknesses in Food Fish Production

From political and economical viewpoint, the production of high-value, high-trophic food fish continues to receive the most support. Farmers are being enticed to shift away from low-value food fish for domestic consumption and towards high-value fish for export as demand and wages rise. Because many high-value food fish are carnivorous, aquaculture relies heavily on the capture of tiny or low-value fish species in the wild, commonly known as "trash" fish.

The extraction of wild fish for non-human use (i.e. fishmeal, fish oil, and farmed fish feed) is increasingly being questioned due to its lack of sustainability and resource consumption. Capturing tiny fish for the purpose of producing feed poses a dilemma for sustaining balanced marine ecosystems and food webs for larger predators. The use of caught fish species for fish farming has the potential to produce future conflict, with 70% of ocean fisheries in need of immediate management and 50% of these currently completely exploited.

Every year, over 30 million tonnes of harvested fish are used in making fishmeal and fish oil. Small pelagic marine fish such as sardines, anchovies, sand eels, herring, and mackerels are used to make feed. At present production rates, human consumption and animal feed requirements are expected to compete in the future. Although the amount of fish consumed by humans has increased dramatically during the 1990s, the usage of fish feed in aquaculture has also increased significantly in the previous two decades. These smaller fish are unfit for human eating due to the methods employed to collect and store them, but the ongoing rise of aquaculture output means that removing junk fish from the seas is unsustainable.

Getting a suitable feed source is a top goal for researchers throughout the world.

Commercial aquaculture has superseded poultry and cattle as the primary user of fish-based animal feeds. Many producers rely on carnivorous species with high trophic levels while focusing on high-value fish species. Because this business is reliant on exports, it is necessary to lessen reliance on catch fisheries for feed raw materials. Small-scale farming, on the other hand, is limited by feed availability and cost, confining small-scale farmers to low-trophic species that are more popular in local markets.

11.3 Aquaculture Production Systems

Aquaculture is a developing, active, and significant high-protein food producing industry. In 2008, worldwide aquaculture output of food fish, comprising finfish, crustaceans, molluscs, and other aquatic creatures for human consumption, reached 52.5 million tonnes. Aquaculture's contribution to overall catch fisheries and aquaculture output increased, growing from 34.5% in 2006 to 36.9% in 2008. The Food and Agriculture Organization of the United Nations (FAO) defines aquaculture as follows: "Aquaculture refers to the farming of aquatic species such as fish, molluscs, crabs, and plants". Farming entails intervening in the raising process to improve productivity, such as regular stocking, feeding, and predator protection. Individual or corporate ownership of the cattle being farmed is also a part of farming. "Aquatic creatures gathered by a person or corporate organisation that has owned them throughout their growth phase contribute to aquaculture for statistical reasons" (FAO 1997). Through the control of a variety of organisms' full life cycles, current aquaculture technology allows for the economic and practical production of a variety of creatures. The "seed" materials (larvae and juveniles) are created under controlled conditions, beginning with broodstock development, eliminating the requirement for juveniles to be collected from the wild. Aquaculture necessitates a complete knowledge of each species' behaviour, habitat and environmental needs, reproductive biology, dietary requirements, larval and juvenile physiology, and disease susceptibility under culture conditions. Furthermore, it entails the creation of all areas of fish husbandry, including the facilities needed for various life cycle phases, such as broodstock holding tanks/sea cages, nursery tanks/cages, grow-out facilities, feed development, fish handling methods, and disease management. For a variety of marine fish, estuarine and freshwater fin fish, and shellfish, such processes and approaches have been established.

Aquaculture has a variety of goals, including the production of low-cost protein-rich, nutritive, palatable, and easily digestible human food, the introduction of new species, and the improvement of existing fish stocks in natural and man-made water bodies through artificial recruitment, the production of ornamental fish for aesthetic appeal, and the efficient use of aquatic and land resources. Another goal has been proposed is the recycling of organic waste from humans and cattle. Providing a source of income through commercial and industrial aquaculture, and the production of sportfish and support for recreational fishing are all included.

11.4 Systems of Aquaculture

Aquaculture methods are classed in a variety of ways, based on the many components and circumstances involved. The classification on the basis of enclosure utilised for culture will be evaluated for the reason of conservation.

11.4.1 Pond Culture

This is the most widely used form of fish farming. In this situation, water is kept in a contained region by artificially constructing a dike/bund, which is used to stock and develop aquatic species. Rain, canal water, and man-made bores are the most common sources of water for ponds (Fig. 11.1). They vary greatly in shape, size, geography, water and soil quality, and are typically built near a moving water source.

Fig. 11.1 Ponds in fish farming

Fig. 11.2 Cage system of aquaculture

When there is flooding, many stocks have fled the pond enclosure and into nearby water bodies, increasing the pond embarkment.

11.4.2 Cage culture

Cage culture is the growing of fish from juvenile to commercial size in a volume of water that is contained on all sides, including the bottom, yet allows water to circulate freely (Fig. 11.2). Cage culture is easily adaptable to non-drainable water locations. Fish culture in cages is a novel way to take advantage of the potential of lakes, reservoirs, and riverine pools. Almost every cultivable species of fish, such as carps, tilapia, trout, catfishes, and others, may be cultivated in cages in theory, based on socioeconomic, ecological, and technological fit. Nonetheless, the system necessitates. The stock is sensitive to external water quality concerns, such as algal blooms and low oxygen, and the stocks might be consistent with local invasion of the organisms and water bodies that contained it.

11.4.3 Pen Culture

Pen culture is described as the rearing of fish in a volume of water that is covered on all sides except the bottom and allows water to circulate freely from at least one side. This approach may be thought of as a cross between pond and cage culture. Mostly shallow areas along the coasts and banks of lakes and reservoirs are utilised to construct fish-raising pens/enclosures utilising net/wooden materials. The bottom of the lake serves as the bottom of the fish enclosure. Pens have the benefit of holding a benthic fauna that provides food for the fish, and polyculture may be done in pens just like it can within ponds. A free interchange of water with the enclosing water body and high dissolved oxygen concentrations define the environment in the fish pen (Fig. 11.3). Because of the high stocking density in a confined space, any illness that starts would spread fast, causing massive stock death and productivity reduction, as well as structural damage, which might allow disease spread to native species.

11.4.4 Raceway

The term "raceway culture" refers to the practice of growing fish in moving water. It is a high-yielding strategy in which fish are stocked at a higher density. Raceways are built with a flow-through system in mind, allowing for the raising of a much huge population of fish. As there is no efficient perfect, this also allows for escapes.

11.5 The Effects of Aquaculture on Biodiversity

Regrettably, the aquatic fauna of the United States is in danger of extinction; up to 70% of all freshwater mussels, 49% of freshwater fish, 30% of plants, and 20% of animals are in danger of extinction (Master et al. 1998). Several studies suggest that

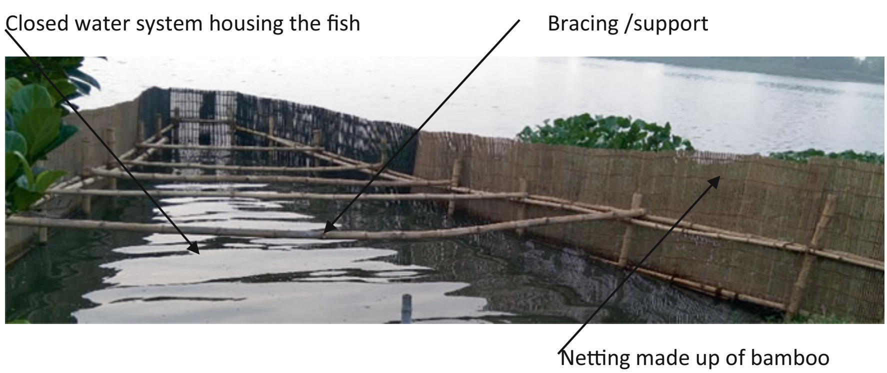


Fig. 11.3 Pen arrangement for fish farming

invasive species, habitat loss, pollution, and exploitation are to blame for the majority of animal extinctions (Wilcove et al. 1998). As a result, it is critical to assess not just endangered species but also the spread of invasive species in order to predict future trends in aquatic biodiversity.

11.6 Mitigation

Environmentally friendly aquaculture system certification has been proposed by Clay (1997) and New (2003) as a way to ensure safe aquaculture operations. Boyd et al. (2005) reviewed a number of species groups and environmental consequences in an assessment of aquaculture concerns that certification should address, concentrating on negative effects that certification programmes should attempt to diminish. Many species' potential environmental impacts from conventional aquaculture systems were graded medium or high, while not all of the negative effects would have an impact on biodiversity (Boyd et al. 2005). There is presently no objective way for comparing and ranking the effects of aquaculture on biodiversity. As a consequence of the variety of aquaculture systems and advancements in management, most effects have both positive and negative components or trends. The following harmful effects have been recognised as threats to biodiversity aquatic conservation based on aquatic biodiversity studies and trends: (1) Farmed fish that have escaped and are in risk of becoming invasive. (2) The relationship between effluents, eutrophication of water bodies, and changes in the fauna of receiving waters. (3) The conversion of sensitive land areas, including mangroves and wetlands, as well as the usage of water. (4) Other resource use, such as the overfishing of fish stocks as a result of fish meal consumption. (5) Disease or parasite transfer from captive to wild populations. (6) Current stocks have been genetically modified as a result of escaping hatchery products. (7) Predator mortality caused by the murder of birds near aquaculture operations, for example. (8) The use of antibiotics and hormones, which may have an influence on aquatic creatures in close proximity to aquaculture operations.

11.7 Negative Implications of Aquaculture on Conservation of Aquatic Biodiversity

11.7.1 Escapement and Genetic Alterations of Wild Stocks

The negative impact of adding species or changing genotypes on biodiversity is likely the most significant aspect of aquaculture as a biodiversity influence. General qualities of successful invading species, according to Ricciardi and Rasmussen (1998), include a wide starting range, great environmental tolerance, high genetic diversity, short generation time, rapid development, and early sexual maturity. Since virtually all of these characteristics are beneficial for farmed fish, many aquaculture species have the potential of becoming invasive. The most invasive species example for the detrimental effects of aquaculture is tilapia, which has invaded numerous continents and displaced many local species. Despite the difficulty of getting reliable information on the sources of most introductions, more than half of reported tilapia introductions were the result of governmental entities purposely stocking tilapia in natural waterways rather than commercial farming (Canonico et al. 2005). When aquarium pets are released into water bodies for purposes other than aquaculture, many other types of fish are introduced. Aquaculture did not cause the majority of invasive fish incursions, although it did help. Only one of the foreign fish species introduced in the Laurentian Great Lakes region was the result of aquaculture (Mills et al.1994; Canonico et al. 2005). Similarly, the very contentious introduction of grass carp (*Ctenopharyngodon idella*) and other Asian carps to North America began when government laboratories began to cultivate and use them for biocontrol purposes instead of large-scale fish farming (Mitchell and Kelly 2006). Because of the nature of aquaculture, the genetic effects of domesticated animals discharged from fish culture in their natural environment are limited. Most aquaculture species are essentially natural, but others have been selectively bred for qualities, such as early maturation, quicker growth, or other characteristics. In numerous species, hybridisation or polyploidy has resulted in infertile individuals. The simplest way to minimise invasive species' detrimental impacts is to avoid farming species that are not native or unique to their region.

11.7.2 The Effects of Effluents on Water Quality

The pollution of receiving water bodies produced by effluent from fish production systems is the second major negative impact of aquaculture on aquatic biodiversity. This has been a cause of concern for a long time, especially in the cage and pen society (Goldburg and Naylor 2005). Wastes are treated and released into water in the hopes that the water will assimilate them into primary or secondary output. Fish farming, like other methods, generates waste, which is assumed to be digested by natural processes. Because aquaculture wastes may be rather large, the potential impact of these wastes is an important issue. The waterways where cage or pond culture waste is disposed of have a considerable influence on the trash's impact. In research, fish farming discharges have been shown to increase local biodiversity in oligotrophic waterways (Soto and Norambuena 2004). In regions near cage or pond culture fish farms, Machias and colleagues (2005) discovered an increase in pelagic and benthic fish species and productivity. Invading species may also be to fault, albeit increasing species richness does not always mean enhanced biodiversity (Scott and Helfman 2001). The assimilative capacity of water may be surpassed by aquaculture demands in situations with high cage densities and numbers of fish in cages. Aquaculture systems, particularly in underdeveloped nations, continue to discharge unclean water. Using settling ponds to sequester particles and oysters to extract suspended contaminants are two common pond effluent treatment technologies. Pollution of nearby rivers, which feed aquaculture systems, puts the industry in jeopardy. Water released from ponds has a much lower quality than water received by downstream facilities.

When intensive culture first took hold, pollution was a major issue. More effective feeds and feeding methods have been developed to solve these difficulties.

11.7.3 Sensitive Land Conversion

Another influence on biodiversity is land-use change linked to aquaculture. The apparent negative impact of shrimp farming in particular has received a lot of attention (Boyd and Clay 1998); some environmental organisations have even suggested boycotting farmed shrimp products. The loss of mangroves to create room for ponds is one of the most significant accusations levelled towards shrimp aquaculture. Furthermore, land is removed and seawater is carried ashore, resulting in soil salinisation. When the intensity of shrimp production grows, disease outbreaks and other factors cause certain aquaculture systems to fail. Ponds may be abandoned if they fail, and owing to soil salinisation, the changed area cannot be returned to a regular production process. Other major concern with shrimp farming is the abandonment of shrimp ponds and the conversion of mangrove habitats to barren areas (World Bank et al. 2002). Shrimp culture production has doubled from 72,000 metric tonnes in 1980 to 2.5 million metric tonnes now. Mangroves have been lost in substantial numbers, although shrimp aquaculture is responsible for less than 10% of worldwide mangrove loss. Increased production of shrimp has been connected to the abandonment of damaged shrimp ponds and a lack of land conversion options, according to many studies.

11.7.4 Inefficient Resource Use

Also, the usage of fish meal and fish oil in the production of meals is a challenge. Over 28.3 million metric tonnes of seafood, including 5.2 million metric tonnes of fish meal, were harvested in 2003 for uses other than human and animal consumption (Tacon et al. 2006). Aquaculture consumed around 46% of the fish meal and 80% of the fish oil production in 2002 (Tacon et al. 2006). Fish meal consumption is likely to climb much more in the future, given current rates of aquaculture growth and the rising importance of intensive aquaculture (Delgado et al. 2003). In 2003, for example, salmon aquaculture utilised 10.3% of fish meal output, while shrimp aquaculture consumed 12.1% (Tacon et al. 2006). Fish meal, on the other hand, is a limited resource, and most fish stocks have already been exhausted (Delgado et al. 2003). Because fish meal is made up of a range of catch species, overfishing affects biodiversity. Fish meal is commonly made from small pelagic fish species, reducing the quantity of food accessible to larger predatory fish at sea. Feeds are now created from by-products of the fish carcass that are not meant for human consumption to replace fish meal. In 1999, by-products were estimated to be worth 372,000 metric tonnes in Norway alone, suggesting that this resource may be used to make future aquaculture feeds.

11.7.5 Disease or Parasite Transfer from Captive to Wild Stocks

Another detrimental effect of aquaculture is the transmission of diseases or parasites from farmed fish to wild fish stocks. These difficulties, as well as concerns regarding antimicrobial resistance originating from antibiotic use in culture, have long been discussed but never demonstrated. Krkosek et al. (2006, 2007) presented mathematical and empirical data to support the transfer of sea lice from captive to wild salmon and to predict that transmission causes considerable mortality in infected wild salmon. As a result of this research, other field studies and models have been established, which predict the extinction of more salmon populations (Ford and Myers 2008). It has been reported that if outbreaks of disease continue, local extinction is a certain conclusion (Krkosek et al. 2007). Extinction predictions for pink salmon in British Columbia's Broughton Archipelago contradict previous models and actual data (Brooks and Jones 2008). These studies have received scathing criticism from both sides of the debate. As a result of Atlantic salmon being bred in cages along the migratory path, the prevalence of sea lice in pink salmon appears to be increasing. The magnitude of the infestation and its influence on salmon mortality are still up for dispute.

11.8 Positive Impacts of Aquaculture

The depiction of aquaculture as entirely negative is distorted, as some of its effects on biodiversity may be positive. Fish farming, for instance, could help ease strain on wild fish stocks, which may already be depleted. By restoring depleted populations with poor reproductive success, aquaculture effluents and waste can enhance local productivity, abundance, and species diversity. Destructive land-use patterns, like slash-and-burn agriculture, might be substituted with more sustainable land-use patterns, such as pond aquaculture, which could generate revenue, reduce poverty, and improve human health. Aquaculture fish can be sold in place of wild-caught fish, decreasing pressure on native populations and increasing biodiversity.

11.9 Global Freshwater Fish Biodiversity

Around 27,977 surviving fish species in 515 families and orders have appropriate scientific reporting (Nelson 2006). At least one species in one-third of all fish families usually spends some of its time in freshwater. Freshwater fish variety is high compared to other systems since freshwater water bodies represent just for 1% of the earth's surface and 0.01% of its water.

Nelson (2006) claims that 11,952 species can only be found in freshwater, meaning that the tropics have the greatest species, and the diversity of fishes increases as one travels from the poles to the tropics. There is just one species in some Arctic lakes, for example, the Arctic char, *Salvelinus alpinus* (Johnson 1980), yet Lake Malawi has at least half a million Cichlidae species (Craig 1992).

Fishes from freshwater are most plentiful in Southeast Asia, South America, and Africa, yet many are still unidentified. For example, the Amazon Basin has about 2000 species, the Mekong Basin has around 1200, and the Zaire system has about 900. According to FAO estimates, inland catch consists of just about 100 fish species or species groupings. In this way, the lack of information at these levels makes quantifying the worth of individual species and species groups as inland fisheries resources problematic.

11.10 FAO's World Major Fishing Areas

Lakes, rivers, brooks, streams, ponds, inland canals, dams, and other land-locked (typically freshwater) waterways are all included in the phrase "inland waters" (Fig. 11.4) (such as the Caspian Sea and Aral Sea). Too far, the Food and Agriculture Organization (FAO) of the United Nations, Rome, has identified 27 significant fishing regions for statistical reasons. There are eight major inland fishing zones that encompass the continents' inland waterways, and 19 large marine fishing areas that cover the Atlantic, Indian, Pacific, and Southern Oceans, as well as their nearby seas. The names of the major inland and marine fishing zones, as well as two-digit codes, are used to identify them.

11.10.1 Africa Freshwater Fishery and Major Fish Species Composition

Africa stands in second position in the world inland fish production. This region is further subdivided as

1. **North Africa**
   (a) **Major countries:**

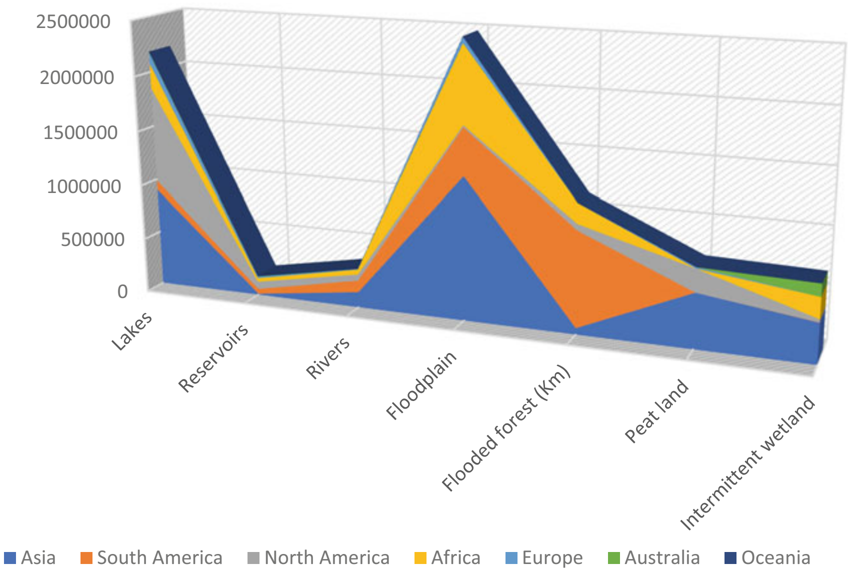


Fig. 11.4 Major surface freshwater resource distribution by continent. (Adapted from Nachtergaele et al. 2011)

Egypt, Algeria, Morocco, Libya Arab, etc.

(b) **Major fish species:**

Freshwater fin fishes such as carps, fraud, and cells. In Egypt, common carp, Nile tilapia, mullets, etc. can be seen. In Morocco, silver carp, grass carp, etc. are present.

2. **Sub-Saharan Africa**

(a) **Major countries:**

Ethiopia, Ghana, Nigeria, Kenya, Tanzania, Uganda, Zimbabwe, Mali, Malawi, Senegal. The most important producers are Magenta, Madagascar, Tanzania, and South Africa.

(b) **Major fish species:**

Tilapia (*Oreochromis* sp.), African catfish, cyprinids.

11.11 Most Commonly Cultured Freshwater Fish Species in Africa

11.11.1 Nile tilapia and perch

Tilapias, often known as cichlids, are a kind of fish that originated in Africa and the Middle East. Because of its flexibility, tilapia has acquired the title “aquatic chicken". Only Chinese carp, salmon, and trout outweigh tilapia in terms of world fish production. Tilapia has eclipsed trout as the most popular economically farmed fish. The Nile perch, Lates niloticus, and a newly imported tilapiine species, Nile tilapia, Oreochromis niloticus, currently constitute the foundation of the fisheries of Africa's Lakes Victoria and Kyoga.

11.11.2 Clarias gariepinus

Drawnets are used to catch one of Africa's most lucrative freshwater species. The FAO estimated a total catch of 27,220 tonnes for this species in 1999. The biggest catches were in Mali (15,091 tonnes) and Nigeria (15,091 tonnes) (9994 tonnes). It was brought in to help with aquaculture and game fish. It may be grilled, fried, or baked, and it could be offered live, fresh, or frozen.

11.12 Inland Fisheries Production

Inland fisheries play an important role in the lives of many people across the world, in both industrialised and developing countries. Inland fisheries supply high-quality protein, critical nutrients, and minerals that are scarce elsewhere on the planet. Inland fisheries provide a "safety net" for developing communities, allowing food production to continue even when other industries fail. Inland fisheries are employed for enjoyment rather than food production in developed countries and a growing number of developing countries, providing another option for socioeconomic advancement. On the other hand, little is known about the state of inland fisheries resources and the ecosystems that sustain them. As a result, perceptions of many resources' genuine status have evolved. According to one viewpoint, the industry is experiencing major problems as a consequence of various uses of inland water bodies and the threats they face. According to the contrary opinion, the industry is growing and much of the output and development has gone unreported. According to FAO data, global capture fisheries output climbed by 1.6 million tonnes between 2004 and 2008, reaching a record high of 10.2 million tonnes in 2008.

11.13 Exotic Species Introduction

Biotic invasions are destroying local biodiversity, ecological processes, human health, and regional economies at an alarming rate throughout the planet. The gradual but subtle replacement of native biotas by non-indigenous species is generating "biotic homogenization", resulting in the loss of regional distinctiveness and the extinction of local species throughout the planet. The pace of homogeneity in freshwater systems is particularly evident. According to the Union of Concerned Scientists, “the rising introduction and spread of invasive species is one of the most serious threats to world biodiversity” (2003).

11.13.1 Ways by Which Exotic Species Affect Native Species

1. The effects of non-indigenous fish species on native fish species include extinction of native species due to competition for food, sex, and other resources, as well as predation on them.
2. Contribution to a reduction in local biodiversity.
3. Bring with them novel parasites and pathogens into the invaded area, thus causing havoc to them.
4. Through mating or by hybridising, there is possibility of eroding or diluting local genetic diversity with the indigenous species.
5. Habitat is altered in ways that render it unsuitable for the local species to thrive.
6. There are economic losses as a result of reduction in ecosystem productivity.

11.13.2 Signs of Invasiveness Possibility

The success of an introduced species in becoming invasive and destructive to native species and ecosystems is determined by both the species’ qualities and the invasion site’s attributes. Indicators of possible invasiveness in a species include the following characteristics.

1. strong physiological tolerance
2. distinctive features not seen in the invaded group
3. ecological adaptability
4. high population growth rates, which coincides with high fecundity and short generation time

11.13.3 Characteristics Making a Region Vulnerable to Biological Invasions

Similarity to the source area, presence of unfilled or underused niches, low native species richness, and anthropogenic disruption of the ecosystem are all features that make a habitat or a geographic region more prone to biological invasions. Extreme changes in soil properties, frequent fires, grazing, fertiliser inputs, hydrological shifts, and habitat fragmentation are just a few of the human activities that make a place vulnerable.

Many non-indigenous species that turn out to be invasive in the imported region are often harmless in their native range, which ecologists find perplexing.

11.13.4 Inadvertent (Accidental) Introductions

The most common method of inadvertent introduction for aquatic invaders is ballast water carried by transoceanic cruise ships. Ballast water was said to be a primary avenue for non-indigenous organisms to establish themselves in North America's Laurentian Great Lakes. For a wide range of aquatic creatures, from ciliates to fish, it is the most common means of dissemination. Although non-indigenous zooplankton may not be a substantial source of exotic fish introductions, non-indigenous zooplankton may directly harm native fish by affecting the trophic dynamics of invading water bodies.

11.13.5 Deliberate Introductions

Several reasons are usually offered for introducing a new species into a lake or river; some of the reasons are itemised:

1. Create new fisheries that are more resistant to overfishing or have a higher economic value than existing fisheries. New species are introduced into recreational fisheries to broaden the range of species available to anglers or to introduce a trophy or sporting value species to a specific location.
2. Fill a "empty trophic niche" if present species are not fully using the trophic and geographical resources available.
3. Pest control—pests and disease vectors have been biologically managed using a number of species.
4. When enough phytoplankton-eating organisms are missing, control water quality in eutrophic situations to eliminate excessive algae.
5. Promote aquaculture—one of the key causes of species movement throughout the world is still aquaculture. Many different species have been introduced to be farmed. Escapes from aquaculture operations have resulted in several successful wild introductions.

The main variables that contribute to the introduction of exotic fishes into aquaculture may be essential if indigenous species' development is inadequate or they do not reproduce in limited waters. Improve the sport fishing sector—the recreational introduction of alien fish has resulted in the demise of several native fish species throughout the world. Ornamental species have spread widely over the tropical world as a result of escapes from breeding facilities and aquaria, for aesthetic and other reasons. Some species have been introduced for religious or cultural reasons as well.

11.13.6 Challenges to Global Fish Introductions

While general interest in finding target species that have or might reach mass cultivation success, particularly during the 1950s and 1960s, led in fast development of aquaculture, fish introductions throughout the world have produced spectacular triumphs and disasters. According to Wilcove et al. (1998), industrialised countries in temperate zones with stringent environmental and biodiversity legislation are more likely to permit species introductions that cause no or minor damage to natural systems. The opposite is true for countries in the world's emerging regions. In the latter example, there were far more beneficial socioeconomic gains than negative environmental consequences. Invasive species, for example, account for around 17% of global finfish productivity. African Tilapia production is substantially higher (about 20–25 times) than that of other African countries combined. In Chile, introduced salmonids sustain a booming aquaculture business that produces over 20% of the world's farmed salmon and employs roughly 30,000 individuals directly. As a result, the scale used to assess the "success" or "failure" of a certain introduction becomes subjective. The problem is not to outright prohibit fish introductions or to wilfully disregard management of their movements. The challenge is to clearly define the dangers and advantages connected with them, and then establish and implement a plan for their responsible use, if necessary.

11.14 Impacts of Exotic Fish Species

11.14.1 Impacts of Introduced Species

1. Ecological (including biological)
2. Genetical
3. Socioeconomical

Direct encounter with invasive species or increasing fishing pressure may cause ecological or genetic changes. According to the US National Oceanic and Atmospheric Administration, increased fishing pressure or changes in usage patterns caused by the presence of newly established species can have an influence on native species (NOAA). The most often reported explanation, according to the database, was aquaculture development. The bulk of known ecological and genetic consequences in open waters, however, is negative.

11.14.1.1 Ecological Impacts

Competition between exotic and native fishes for living space with similar niche preferences, for food with similar kinds of feeding habits, or omnivorous habitat eating all other species' preferred food, predation on native fishes, and the spread of parasites and pathogens are some of the most common ecological concerns. The African catfish *C. gariepinus* was introduced in India; however, the increased interest in cultivating this exotic catfish poses a major threat to natural stock of other species. The African catfish, according to study in the biology of this peculiar catfish, is a ferocious predator. The African catfish *Clarias gariepinus* (Burchell) was brought into Thailand and Vietnam and is being used to interbreed with the local walking catfish *C. macrocephalus* (Gunther). The hybrid is widely cultivated and valued by Thai farmers because of its much faster growth rate than the indigenous species and good meat quality. Only Thailand produces hybrid catfish, accounting for more than 17% of worldwide catfish output in recent years (FAO 2002). In 2002, the Nile tilapia was Asia's sixth most produced freshwater species, and it must be regarded Asia's most important intercontinentally imported aquaculture species.

For more than four decades, tilapia has been employed in sewage-fish culture systems in India, with no reports of disease transmission among clients or considerable mortality among cultured stocks (Nandeesha 2002). There is no indication that this influx has had an impact on the biodiversity of the region (De Silva et al. 2004).

China is the top producer of farmed tilapias in Asia, and it is the only foreign species that is now relevant for aquaculture in this country. Nonetheless, tilapias make a tiny contribution to overall inland output in China, whereas they make a much larger percentage output in the Philippines and Sri Lanka.

11.14.1.2 Genetic Impacts

The genetic effects of exotic fish introduction on native fish can be divided into two categories: • Decrease in effective population size caused by genetic effects of introduction in addition to ecological and biological factors • Alteration/extinction of gene pools of species/stocks due to crossbreeding, hybridisation, and backcrossing. Crossbreeding is the interbreeding of distinct stocks, whereas hybridisation is the interbreeding of different species or genera.

11.14.1.3 Socioeconomic Impacts

The socioeconomic consequence is visible on two different levels: (1) capture fisheries and (2) aquaculture. Because alien fishes never command a greater price than native types, and because the presence of exotic species in natural waterways reduces native fish output, the total economic return for stakeholders in capture fisheries decreases. Conversely, in most situations, it gives instant benefit without regard for long-term ecological effects in aquaculture.

11.15 Efforts to Regulate Introductions at the International and National Levels

11.15.1 Institutions Responsible for Monitoring of Exotic Aquatic Species

It should be acknowledged that aquaculture is the ultimate measure in the production of edible fish. Species introductions will continue to be a viable option for increasing aquaculture and fisheries productivity and profits. To address the issue of species introductions, a proportion of global, regional, and national institutions have been formed. They are as follows:

1. World Trade Organization (WTO).
2. The World Organization for Animal Health is a non-governmental organisation that promotes animal health (OIE).
3. The International Council for the Exploration of the Sea is a non-profit organisation dedicated to the study of the sea (ICES).
4. United Nations Food and Agriculture Organization (FAO) (Code of Conduct for Responsible Fisheries).
5. NACA/SEAFDEC/ASEAN Regional Initiatives.

11.15.2 Suggested Strategies to Be Followed While Introducing Exotic Fish Species

- Fish introduction should be avoided as much as feasible, and efforts should be made to boost native species production using biomanipulation or biotechnological approaches. More native species that can be grown profitably should be found and assessed as a top priority.
- If indeed the introduction is necessary, the greatest steps should be taken prior to its introduction, and it should not be permitted in natural water until a thorough investigation of the long-term influence on the ecosystem has been completed. Prior to allowing such introductions, ecological connections, genetic problems, socioeconomic implications, and probable disease infestation should all be properly investigated.
- A central body or panel should be established to investigate the planned introduction’s effects, risks, and benefits.
- Importing and cultivating broods or seeds of certain species that have been shown to be damaging to the native fauna and ecology should be prohibited entirely.
- For imported live specimen shipments in the ornamental fish sector, stringent quarantine precautions should be implemented. It must be guaranteed that they do not mistakenly escape into natural waterways, either from hobbyist aquariums or during shipping.

- Creating awareness of native types via training and education may motivate ornamental fish sellers and buyers to utilise them.
- Fish introduction or commerce that is prohibited or unofficially/illegally done should be punished by law. It is necessary to introduce comprehensive legislation.

The worldwide history and current state of alien species introduction in many nations, as well as analyses of their ecological, biological, and genetic impacts, clearly reveal that certain species have a detrimental influence. In addition to direct effects on eco-biological consequences, certain fish have gone extinct as a result of genetic variability and heterozygosity loss, hybridisation between alien and native species, and other factors.

11.16 Conservation of Inland Fish Biodiversity

With world's rapid development, population explosion, and ever-increasing demand for fish as a protein-rich food, the many country's aquatic ecosystems are constantly under threat from anthropogenic stresses, such as habitat destruction, overexploitation, wanton killing of juveniles and adults, excessive water abstraction leaving insufficient water for fish, aquatic pollution, diseases, and uncontrolled exotic introduction. Fish populations have shrunk due to overexploitation of fish resources combined with habitat loss. Consequently, of these circumstances several species of fish in certain traditional fishing sites are fast diminishing, and some have become endangered.

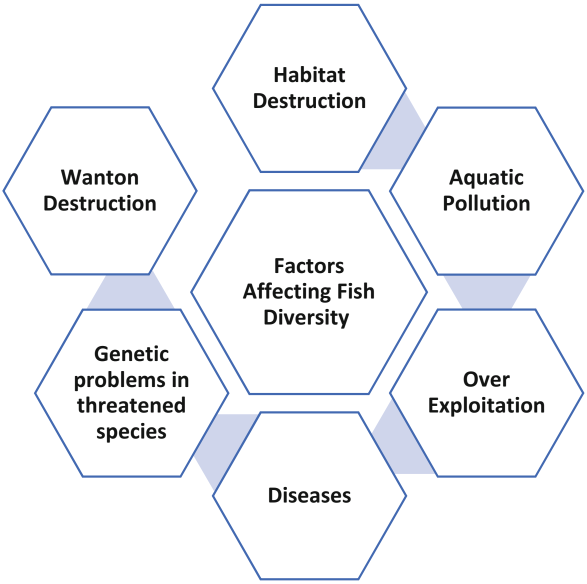
11.17 Factors Affecting Fish Diversity

Because of the country's rapid general growth and constant increasing demand for fish as a food source, water resources are always under stress from man-made pressures to the disadvantage of aquatic flora and fauna. Although this decreasing trend of individual fish species is frequently linked to multiple proximate factors, the possible causes of fish extinction in coastal habitats have been recognised as shown in Fig. 11.5.

11.17.1 Habitat Destruction

Siltation from catchment regions has ruined the feeding and spawning habitats of many fishes, in addition to affecting the environment owing to dam building. Fish habitats and local fish communities have been drastically altered as a result of power dams and reservoirs. Reservoirs, which are adverse for rheophilic species, have

Fig. 11.5 Factors affecting fish diversity



resulted in the loss of highland rapid flowing habitat. Excessive water loss from river courses for agriculture, household, and industrial applications, leaving insufficient water for pleasant fish life, is another primary cause of fish germplasm depletion.

11.17.2 Over-Exploitation

Over-exploitation of fishing resources, owning to their exceptional financially viable, has been a contributing factor in worsening the population's susceptibility. Tor spp. are disappearing at a quicker rate in highland waters, *Notopterus chitala* in warm waters, and *Lates calcarifer* in brackish water habitats.

11.17.3 Wanton Destruction

A number of food and game fishes in highland waterways have been impacted by indiscriminate dynamiting, electrofishing, and use of poison for brood fishes during spawning season.

11.17.4 Aquatic Pollution

Pollution is most likely the single most important cause driving large population declines in many fish species. These are wreaking havoc on genetic thresholds, which, in addition to their direct harmful effects, might result in lasting damage to genetic resources. Chemical contamination from factories and plants in the many industrial cities has wiped out several endemic fishes that formerly thrived in the area's aquatic environments.

11.17.5 Diseases

Among the range of various diseases caused by bacteria, fungi, and viruses, the most virulent and menacing one threatening many species is the Epizootic Ulcerative Syndrome (EUS).

11.17.6 Genetic Problems in Threatened Species

Natural fisheries decline and recovery are thought to be genetically caused by inbreeding, negative selection, and a lack of adoption; however, hatchery stock restocking programmes are unlikely to fully solve the problem because these stocks were selected for adaptation to hatchery conditions rather than natural habitats. Because genetic variety is a key feature in population dynamics that allows animals to adapt to changing environmental conditions, any loss of genetic diversity reduces evolutionary flexibility. As a result, organisms are less able to adapt to their surroundings, increasing the likelihood of extinction. Genetic bottlenecks, genetic drift, and homozygosity build-up are among the serious genetic issues that plague the tiny genetically effective population.

11.18 Strategies for Fish Biodiversity Conservation

The arguments for food security and biodiversity protection are both compelling. Is it possible to find a solution that does not put them at odds? There are undoubtedly technical changes that can be made to fishing and aquaculture techniques to lessen their ecological footprints and, as a result, their negative ecosystem consequences.

Concerns over the loss of aquatic biodiversity, as well as the possible social and economic ramifications, have prompted a variety of regional and national efforts to conserve and manage aquatic resources sustainably (Fig. 11.6).

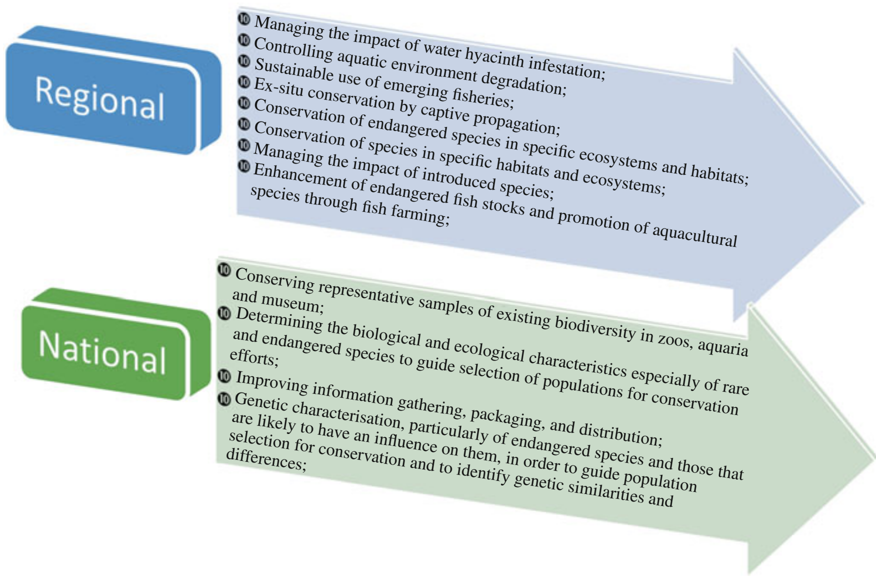


Fig. 11.6 Efforts towards conserving and management of aquatic resources

It is critical devising all available conservation and rehabilitation strategies in order to prevent future deterioration of our fish germplasm resources. The conservation policy should encourage management techniques that preserve aquatic ecosystem integrity, avert endangerment, and aid threatened species recovery. Some of these approaches include the following methods.

11.18.1 In Situ Conservation

In situ conservation is the technique of preserving and restoring viable populations of species in their native habitats, or, in the case of domesticated or produced species, in the environments where they have formed their unique characteristics (Article from the Convention on Biological Diversity 2) (Jena and Gopalakrishnan 2011). This method of conservation takes into account data on fish and habitat diversity, habitat use, life cycle characteristics, as well as human involvement and other socioeconomic factors (Jena et al. 2011). In situ protection of marine ecosystems is achieved by designating specific areas as Marine Protected Areas (MPAs), National Parks, Wildlife Sanctuaries, or Biosphere Reserves. MPAs protect not just depleted, vulnerable, uncommon, or endangered species and populations but also their ecosystems.

11.18.2 Ex Situ Conservation

This strategy is used to conserve species outside of their natural habitats, either by keeping the population alive in a genetic resource centre or by employing gene pools, gamete storage, and germplasm banks. In the case of fishes, as well as a number of other species, rapid freezing of gametes to ultralow temperatures has been shown to be efficient. For conservation and aquaculture sustainability, the ability to preserve fish milt, eggs, and embryos without losing viability is crucial. (1) The construction of a gene bank for the conservation of endangered fish genetic resources and the development of a gene bank for the conservation of endangered fish genetic resources are two advantages of cryopreservation. (2) Seasonal brooders have year-round access to gametes; (3) Germplasm may readily be moved over a geographical region. (4) Assists in the process of selection and hybridisation. Induced breeding in several cultivable species is complicated by insufficient milt production or asymmetry in the maturing of the two sexes. Milt-related difficulties can be solved with cryopreserved sperm. Teleosts and crustaceans' eggs and embryos have yet to be cryopreserved due to their large size, large volume of yolk, and stiff chorion with a low permeability coefficient. Fish cell lines, embryonic stem cells, and germ cells from Indian fishes, as well as cloning procedures, must be developed for long-term storage of fish eggs and embryos (Jena and Gopalakrishnan 2011).

11.18.3 Live Gene Banks

Live gene banks help delist vulnerable species by reproducing them in captivity and replenishing them in species-specific recovery programmes. The goals of live gene banks are to gather endangered, uncommon, and vulnerable fish species and maintain their populations on a farm as well as to study their growth, maturity, survival, and adaptability in controlled conditions, and to investigate their life cycle characteristics as a tool for both in situ and ex situ conservation (Jena and Gopalakrishnan 2011).

11.18.4 Tissue Preservation

This is a quick way to store biological material for longer periods of time without having to follow any species-specific methods, and it can be used to regain genetic information for hereditary adaptation experiments afterwards (Jena et al. 2011).

11.18.5 Breeding in Captivity

These programmes have become the primary method for replenishing diminishing populations, particularly vulnerable species, in their native habitat while also supplementing and increasing wild species yields. These procedures for captive breeding and larval rearing of various ichthyofauna have had a lot of success (Jena et al. 2011).

11.18.6 Aqua Ranching

This strategy is used to improve resources by seeding open waterways with desired aquatic species and providing them with proper built habitats so that the animals may defend themselves from natural hazards and grow to a level when predation and juvenile mortality are considerably reduced. This technique can be used to restock degraded resources, including lakes, streams, estuaries, and even seas (Rout et al. 2007).

11.18.7 Biomass Conservation

This includes the population's long-term viability. This may be achieved by creating safe zones in certain settings. This type of conservation will be crucial in reducing the pace of species extinction (Rout et al. 2007).

11.18.8 Translocation

Stripping wild fish, fertilising their eggs in the field, returning the broodfish back into the donor water body, and transferring the species as fertilised eggs, yolk-sac larvae, or juveniles into other water bodies to produce self-sustaining populations in case the original populations go extinct (Rout et al. 2007).

11.18.9 Control of Exotic Fishes

Exotic fish introduced indiscriminately may obliterate the indigenous ichthyofauna. When bringing a new species, it is crucial to evaluate the prospective species' biology, its genetics, and potential influence on native species in the natural habitat in order to minimise the potentially disastrous environmental and socioeconomic repercussions of the alien species' introduction (Rout et al. 2007).

11.18.10 Sustainability in Fish Harvest

Regulation of aquatic resources especially fisheries, exploitation in traditional fishing grounds, is required. To maintain a sustainable resource, brood fishes and juveniles must be preserved. To protect brood, there must be strictly enforcement in size limits for net and mesh. The use of dynamite and chemicals to kill fish at random must be absolutely prohibited (Rout et al. 2007).

11.18.11 Implementation of Closed Seasons

The term "closed season", sometimes known as a "biological rest period", refers to the prohibition of fishing during a fish's reproductive period. It is a method of lowering fishing pressure on stocks when they are at their most productive, allowing fish to lay eggs to restore the population lost due to fishing and other natural reasons. If a sufficient number of fishes remain to breed, the "closed season" can expand the supply available for fishing in just a few years by "preserving the pregnant fish". Other sorts of fishing pressure, such as the use of unlawful small mesh size nets, light fishing, poisons and harmful chemicals, and dynamite, will be most successful when a "closed season" is implemented.

11.18.12 Habitat Restoration

Based on the type of habitat degradation, situation-specific habitat restoration programmes must be implemented. In the case of sedimentation/siltation, for example, deforestation efforts must be halted promptly, along with a substantial afforestation programme in erosion-prone areas. Polluted water bodies require instantaneous attention, which can be achieved by maintaining strict adherence to pollution control regulations (Rout et al. 2007).

11.18.13 Mass Awareness

It is commonly established that the effectiveness of biodiversity conservation depends on raising public awareness about the diverse ecological, socioeconomical, nutritional, cultural, artistic, recreational, pharmaceutical, and other services available to mankind. As a result, every citizen bears responsibility for preserving declining diversity.

11.18.14 Geographic Information System

The use of GIS and remote sensing techniques has grown in importance in the analysis of natural resources, particularly water environments, and is now being utilised as a tool for fishery resources and conservation efforts.

11.19 The Interplay: Is There a Way Forward?

According to the research, there are opportunities for raising fish and aquatic invertebrates sufficiently to contribute considerably to global food security in a world with a growing human population. These alternatives do not come without a price tag. Almost all of the possibilities, if pursued aggressively, would work against growing global biodiversity protection agreements. Rice and Garcia (2011) highlighted some activities required to balance the food fish security and biodiversity conservation (Fig. 11.7).

11.20 Conclusion

If imbalance in the fish production and biodiversity could have ecological (disease, climate change, or overharvest), genetical and socioeconomic impact on both human and fish population, widespread starvation or malnutrition as well as ecologically unsecured environment could be the consequence. To preserve the long-term sustainability of our food fish supply, we must safeguard our natural biodiversity (from overfishing) and create new and improved aquacultural practices that pose little or no danger to natural stocks and the environment.

This can be accomplished by involving stakeholders in order to create collaborative and integrated partnerships that provide a future in which healthy and productive natural systems provide long-term services to people and the environment.

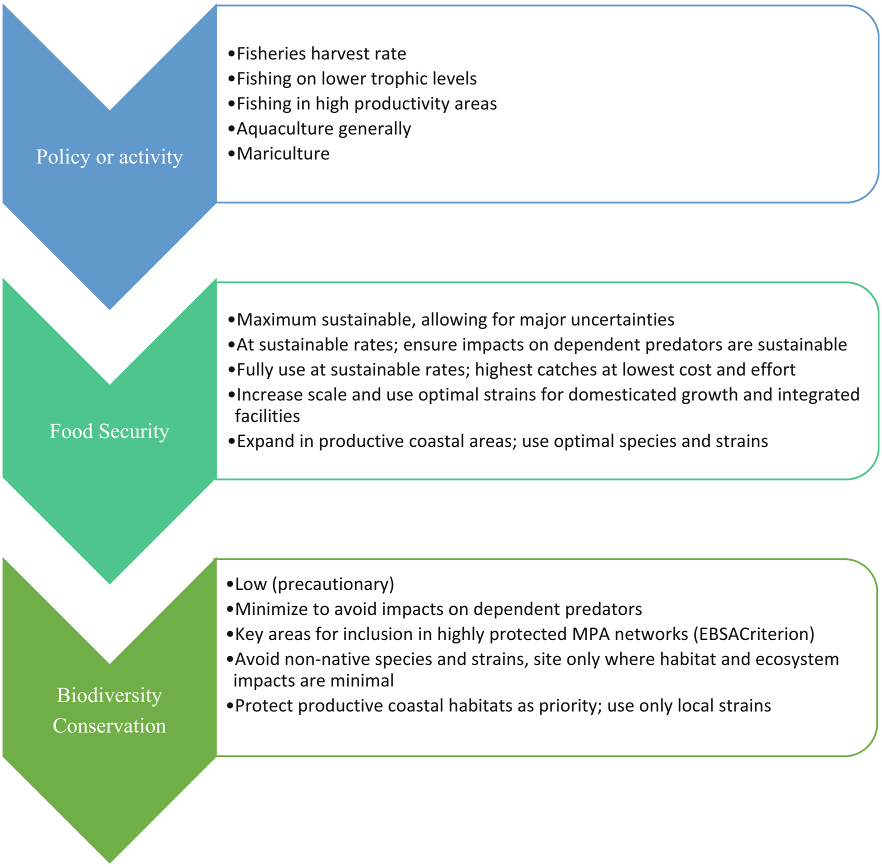


Fig. 11.7 Required activities in balancing food fish security and biodiversity conservation. (Adapted from Rice and Garcia 2011)

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Chapter 12
Impact of Pharmaceutical Compounds on the Microbial Ecology of Surface Water Resources

Odangowei Inetiminebi Ogidi

Abstract Recent years have seen a rise in the study of the environmental effects of pharmacological substances. Pharmaceutics are a significant pollutant of aquatic ecosystems, including surface water resources. In addition to waste items, pharmaceutical products that have not been properly disposed of also contribute to these contaminants. The microbial ecology is threatened by the long-term exposure to subtherapeutic concentrations of the pollutants. Pharmaceuticals have been found in a variety of environmental waterways because of their widespread usage and partial removal. There are additional ecotoxicological impacts from their long-term persistence in the environment and chronic exposure to organisms. Pharmaceutical effluents have been disposed of in an irrational manner, resulting in a devastating environmental impact, particularly on surface of water resources' microbial ecology. As a growing pollutant, this chapter covered pharmaceutical compounds, their origins and routes in the environment, the microbial ecology of surface water, the effects pharmaceuticals have on surface water and how to protect surface water from pharmaceutical compounds.

Keywords Pharmaceutical compounds · Surface water · Pollution · Microbial ecology · Aquatic environment

12.1 Introduction

In the National Geographic Encyclopedia, surface water is defined as "any body of water above earth". This includes streams and rivers, lakes, reservoirs and wetlands. Even though the ocean is salt water, it is still termed "surface water". Humans, animals and the environment are all at risk because of surface water contamination. Human population and urban growth are expanding at unprecedented rates, which is causing havoc to surface water quality throughout the globe (Okereke et al. 2016).

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Emerging pollutants in aquatic environments have been observed all over the globe in the last several years, mostly as a result of progress in the industrial and medical fields. Even while contaminants of growing concern have been present in the environment for decades, analytical technologies capable of detecting these pollutants at ecologically relevant quantities have just recently been developed in the last 10–15 years (Onesios et al. 2009; Ternes and Joss 2015; Ternes 1998). Pharmaceuticals, nanotechnology, illegal narcotics, synthetic musks, food additives, phthalates and hormones/steroids, industrial compounds/by-products, personal care and veterinary goods are some of the pollutants of rising concern (Gavrilescu et al. 2015; Lapworth et al. 2012; Mailler et al. 2016; Thomaidis et al. 2013). Despite the dangers these chemicals pose to the environment and public health, water quality framework standards for these compounds do not now exist (Thomaidis et al. 2013; Ncibi et al. 2017).

In order to sustain and maintain human health, pharmaceuticals, a well-known class of contaminants of emerging concern, have been essential. Life quality and illness relief have been ensured by pharmaceuticals. There were more than 160 novel antibiotics and semi-synthesised derivatives sold commercially between the 1940s and early 1970s, which established the cornerstone for the treatment of infectious illnesses as the contemporary pharmaceutical industry grew (Ternes 1998).

Since the discovery of penicillin in the early twentieth century, antibiotics have been hailed as modern-day miracle cures. Organ transplantation, surgical prophylaxis, protection of newborns from sepsis and cancer treatment are all made possible by effective antibiotics. The growth of antimicrobial resistance comes despite the fact that medicines have been very successful in lowering death and morbidity from common diseases (Gavrilescu et al. 2015). This topic has been acknowledged among the top ten public health hazards by the World Health Organization (2020). There are considerable volumes of antimicrobial drugs of pharmaceutical origin currently detected in sewage and wastewater treatment facilities (WWTPs) as a result (Rizzo et al. 2013). More and more antibiotic molecules are turning up in terrestrial, freshwater and marine habitats due to a lack of regulation of antibiotic pollution at the local and global levels (Boy-Roura et al. 2018).

But their widespread use has resulted in their existence in the environment, which poses a hazard to living things (Ebele et al. 2017). The scientific community has expressed worry about medications' impact on non-target creatures. As a result, in addition to other methods for reducing or preventing pollution, it is critical that new technologies for recovering or remediating polluted environments be developed as soon as possible. Here, we'll look at how antibiotics, as well as other medications, end up polluting surface water resources, both indirectly (via antibiotic resistance) and directly (through environmental pollution).

12.2 Pharmaceutical Compounds as Emerging Contaminants

New environmental pollutants known as "emerging contaminants", such as pharmaceuticals, have been the principal focus of concern in the aquatic environment during the last two decades (Kummerer 2008; Van De Steene et al. 2010). In both human and veterinary medicines, pharmaceuticals may be natural or manufactured substances used to treat or prevent a variety of disorders. Compounds that have more than one ionisable group tend to be lipophilic or moderately soluble in water, and likely to be polar molecules with diverse structures and activities (Boy-Roura et al. 2018). Passing through cell membranes, pharmaceuticals are able to remain active molecules in the environment after being expelled from the body (Boy-Roura et al. 2018). Pharmaceutics are broken down into 24 therapeutic classes, each of which contains between 10,000 and 20,000 distinct medications (Stadlmair et al. 2018; Food and Drug Administration 2020).

Because of their low volatility, pharmaceuticals are easily dispersed in the environment as aqueous solutions or suspensions. However, certain pharmaceuticals may bind to soil particles and enter the food chain (Comerton et al. 2009). The presence of medicines in aquatic ecosystems has been widely known in industrialised nations owing to its potential environmental and health implications. Antibiotics, lipid regulators, beta-blockers, steroids and associated hormones, cancer medicines, diuretics, anti-epileptics, tranquillisers, non-steroidal anti-inflammatory medications, anxiolytics, proton pump inhibitors and analgesics are some of the pharmaceuticals that have been categorised by the FDA (Ngumba et al. 2016) (Fig. 12.1).

The scientific community is concerned about medicines persisting in the environment, given their widespread and increasing usage and manufacturing, as well as the possible toxicological effects they may have on non-target species (Silva et al. 2015a, b; Heiss and Küster 2015; Puckowski et al. 2016). Concerns have also been raised about the potentially harmful consequences of these chemicals on ecosystems and human health (Ebele et al. 2017; Picó and Andreu 2007).

Studies in the laboratory show that pharmaceuticals can disrupt the endocrine system, alter the structure and function of natural microbial communities, harm invertebrates and fishes and lead to the emergence of antibiotic resistant genes and bacteria in the case of antibiotics, as shown by these studies (Pomati et al. 2006; Ding and He 2010; Finley et al. 2013; Marti et al. 2014; Wellington et al. 2013; Fernandes et al. 2015; Alvarino et al. 2014). Examples include mianserin, an antidepressant that inhibited the development of zebrafish larvae and altered their physical and biochemical markers, such as their metabolic rate (Yang et al. 2018). Another research found that Rhamdia quelen (catfish) had oxidative stress, inhibition of liver enzymes, genotoxicity and alterations in steroid hormones as a result of paracetamol exposure (Guiloski et al. 2017).

More emphasis has been made to the environmental and aquatic consequences of medications as evidence of their detrimental effects grows. Some of these

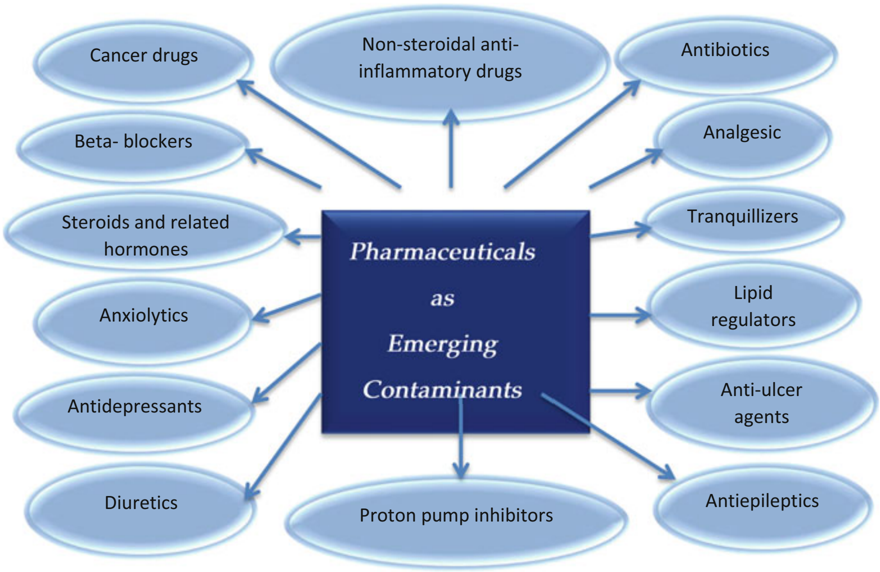

Fig. 12.1 Chart on pharmaceuticals as emerging contaminants of aquatic environment

compounds have already been included in the second and third Watch Lists despite the lack of regulation regarding the presence of most pharmaceuticals in aquatic environments. These include antibiotics such as amoxicillin, ciprofloxacin, erythromycin, clarithromycin, azithromycin, sulfamethoxazole and trimethoprim and (i2) hormones such as 17-Alpha-ethinylestradiol (EE2).

12.3 Pharmaceutical Sources and Pathways in the Environment

Europe produces about 100,000 human and veterinary medications each year; statistics on their usage exist (Kümmerer 2009), but in Africa and other emerging countries, such as India, there is a paucity of information (Wood et al. 2015). It is difficult to keep track of medication use and consumption since drugs are used in different ways in different countries, and some may only be purchased with a prescription while others can be purchased over the counter or online. Developing countries have an even greater challenge with this issue.

12.3.1 Primary and Secondary Sources

There are two types of entry points for pharmaceuticals into the ecosystem: primary and secondary. Manufacturing companies, hospitals and care homes are the leading sources of pollution. Sewage systems are the primary source of medicines entering secondary sources such as STPs and landfills. Pharmaceuticals may be released into the environment via the use of these secondary sources. Oral, topical, subcutaneous, nasal, intramuscular, intravenously, pessarially or rectally are all ways that drugs can be administered that open up the possibility of contamination of the surrounding environment during the administration process. Environmental contamination can also occur when drugs are administered orally, topically, subcutaneously or nasally. Different stages of hepatic metabolism take place when these medications enter the body, resulting in therapeutic responses when the chemicals bind to receptors (Triebskorn et al. 2004).

12.3.2 Pathways of Excretion

Drugs are expelled predominantly via the kidneys, although they may also be eliminated through the faeces, skin or lungs. Conjugates, metabolites of the parent chemical, or the parent compound itself may be excreted intact by the body (Crane et al. 2006; Luo et al. 2014). Demethylation processes in the liver may convert fluoxetine to norfluoxetine (the primary active metabolite), for example (Altamura et al. 1994). As an example, in humans, diclofenac is biotransformed and excreted mostly in the urine (65%) and bile (35%) as sulphates and glucuronide conjugates (Altenburger et al. 2015). While amoxillin and chloramphenicol are mostly removed from the body in this manner, amoxicillin and chloramphenicol are primarily eliminated as glucuronides (70–90%) and as unmodified parent compounds (5–10%) (Hilton and Thomas 2003). Waste products such as excreted metabolites and parent chemicals are flushed down the drain. Waste water may either be discharged into waterways or accumulated as biosolids in agricultural land regions following treatment (Kolpin et al. 2002; Rooklidge 2004). Furthermore, manufacturers urge that expired pharmaceuticals be returned to pharmacies for safe disposal in landfills or incinerators in developed countries like Western Europe and the United States, although this seldom happens (Bound and Voulvoulis 2005).

12.4 Occurrence of Pharmaceuticals in Aquatic Environment

The first time pharmaceuticals were found in aquatic environments was in the 1970s (Tabak and Bunch 1970). The presence of medicines in the aquatic environment has been the subject of several investigations. Because of their low volatility, pharmaceuticals are mostly dispersed via aquatic media and then through food chains (Nikolaou et al. 2007). Despite their limited environmental persistence, medications are all around us thanks to their greater release rate than transformation rate (Bendz et al. 2005). Changes in sewage composition, weather, and treatment plant design and operation all have a role in active pharmaceutical ingredient transformation (Roberts and Thomas 2006). Use of pharmaceutical waste as an agricultural fertiliser may allow it to go to the terrestrial environment, where it might infiltrate surface and groundwater supplies (Carlsson et al. 2006).

Wang et al. (2020) studied the presence of 36 pharmaceuticals in surface water samples from Beijing, Changzhou and Shenzhen in China, and 28 chemicals were identified. One nanogram per liter of atenolo (52.9), Sulpiride (77.3) and indomethacin (50.9) were the highest average values of these four drugs. In Costa Rica, Spongberg et al. (2011) collected 86 samples of 49 surface water from coastal areas that get both treated and untreated sewage. Metoprolol, bisoprolol and propranolol have also been discovered in surface water samples at lesser amounts (Hirsch et al. 1999). In Switzerland, surface water tests often included beta-blockers with amounts as high as ng L^{-1} (Alder et al. 2010).

Diclofenac, chloroquine, paracetamol and ciprofloxacin had average values of 17 g L^{-1}, 5 g L^{-1}, 3 g L^{-1}, and 1 g L^{-1}, respectively. Ikpa river basin freshwater environment in the Niger Delta, Nigeria, was studied by for the presence of and dangers presented by emerging organic pollutants (EOPs) between April and June 2013 (medium to heavy rainfall period).

Seventeen different substances at ng L^{-1} concentration level including seven antibiotics (acetamidophenol; chloramphenicol; co-amoxiclav; ciprofloxacin; erythromycin; lincomycin; roxythromycin; and sulfamethoxazole); three bactericides/antimicrobial agents (sulfathiazole; triclosan; and triclocarban); and one anti-sulfamethoxazole, erythromycin and ciprofloxacin were of low maximum MEC values, as did erythromycin (11.4 ng L^{-1}) and erythromycin (2.3 ng L^{-1}) (2.8 ng L^{-1}).

12.5 Microbial Ecology of Surface Water

The surface water environment's taxonomic diversity is mostly based on three key domains. Bacteria, Archaea and Eukarya are the three kingdoms of life, excluding viruses, which are non-living entities. Physiological, structural and biochemical traits may be used to identify organisms in various categories. The Eubacteria, which comprises bacteria, actinomycetes and blue-green algae, is well-represented in surface water environments. Archaea is a specialised group of organisms that can only live in very cold or very hot freshwater habitats. From femtoplankton to macroplankton, planktonic creatures may vary in length from 0.2 to 200 mm, with five distinct size groups.

Surface freshwater microorganisms may also be split into two broad categories based on their eating habits: the Autotrophs are organisms that produce all of their own carbon compounds by converting atmospheric CO_2 into their raw materials. Inorganic compounds such as nitrogen and phosphorus supply them with the nutrients they need. Microalgae and photosynthetic bacteria are among the microorganisms that make up the primary producers in freshwater surface ecosystems. The heterotrophs, on the other hand, rely on organic substances for their carbon supply. Microbes such as bacteria, protozoa and fungus that live in surface water tend to be heterotrophic. Saprotrophy, predation and interaction with live creatures all play a role in heterotrophs' feeding. Protozoa and other protozoa are examples of saprotrophic organisms, which obtain their nutrients from non-living matter by either taking up soluble compounds directly or secreting external enzymes and then taking up the hydrolytic products (bacteria and fungi).

An important third characteristic of heterotrophy is the ability of organisms to form mutually beneficial relationships with other living things. In parasitism, the parasite is completely dependent on the host. For example, planktonic bacteria take up DOC, detritus is broken down by benthic organisms like bacteria and fungus, and parasites like viruses and fungi restrict phytoplankton populations in freshwater habitats, including marine ones. The water monitoring can be used to analyse *C. perfringens* spore and vegetative forms and their distribution. *C. perfringens* is a great indication of faecal pollution since it lives the longest in contaminated water (Bezirtzoglou et al. 1996, 1997, 1994; Maipa et al. 2001; Savvaidis et al. 2001). Many studies have shown that the percentage of spore-forming bacteria to total bacterial biomass in rivers is statistically more significant than the ratio of spores to vegetative forms.

Vulnerable kinds of vegetation cannot thrive in rivers because of their length and the variety of sample sites (source vs. downstream) and stress and environmental conditions (Bezirtzoglou et al. 1996). Most of the time, rivers are where you will find more resistant spore types (Bezirtzoglou et al. 1996). The organism *C. perfringens* is used in many countries to detect remote faecal pollution (Bezirtzoglou et al. 1996; Hirn et al. 1980; Pinfold 1990), but it cannot be used as a specific indicator organism to distinguish between human and animal faecal contamination because it is excreted by both humans and animals (Oragui and Mara 1983). *R. coprophilus* was utilised as a particular biomarker of animal faecal pollution in epidemiological research and pinpoints the source of water contamination (Sorensen et al. 1989; Oragui and Mara 1983).

12.5.1 Microbial Evolution

Additionally, the selection pressures exerted by antibiotic contamination might influence the evolutionary processes seen in microbial communities in a variety of ways, as stated above (Martínez 2017). In response to antibiotics and other environmental pressures, different bacterial species or even lineages within a species exhibit phenotypic variation. Due to changes in gene expression or changes in essential physiological features, several bacterial populations have variable tolerance levels to antibiotics (Sanchez-Romero and Casadesus 2013; El Meouche and Dunlop 2018).

The use of antibiotics, on the other hand, may limit microbial diversity by encouraging the emergence of microbial lineages that are resistant or tolerant to antibiotics. If, on the other hand, antibiotic doses are used sparingly, moderate selection forces might encourage the emergence of bacteria lineages with higher levels of phenotypic and genotypic varieties. Antibiotics such as amikacin and ciprofloxacin were found to select for larger colonies in Staphylococcus species, which was linked to increased genetic diversity and adaptation in several other species of bacteria that were exposed to intermediate concentrations of these antibiotics (Lee et al. 2018; Saxer et al. 2010; Justice et al. 2008).

Antibiotic treatment has been proven to enhance genetic diversity in bacteria by activating the bacterial SOS response, resulting in a higher mutation rate throughout the genome (Foster 2007), as well as by directly mutagenic action on DNA (Foster 2007). Both conjugation (Maiques et al. 2006) and competence (uptake of extracellular DNA) have been reported to promote antibiotic-induced horizontal genetic material transfer across bacteria (Slager et al. 2014). To sum up, most antibiotics have been found to influence transcriptional gene regulation, either directly or indirectly, through mechanisms such as riboswitches (Blount and Breaker 2006) and quorum sensing (Rémy et al. 2018), leading to an increase in phenotypic variability and, in some cases, virulence (Davies et al. 2006; Rémy et al. 2018). Together, these mechanisms increase the genetic and phenotypic diversity of bacteria exposed to antibiotics. As a result, antibiotic resistance may continue to evolve as selection pressure grows (Rice 2004).

12.5.2 Microbial Diversity and Ecosystem Functions

Ecological functions such as decomposition and primary productivity in a wide range of environments can only be accomplished by bacteria and fungi that live in aquatic environments (Lozupone and Knight 2007; Caporaso et al. 2011; Torsvik et al. 2002; Gibbons and Gilbert 2015; Van Bruggen et al. 2019). Antibiotic contamination may exert selective pressures on the overall microbial community composition, either by diminishing taxonomic diversity or changing microbial composition. Generally speaking, antibiotic exposure favours the growth of Gram-negative bacteria over Gram-positive bacteria. In the latter case, the lack of an exterior cell membrane makes them more susceptible to medicines and disinfectants (Delcour 2009). Antibiotic use may therefore lead to the extinction of important microbial groups that play important ecological functions. Bacteria that play a key role in carbon cycle and primary production are reduced by antibiotic contamination in aquatic settings (Ding and He 2010; Eckert et al. 2019; Grenni et al. 2018).

Antibiotics may also interfere with the activity of bacterial enzymes, including dehydrogenases, phosphatases and ureases, which are regarded markers of soil activity (Cycoń et al. 2019). Finally, the disturbance of microbial communities by antibiotics may lead to an increase in the prevalence of aquatic parasites and diseases. Because of the eutrophication of freshwater ecosystems caused by antibiotic pollution, a number of harmful Cyanobacteria species have been seen to grow, presenting health hazards to people (Drury et al. 2013).

12.6 Impacts of Pharmaceuticals on the Microbial Ecology of the Aquatic Environment

12.6.1 Impacts of Antibiotic Contaminants on the Microbial Ecology of the Surface Water

Most biogeochemical cycles are entirely mediated by microorganisms, proving the functional significance of microbial biodiversity in maintaining biological activities in surface water. The presence of antibiotics in various environmental matrices at varying amounts is a major problem. Fluoroquinolone ciprofloxacin, for example, has been identified in surface water (Gracia-Lor et al. 2011; Petrović et al. 2014; Osorio et al. 2016), groundwater (López-Serna et al. 2013) and sediments (López-Serna et al. 2013; Vazquez-Roig et al. 2012; Wu et al. 2014; Leal et al. 2012; Zhao et al. 2010). A macrolide antibiotic called erythromycin was identified in surface water (Kay et al. 2017), drinking water (Gaffney et al. 2015), groundwater (López-Serna et al. 2013) and wastewater sludge (Kay et al. 2017; Gaffney et al. 2015; Ho et al. 2014). As an ecological factor, antibiotics may alter natural bacterial populations (e.g. the extinction or suppression of particular bacterial groups) in the environment (Allen 2010). Even non-target creatures with critical ecological roles are affected by the consequences (Woegerbauer et al. 2015; Pallecchi et al. 2008).

Antibiotics have been linked to a decline in microbial diversity, according to several research. Biological communities' development and enzyme activities, as well as ecological processes like biomass generation and nutrient transformation, might be adversely affected, resulting in a loss of functional stability (Koike et al. 2007; Pauwels and Verstraete 2006). There is a wide range of microbial groupings that may be targeted by broad-spectrum antibiotics, including fungi, bacteria and even single species. An antimicrobial agent has a selective impact on bacteria, and this results in changes in the quantity of microbial species and interspecies interactions. According to the European Food Safety Authority (EFSA), these effects are influenced by the microbial groups involved, environmental variables such as water and antibiotic concentrations (Święciło and Zych-Wężyk 2013). A number of factors including soil texture and adsorption capacity, and pH as well as water content, temperature and the frequency with which antibiotics are applied may have an impact on the pharmacokinetics of antibiotics, such as freezing and thawing as well as rewetting and rehydration (Aminov and Mackie 2007).

Some of the updated current researches on the effects of antibiotics on soil and water microbial community structure explains the impacts of pharmaceutical contaminants (Hou et al. 2015; Martinez 2009; Conkle and White 2012). An antimicrobial drug may alter the nitrogen transformation, methanogenesis, reduction of sulfuric acid and the cycle of nutrients as well as organic matter degradation (Roose-Amsaleg and Laverman 2016). Sulfonamides, for example, have been shown to alter microbial diversity by lowering microbial biomass and the interaction between bacteria and fungus (Hammesfahr et al. 2011). Several prokaryotes conduct nitrification and denitrification as part of the nitrogen cycle, with ammonium-oxidising bacteria and archaea (AOB and AOA) doing nitrification in particular (Cui et al. 2014). Sulfonamides, fluoroquinolones and the antibiotic tylosine have been found to alter the nitrogen-mediated behaviour of microbial communities in the presence of environmental concentrations of these compounds (Roose-Amsaleg and Laverman 2016). As a result, it is difficult to generalise about the impact of antibiotics on biogeochemical processes due to the absence of conventional assays.

These surface water bodies have been a source of growing worry and awareness because they contain antibiotics, which encourage bacterial resistance. Complex processes such as intracellular alteration and/or inactivation of the antibiotic, membrane exclusion, intracellular sequestration, decrease in target sensitivity and expulsion from the cell are all possible ways in which this might occur (Marti et al. 2014).

12.6.2 Impacts of Non-steroidal Anti-Inflammatory Drugs on the Microbial Ecology of the Surface Water

Drugs classified as non-steroidal anti-inflammatory agents (NSAIDs) treat a wide range of acute and chronic inflammatory conditions and are widely used across the globe (Monteiro et al. 2017; Manrique-Moreno et al. 2016). NSAIDs are often used to alleviate symptoms of inflammation and discomfort, as well as to reduce fever, and in certain cases, to treat rheumatoid arthritis (Embrandiri et al. 2016). Prostaglandin biosynthesis enzymes COX-1 and COX-2 are non-selective inhibitors of cyclooxygenase isoforms, which are involved in the production of prostaglandins that play a role in pathogenic processes such as inflammation (Mezzelani et al. 2016; Santos et al. 2010).

NSAIDs are one of the most often prescribed and self-administered families of medications, in part due to their cheap cost and easy availability to over-the-counter versions (Elizalde-Velázquez et al. 2020). NSAIDs are found in wastewater treatment plant effluents owing to their inability to be effectively removed by such facilities, resulting in their discharge into the aquatic environment (Ziylan and Ince 2011; Cortés et al. 2013). These substances account for 15% of all drugs found in monitoring studies across the globe, making them the most often found in aquatic environments (Cortés et al. 2013). Ketoprofen, fenoprofen, naproxen, mefenamic acid, diclofenac and ibuprofen were discovered at g L^{-1} levels in the aquatic environment, with a major fraction coming from wastewater facilities, as did ibuprofen and fenoprofen (Ziylan and Ince 2011). Surface waters, seawaters, groundwaters (López-Serna et al. 2013), drinking waters (Gaffney et al. 2015); waste waters (Kumirska et al. 2015; Petrie et al. 2016) and sediments (Kay et al. 2017; Gros et al. 2012; Petrie et al. 2016) have all shown NSAID diclofenac, naproxen and ibuprofen. (Biel-Maeso et al. 2017).

Because non-steroidal anti-inflammatory medicines are constantly entering the aquatic system, it is impossible to know how much they will affect the environment or what kind of biota they'll affect in the future. NSAIDs' potential ecotoxicological impact on aquatic microorganisms at various trophic levels is a major cause for worry given their widespread use in the environment. The nitrification and ammonification rates of NSAIDs pollutants are often employed in risk assessments of microbial-mediated processes. In contrast to the ammonification process, the nitrification process is widely recognised to be more sensitive to a wide range of substances. Small groups of bacteria are responsible for the first, whereas a diverse array of aquatic microbes mediate the second. Antibacterial activity against Gram-positive bacteria has been found by several investigations (Dastidar et al. 2000). Another possibility is that some of the microbes that are then mineralised have died, resulting in a rise in ammonium concentrations. NSAID formulations may include ingredients that induce ammonifying bacteria, increasing ammonium generation in the process.

Biofilms comprised of both bacteria and algae were found to lose nearly 70% of their starting biomass after only 4 weeks of exposure to the 0.1 mg L^{-1} DCF concentration. The potential of some microbes to adapt to this molecule was shown by Cytophaga bacteria, which survived and degraded up to 97% of the parent drug in only 5 days after its application. Over the course of two seasons, the river biofilms studied by Lawrence et al. (2007) were exposed to DCF concentrations that were ecologically relevant (0.01–0.1 mg L^{-1}). Cyanobacteria biomass was lowered in the summer when the concentration was lower in the spring, although algal biomass was unaffected. At the greatest concentration in spring, the biomass and biofilm thickness of cyanobacteria grew more rapidly. As well as changing the bacterial population, this medication also altered the carbon usage patterns determined by the Biolog technique.

Because certain bacteria may flourish in the presence of an NSAID, this ability may be due to the NSAID-induced mortality of others (Dastidar et al. 2000; Paje et al. 2002; Lawrence et al. 2007). Antibiotic-resistant bacteria may take use of the nutrients provided by dying cells, leading to a rise in their population. Although it has been shown that in many circumstances, anaerobic or sterile environments slow down the abiotic breakdown of NSAIDs, this mechanism may still play a significant effect.

Aspirin, as well as ibuprofen (racemic and S-(+)-ibuprofen), were found to have a negative effect on the green algae Scenedesmus obliquus' growth and cellular structures. This was followed by a decrease in photosynthesis, as well as a decrease in carbon assimilation and photorespiration when exposed to the four NSAIDs (Wang et al. 2020). Ketoprofen was shown to be the NSAID with the greatest toxicity to Scenedesmus obliquus, according to the authors, which they attribute to the drug's high liposolubility and bioavailability (Wang et al. 2020).

12.6.3 Impacts of Antidepressants on the Microbial Ecology of the Surface Water

Antidepressants have long been known to be found in surface waters across the world (Daughton and Ternes 1999). Microorganisms may be harmed as a result of these pollutants' widespread use and biological activity even at low concentrations (Monteiro and Boxall 2010). Antidepressants are a class of medications with a long history of usage in the treatment of mental illness. Tricyclic antidepressants, norepinephrine reuptake inhibitors, monoamine oxidase inhibitors (MAOIs) and selective serotonin reuptake inhibitors (SSRIs) are all antidepressants (Lajeunesse et al. 2008; Sehonova et al. 2019). The SSRI family of antidepressants is the most often prescribed of them (Shaliutina-Kolešová et al. 2020). Due to SSRIs' therapeutic efficacy and greater acceptance and safety than other antidepressants (such as TCAs or SNRIs), SSRIs continue to be the first-choice treatment for depression (Schultz and Furlong 2008; Gołyszny and Obuchowicz 2019). Antidepressants are used to treat clinical depression, OCD, panic disorder, ADHD and eating disorders (nervous bulimia and compulsive ingesting) (Bulik et al. 2012). Most often given antidepressants are fluoxetine, paroxetine, citalopram and sertraline (SSRIs), as well as venlafaxine (SNRIs) and duloxetine (SNRIs) (Silva et al. 2015a, b; Fong and Ford 2014). Serotonergic, dopaminergic and noradrenergic neurotransmission are modulated by SSRIs, SNRIs and TCAs (Fong and Ford 2014).

Improper dumping and inadequate wastewater treatment are the primary routes through which antidepressants infiltrate aquatic habitats. More than one study has shown the presence of antidepressants in various settings (waste waters, surface waterways and/or drinking waters) (Benotti and Brownawell 2009; Gros et al. 2012). Some antidepressants have been found in surface waters (Gros et al. 2012) and waste waters (Venlafaxine and citalopram) (Petrie et al. 2016). Seawater and groundwater were also shown to contain them (Gros et al. 2012; López-Serna et al. 2013). It was found in quantities of 1.15–575 ng L^{-1} in surface waters, and at lower levels in saltwater (52 ng L^{-1}) (Gros et al. 2012). Surface water concentrations of the antidepressant paroxetine ranged from 0.27 to 40 ng L^{-1} (Gros et al. 2012) and groundwater values (5.17–30.2 ng L^{-1}) were comparable (López-Serna et al. 2013). Antidepressants, like other medications, may be found in a variety of environmental quantities. Antidepressant intake patterns, detection techniques and, most significantly, the behaviour of each antidepressant in the environment are all factors that might explain this difference.

Antidepressants may have an impact on living creatures even at extremely low quantities, hence their presence in the environment is a major problem (Schultz et al. 2010; Simpson et al. 2007). Chronic use of antidepressants may worsen this issue by increasing the amount of time people are exposed to these substances in the environment (Silva et al. 2012). When it comes to fish, mollusks and protozoans, serotonin has been shown to regulate a number of physiological processes (Silva et al. 2012). Antidepressant side effects in organisms have been the subject of several investigations. Johnson et al. (2007) reported that the SSRIs fluoxetine, fluvoxamine and sertraline displayed hazardous effects on algae, with IC10 values ranging from 4.6 to 6100 μg L^{-1} (depending on the algal species) following 96 h acute growth suppression (Johnson et al. 2007).

Venlafaxine, amitriptyline and sertraline, three antidepressants, were studied by Sehonova et al. (2019) on the early life stages of non-target aquatic organisms (Danio rerio and Xenopus tropicalis), which showed swimming alterations at high antidepressants concentration (i.e., concentrations above those found in the environment) (Sehonova et al. 2019). In addition, both species' embryos were shown to have deadly and sublethal effects at the highest amitriptyline dose examined.

Prozac at 20 mg L^{-1} (a dose previously proven to affect algae and surface water microorganisms) and 20 mg L^{-1} (the median concentration observed in fresh waters throughout the United States) were studied for their ecological effects on algae and surface water microorganisms (Richmond et al. 2016; Silva et al. 2015a, b). Biofilm colonisation, GPP, NPP and ER were all influenced by fluoxetine, indicating that very low but ecologically realistic concentrations constitute an ecological concern. There is a lack of research on how antidepressants, particularly fluoxetine, affected organic matter breakdown and microbial communities (Reisinger et al. 2017).

Freshwater microbial communities, such as those found in streamside channels and lakes (Kreutzweiser and Capell 2003), have been studied using BIOLOGVR plates (Christian and Lind 2006). One prior work (Lawrence et al. 2005) employed this method in aquatic biofilms treated to a variety of medications, but no pharmacological treatment affected carbon consumption. Using BIOLOGVR redox plates, no change in microbial activity was observed. BIOLOGVR plates are a quick and easy way to characterise the activity and diversity of microbial communities; however, they may favour bacteria that are easy to remove (Stefanowicz 2006).

12.7 Protection of Surface Water Against Pharmaceutical Compounds

It is prudent to question whether pharmaceuticals and their residues should be regarded as safe until proven unsafe, or unsafe until proven safe, given the potential threats they pose to human and environmental health and the haphazard and inadequate state of the regulatory regime for managing those threats. Humans and other creatures benefit from pharmaceuticals because they solve health issues, enhance well-being and even lengthen life. When discharged into the environment incorrectly, they have the potential to cause significant damage to human health, surface water microbial ecology and a myriad of other species (Gabriel 2015). Is it worth to keep making drugs, even if it means compromising the health of people and the environment? Even though it increases prices and stifles innovation, should we limit medications to prevent them from entering the environment?

Pharmaceutical regulation will raise prices and hamper innovation; pharmaceutical regulation will hurt people and the environment. These two perspectives may look mutually exclusive, but they need not be mutually exclusive. For the pharmaceutical sector, the issue is to strike a balance between recognising and mitigating environmental dangers connected with drugs while also taking into account the possible consequences of regulatory and legal constraints. To minimise extra expenses for pharmaceutical research, manufacture and distribution, the issue is to create a technique that reduces the possibility of pharmaceutical contaminants reaching the nation's surface waters, such as rivers, lakes and aquifers. Targeting the earliest phases of the pharmaceutical product lifecycle for regulatory action may help find a medium ground (Gabriel 2015).

When it comes to pharmaceutical policy, there are a number of places where standards and regulations might be imposed. To demonstrate the many interconnections between pharmaceutical production and distribution businesses, medical institutions, people and the disposal and treatment of pharmaceuticals, C.G. Daughton has created an environmental lifecycle chart. There are six major phases in a pharmaceutical's lifespan during which regulatory intervention may be needed and used, as summarised in Daughton's figure. Products' design and manufacture, retail sale and distribution, consumer usage, waste disposal treatment and post-disposal care are all included in this category (Gabriel 2015).

The existing regulatory framework for pharmaceutical pollutants in the environment focuses mostly on waste disposal and post-disposal treatment, as shown above. Because it is unlikely that regulatory-imposed techniques or processes can effectively treat or remove all of the thousands of different pharmaceutical substances and their varying active ingredients and components at the disposal and post-disposal stages, a narrow approach is both flawed and inadequate. As a result, removing or lowering pharmaceutical pollutants from the environment by focusing on the end of the pharmaceutical lifecycle is unlikely to be a huge success. Preventing pharmaceutical pollutants from entering the environment during the first four phases of the pharmaceutical lifecycle may be more wise, in keeping with Benjamin Franklin's maxim that "an ounce of prevention is worth a pound of cure" (Gabriel 2015).

12.8 Conclusion

People, animals and crops all benefit from the use of pharmaceuticals to treat a wide range of illnesses. Aquatic systems might be contaminated by the absorption and excretion of these medicines. Pharmaceutics are an emerging threat to the aquatic environment, and this is a good reason to conduct extensive research on pharmaceutical contaminants, their sources and pathways in the aquatic environment, microbial ecology of surface water and the effects of pharmaceuticals on microbial ecology in the aquatic environment. Stakeholders, manufacturers, regulators, veterinarians, pharmacists and consumers must work together to come up with solutions for reducing pharmaceutical levels in aquatic environments that are detrimental to aquatic life. To ensure that pharmaceutical substances are not polluting our surface waterways, the pharmaceutical sector should design and execute pollution control measures and monitor their compliance.

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Chapter 13
Effects of Water Pollution on Biodiversity Along the Coastal Regions

Adams Ovie Iyiola, Akinfenwa John Akinrinade, and Francis Oluwadamilare Ajayi

Abstract Water is an indispensable resource and is the basis of all forms of life processes on earth. Its importance cannot be overemphasized as it is a key input in food production, which is essential for growth and metabolic processes and a major component of blood, which serves as the transport system in animals. Another significance of water is the safe habitat it provides for fish and other aquatic creatures. Conversely, its presence in the right quantity and quality is important for aquatic biodiversity conservation. As elaborated by the UN, SDG 14 emphasized the sustainability of "life underwater" by protecting them from all forms of pollutants most especially from land-based anthropogenic activities which may find their way either directly or indirectly into the receiving water bodies. The coastal regions, most especially the Niger Delta regions are rich in mangroves, finfish and shellfish resources such as the Penaeids, *Macrobranchium* spp., *Pseudotolithus elongatus*, *Sardinella maderensis*, *Elops lacera*, *Mugil cephalus*, etc. which may be endangered due to the exploration from the huge deposits of crude oil and other threatening anthropogenic activities. Based on these available resources, several conflicts may arise which has led to various changes in the environment. Hence, intense activities coupled with lack of monitoring and environmental impact assessment procedures due to insecurity have caused huge environmental destruction to their landscape and agricultural lands and reduced economic returns of natives who depend on the water as a source of livelihood. Developing and developed countries carry out environmental impact assessment which gives insight into the effects and threats of anthropogenic activities and their impacts on the environment. This will serve as a guide for prompt and right actions towards preserving the ecosystem and most especially

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the conservation of aquatic biodiversity. To this end, this paper highlights the anthropogenic activities along the coastal regions and management procedures that can be tailored towards biodiversity conservation in coastal regions as elaborated by SDG 2 (Zero hunger).

Keywords Pollutants · Sustainability · Marine biodiversity · Sustainable development goals

13.1 Introduction

Coastal areas are located at the interface between the land and the sea. It is a continuation of the coastal land, intertidal regions and aquatic systems which includes a network of rivers and estuaries, salt marshes, wetlands, islands, intertidal and transitional areas, and beaches. It is a narrow transition that connects terrestrial and marine environments which are the most valued and productive ecosystems in the world (Crossland et al. 2005). The coastal zone areas of the world houses the major cities while about 40% of the entire human on the planet resides between the 100 km of this area (Nicholls et al. 2007).

The relationship between humans and coastal resources are interconnected, within these zones, there is a dire need for equilibrium and sustainability for development in the world. Intense efforts are being made to know and improve the relationship between humans, society and coastal ecosystems with over 100 international coastal zone protocols and conventions, all geared at sustainability. There is a need for humans to realize that there must be a balance between the development and conservation of coastal zones. The problems faced in this region must be identified, and a potential solution in terms of both scientific and technological must be proposed to meet the Sustainable Development Goals (SDGs) as emphasized by SDG 14, which addresses conservation measures and sustainable use of marine resources for sustainable development. With this in mind, SDG 14 which emphasizes the sustenance of life underwater will be in place. This is so because they are majorly affected by the impacts of anthropogenic activities either directly or indirectly. If the adverse situation persists, fisheries biodiversity depletion will result thereby resulting in the nutrition and well-being of humans being threatened as noted by SDG 2. This review identifies the anthropogenic activities, resources, uses and management procedures of coastal regions for the sustainability of the environment and fisheries biodiversity.

13.1.1 Resources and Uses of Coastal regions

The coastal region consists of diverse biological and physical resources such as the following:

- Fish and marine life which serve as food for humans
- Sand and sediments maintain healthy beach and dune systems

Coastal regions are divided into the coastal land and coastal sea. The coastal land functions for human settlement, trading and activities of industries, amenity and agriculture while the coastal sea is used for mining, fishing and transportation and presents issues relating to depletion of fish biodiversity in the region. When these areas are congested, there is a potential threat to fishery resources such as over-exploitation, pollution by dumping of wastes and other forms of conflicts. Coastal regions are mostly referred to as the sink for the continents because they receive all pollutants from land-based activities (Ogamba et al. 2021).

Based on numerous activities around this region, efficient management of resources for sustainability is important. As the coastal regions are changing, access and availability towards various resources in this region change as well. A river that flows into the coastal regions is also affected as a result of water withdrawal from various activities such as irrigation and washes the land of all pollutants.

13.1.2 Sources of Water

Most of the water utilized by communities for drinking and other domestic purposes originates from various sources such as rivers, springs and underground sources (Izah et al. 2016; Izah and Srivastav 2015). Although some sources, for example, deep wells, are free of microorganisms that cause contamination and can be considered clean. Despite this, water treatment is required to ensure it is safe before drinking. Water from a particular source can be used for several purposes in many developing countries, including washing, swimming, bathing and so on.

As water is used for human activities, refuse and sewage can be dumped in return to water bodies. Sewage is defined as wastewater containing a variety of debris, chemicals and microorganisms that drains from homes and businesses. For consumers and other users, contaminated water is regarded as a potential health hazard. When the concentration of faecal material is high, water is regarded as unsafe for drinking, because pathogens are suspected to be present.

13.1.3 Importance of Water

Water is a fundamental requirement for all life processes and its importance is undeniable, either directly or indirectly (Aigberua et al. 2020; Seiyaboh et al. 2020a, b; Ben-Eledo et al. 2017a, b; Seiyaboh and Izah 2017a, b; Agedah et al. 2015). Water is required for all processes such as environmental, industrial and metabolic and it can serve as a solvent, metabolite, buffer of temperature and lubricant in living organisms (Hanslmeier 2011). Water is categorized as polluted when some of the water quality parameters have been altered as a result of various human activities, thereby making it unfit for use.

Pollution of water can pose danger to the environment and humans who depend on it for several uses. Pollutant effects vary depending on the type and source of the pollutant; carcinogens are categorized as pollutants from hormones, pharmaceuticals, cosmetics and personal care product wastes, and endocrine disruptors are from heavy metals, dyes and other organic pollutants (Adeogun et al. 2016). These pollutants come into the aquatic system via various channels but are mostly human-caused. This has become a major source of concern for environmentalists because of the various underlying danger they can cause to the environment (Izah and Angaye 2016). The actions undertaken to clean up polluted areas and water bodies are usually more expensive than implementing pollution prevention measures. Although facilities for the treatment of wastes have been installed and improved in many countries. Despite these investments, the issue of water pollution remains a serious problem. In some cases, improved measures applied in wastewater treatment have only resulted in increased pollution from other sources of pollution such as wastewater sludge. The best approach is to prevent the generation of waste rather than the treatment of the waste (Iyiola and Asiedu 2020).

In a developing country like Nigeria, agricultural practices have contributed to the pollution of water. Water pollution is majorly from sources such as laundry activities, washing of chemical bottles and clothes used for application of chemicals, and excessive application of agricultural fertilizers. Water is important in the existence of all creatures; hence, its preservation and long-term supply must be ensured. Industries dump wastes that are untreated into the water bodies despite the laws on the appropriate waste discharge procedures and limits for sustainable ecosystems. As a result, enforcing efficient measures in environmental protection will benefit the environment and humans to a large extent. These policies on environmental protection will operate better if they are tailored to the goals and objectives of individuals and parties involved in environmental degradation. This approach will be the right direction in reducing water contamination.

For example,

- Expansion of urban and rural water supply and catchment systems for rainwater, particularly on small islands, in addition to the reticulated water-supply system;
- Disposal of excreta and sewage using wastewater treatment systems in urban and rural areas;
- Where necessary, the expansion of sewage treatment facilities and drainage systems;
- In both urban and rural locations, treatment and safe reuse of home and industrial wastewaters;
- The prevention of waterborne illnesses;
- Raising public knowledge and engagement in public information.

13.1.4 System of Farming

Farming systems have contributed immensely to the issue of pollution in Nigeria. The vast majority of its lands are farmed by small-scale farmers who possess the land as a result of family inheritance, gift or purchase. Although some portions of the farming techniques, including ploughing, harrowing, ridging, threshing and water pumping are mechanized, most farmers rely heavily on human and family labour. Family members are usually involved in activities such as sowing, transplanting and other laborious tasks, application of fertilizers is typically done by hand through broadcasting, and backpack sprayers are used for the treatment of pesticides. The local government has a limited number of tractors, whereas the majority of tractors are privately held and can be rented privately through local cooperatives.

13.1.5 Indigenous Way of Disinfecting Water

In today's world, a variety of advanced water purification devices are commonly used. For some rural residents who cannot afford these expensive treatment technologies, water pollution is a major concern (Shannon et al. 2007). The disinfection by-products that remain after treatment are another reason why herbal water treatment should be encouraged. Few researchers employ their antibacterial extracts directly in water treatment, which is worth highlighting. Many groups stop after discovering the antibacterial properties of their research plant, while others go to using the extracts in water treatment. For example, against salmonella, alcoholic, aqueous, and fresh juice extracts of *Ocimum sanctum* (tulsi) and *Azadirachta indica* (neem) were utilized in a study. With well water, the alcoholic extract performed best, while with lake water, the aqueous extract performed best (Tanushree et al. 2013). Similarly, one study looked at the usefulness of tulsi, neem and amla in healing microbiological diseases with no side effects, while another looked at the effectiveness of these three herbs in water purification using E. coli eradication to determine the performance of each herb. A mixture of 1% concentrations of each herb was shown to be less effective than a synergistic combination of the three (Rajesh and Wankhade 2016).

Ajayi et al. (2017) observed the effectiveness of moringa usage in the treatment of water and its awareness among south-western farmers in Nigeria. Out of the 16 identified uses of moringa plant, only 2 honey/sugar juice purifiers (67.9%) and water purification material (76.3%) were perceived by the respondents as highly effective (Ajayi et al. 2017). Because of the evident benefits of natural disinfection, greater study into natural products for water purification is required. This will in no small part assist rural residents in assessing affordable clean water and so living a healthier lifestyle.

13.1.6 Water Pollution and Impacts on Climate

The existence of all species on earth, including humans, depends on water. Managers of water resources ensure that the quality of water is preserved and maintained for the use and this function is provided by wastewater treatment plants. Arnell et al. (2014) estimated in reports that an estimated five billion out of a total population of eight billion would live in water-stressed areas by the year 2025. The rising global contamination of freshwater systems is a major environmental problem faced by humanity in the world today. This is a result of the release of industrial and chemical materials being dumped into their pathways/runways, primarily in the form of micro-pollutants.

Most of these pollutants, according to Schwarzenbach et al. (2006), are present at low concentrations; nonetheless, many of them can cause major toxicological problems, particularly when such compounds are included as elements of composite blends. Several micro-pollutants have been reported in the literature (Metz and Ingold 2014) that are resistant to current treatment and are thus transmitted to the aquatic environment. Steroid hormones, pesticides, industrial chemicals, medications and a variety of other developing compounds are among them. As a result, both aquatic and human life are endangered. As a result, it is no surprise that freshwater contamination is a major public health hazard that deserves global attention.

13.2 Coastal Regions and Anthropogenic Activities

13.2.1 Transportation in the Ports and Marine Environment

The development of support facilities and ports are of different types:

- The port facilities, refineries and infrastructure support are required for offshore oil and gas development.
- The channels, shipyards, port facilities and land areas are required by the shipping industries for their storage containers.

13.2.2 Waste Disposal

The large harbours of coastal cities and ports that are industrialized generate tonnes of pollutants such as oxygen depletion organic wastes and toxic wastes from industrial discharges, all of which pose serious health issues to humans and oxygen depletion for fish species in the aquatic environment. Most lagoons and estuaries in coastal areas are degraded majorly by pollutant discharges from land activities. Apart from the mortality it causes to fish species, pollution can cause a gradual disappearance of finfish and shellfish or the natural carrying capacity of the environment. The coastal areas are very prone to pollution by streams and rivers as well as agricultural run-off (Ogamba et al. 2017a, b, 2015a, b).

The land-based pollution sources are responsible for over three-quarters of marine pollution via rivers, direct discharge and from the atmosphere. Other sources of pollution may come from dumping, shipping, mining offshore and the production of oil. The activities on land impact the aquatic environment by discharging pesticides into the sea, heavy metals, and harmful wastes which may cause, changes in salinity, and siltation. Coral reefs and benthic communities are destroyed by siltation and increased nutrients from agricultural run-off and sewage. All of these can have a direct effect on the sustainability of fish for human consumption. There is a need to protect fish species as well as the environment by enforcing strong incentives to avoid various discharges into the marine environment.

13.2.3 Urban Settlement

The coastal lands are areas for human settlement, agriculture, industry, trade and areas for marine transport using various types of boats and recreational activities. Based on these activities, this area is prone to increased pressure from human activities, thereby generating various wastes, pollutants, garbage and chemical discharges that affect the land negatively. All of these washes to the shoreline which affects the mangroves and fish species in the aquatic environment.

13.3 Human Anthropogenic Activities Along the Coastal Region

Anthropogenic activities have been on the increase in the world today due to many factors like industrialization, mechanized agriculture, population increase and many other factors that associate with a civilization which its effect can be felt by the celestial, terrestrial and aquatic environment (Izah and Seiyaboh 2018; Izah et al. 2018, 2017). The effect of this on each habitat varies and humans have considered aquatic environments as a haven for offloading wastes generated from activities. The coastal region has been on the receiving end in terms of the effect of the human activities due to migration of people in the world to this area. This might be because of the diverse resources and intrinsic nature of the aquatic environment. Humans began settling along the coast in the Mid-Holocene when global sea-level rise slowed, lured by the abundance of rich agricultural lowlands and fisheries resources (Fan et al. 2017). By 2025, the coastal region's population is expected to account for 75% of the total human population. The world's coasts have evolved into global socio-economic centres, allowing over half of the world's people to live on only 12% of the planet's surface (Crossland et al. 2005).

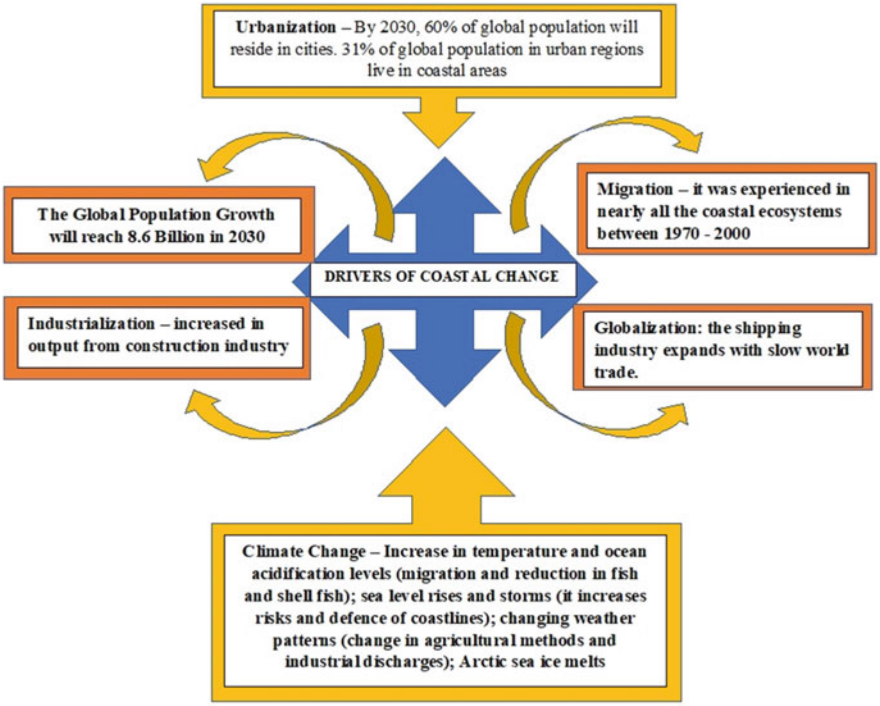

Fig. 13.1 The drivers of coastal change

The ocean is home to 50–80% of all life on the planet, and many of these plants and animals live along the coast. Over half of the world's coastline has been altered for industrial purposes, fisheries, and flood, tsunami, erosion, floods, and storm damage prevention (Dafforn et al. 2015). In the last few decades, 50% of salt marsh, 35% of mangroves, 30% of coral reefs and 29% of seagrass have been lost globally (Barbier et al. 2012). This can be connected directly to human adaptation to life in the coastal region while exploring its resources. As illustrated in Fig. 13.1, there are various drivers of coastal changes which may be migration, climatic change, globalization, industrial processes, population growth and urbanization. The future of the coastal ecosystem is under serious threat due to the activities of humans across the coastal land and shore. Analysis is essential to determine the current impact of human activities across the coastal regions so that suitable measures can be put in place to manage the precious resources represented in the aquatic habitat.

13.3.1 *Some Profound Anthropogenic Activities*

13.3.1.1 Dredging/Land Reclamation

The role of benthic communities is important as they transfer materials from primary production by phytoplankton, benthic macrophytes and coastal wetlands to the upper levels in the food web and fish species that are exploitable in the coastal areas (Izah et al. 2022). It is therefore essential to understand the extent to which dredging can affect the benthic environment of the coastal region. Humans have been involved in dredging mainly for construction and land reclamation which is now the order of the day in what is termed as the modernization of the coastal environments. Coastal wetland areas and biodiversity loss are decreased by dredging activities, reduction of sediments from riverine input and decreasing shoreline growth (Newton et al. 2020).

13.3.1.2 Oil Mining

The products from oil exploration have distinct effects on the coastal area. These effects are a function of the composition, concentration and the elements in the environment (Antunes de Carmo et al. 2005). The chemical composition of the coastal water is of no argument on how germane it is to the biological composition of the environments as it has lots of impact on their survivor and this is what oil spill is doing, it is attacking the healthy chemical composition of the coastal environments. From a biological point of view, the effects of oil mining on the environment vary and are complex with some immediately obvious, while others manifest after a long period (Antunes de Carmo et al. 2005). The impact is not only limited to the Aquatic fauna alone but also to its flora which happens to be the primary producer of the ecology food web of the ecosystem. Rabalais and Turner (2016) reported that oil spill from the deepwater oil horizon has contaminated the sediment of the Mississippi wetland while Newton et al. (2020) claim that the spill has degraded the salt marsh vegetation, decreasing marsh vegetation, covering and killing fauna in the marsh areas. Nigeria's famous oil spill of 1980 that found its way into the Atlantic Ocean was reported to damage 340 hectares of mangrove. The oil spill finds its way into the beach of the coastal region causing more damage to the environment. Oil spilled can settle on the beach, killing organisms that live there and can settle on the ocean floor and kill benthic organisms.

13.3.1.3 Aquaculture

The farming of salmon is carried out in sheltered areas along the coastal zones. The limited space and problems such as disease outbreak have made farmers venture into new areas which may be marginal and ecologically sensitive or in conflict with diverse traditional uses for the production of salmon (Cripps and Kelly 1996; Muir

1996; Millar and Aiken 1995). The new location they seem to choose is the coastal region which comes with a lot of implications for the aquatic environment, this is in addition to the increase in knowledge about aquaculture. For example, food conversion ratios have reduced, nitrogen and phosphorus levels in the fish diet have also decreased, and antibiotics usage has dropped 90% per unit weight (Beveridge et al. 1997). Upgrade in the knowledge of how to manage feed by detecting the actual feed conversion ratio of most cultured fish has reduced the number of faecal waste produced by fish, but it has also increased the number of fish on a fish farm and also the number of fish farms thus increasing the net discharge of faecal waste into its environments.

Fish farms nowadays have gone beyond offshore but also onshore in the coastal region which comes with a lot of implications like the escape of the cultured fish into the water body altering the genetic structure of the region. The most damaging environmental consequences of aquaculture are the species escape and the establishment of a self-sustaining and introduced species or the alteration of indigenous (native) gene pools (Arthington and Blühdorn 1996). Whereas, some of these new species are invasive in nature out-competing the native species leading to biodiversity loss in the region. Lassuy (1995) linked the decline in the native species listed as endangered or threatened by the U.S. Federal Endangered Species Act to the presence of non-native species that escape from culturing facilities. Pollution of the coastal environment can result from faecal waste released into the environment and Bergheim and Åsgård (1996) reported an estimate of 162 g of faeces from the production of 1 kg of Atlantic salmon.

13.3.1.4 Agriculture

A major source of pollution that causes degradation of coastal waters is the non-point pollution sources. Agriculture and urban run-off is a major source of pollutants from land which brings suspended organic, mineral matters, and inorganic nutrients which results in eutrophication (N, P extra loads). Xenobiotic substances are also released which have toxic effects on natural ecosystems. The increase in technology has made agriculture more sophisticated than just waiting for seasonal pattern of rainfall, an option such as farming near the coastal region has become eminent in this season of global warming which its main effect is seen in rainfall patterns being disrupted. Oxygen is depleted as a result of waste discharge from various sources such as agricultural run-off which is a major threat, chemical leaching from fertilizer, wastes from aquaculture, nutrients such as nitrogen and phosphorus which are both used in industries, and toxins that are persistent in the environment can end up in coastal waters, leading to oxygen depletion and creating a dead zone in the marine environment.

13.4 Water Pollution and Biodiversity

In developed, and developing countries, the pollution of water is a major challenge that these areas are facing and it affects the health of the environment and humans in the world. The issue of water pollution has caused a crisis in several countries of the world (FAO 2017). The issue of water quality and policies to sustain it was recognized as a focal point in the 2030 Agenda for Sustainable Development (United Nations 2016). The principal sources of pollutants to aquatic aquifers are human settlements, agricultural practices and industrial activities. Globally, industrial activities are reported to discharge millions of pollutants per year, and about 80% of municipal wastewater is constantly released into streams (WWAP 2017). Ecosystems are threatened by the migratory increase and population growth which can cause issues of climate change and degradation of natural sources of water. This affects aquatic resources and has been reported to be on the decline in many countries (UNEP 2016). To this end, as adopted in the Sustainable Development Goals (SDGs) in 2015, the human ecosystem is a major pivot of this programme.

Globally, lakes in the world occupy about 4.2 million km^2, and there is a total of 300 million lakes in the world; while the man-made ones occupy 335,000 km^2. The wetlands cover a continental area of 12.8–15.8 million km^2. MEA (2005) reported that more than 10% of all animals and one-third of vertebrates dwell in inland bodies of water. The relationship between the functions in an ecosystem and biodiversity is a significant one, with biodiversity loss being related to the loss of ecological functions. Researchers are intensifying efforts to understand how the loss in biodiversity can affect ecosystems (Hooper et al. 2005), most especially in freshwater ecosystems (Dudgeon et al. 2008; Covich et al. 2004; Gessner et al. 2004). Biodiversity is a principal component of coastal ecosystems and it is important to know its relationship with the quality of water, its importance on biodiversity, its relationship with ecosystems and its potential threats.

13.4.1 What Is Coastal Water Pollution?

Pollution is one of the challenges that humans are facing within the twenty-first century. It is a major issue in coastal environments, thereby causing health issues for humans and organisms (Fent 2007). The immune system of fish species in these areas is affected directly or indirectly (Poulin 1992). The coastal areas are rich areas for human activities and fishing activities and the sources of pollutants are the effluents from industries, run-off from agricultural lands and dumping of sewage from municipal sources, thereby making the water unfit for use by humans (Abdel Gawad et al. 2018). Water from agricultural processes may contain chemicals such as pesticides and herbicides which impact negatively on the water. The effluents from industries are very toxic and contain heavy metals (Dakkak 2013). Dumping of sewage may affect the biological processes of fish species (Guerriero et al. 2018).

13.4.2 Importance of Biodiversity

Biodiversity underlines most of the processes in abiotic ecosystem and it involves diverse species, genetics and variation in an ecosystem. MEA (2005) reported that only two million species were described out of the 5–30 million estimated species abundance in the world. The Millennium Ecosystem Assessment (MEA) elaborated the roles of biodiversity in an ecosystem, viz,

- Supportive roles which involve compositional, structural and practical boosting of ecosystem diversity
- Regulatory roles which involve biodiversity impacts on production and ecosystem resilience
- Cultural roles involve the aesthetic, spiritual and recreational activities carried out by humans from biodiversity
- Supplying roles which cover the freshwater supply, indirect food supply, etc.

Based on these roles, it was argued that a framework for sustainable development should be created and must be explicit on biodiversity and how it affects humans (Seddon et al. 2016).

13.4.3 Case Studies on Coastal Water Pollution and Biodiversity

Aquatic organisms have different levels of vulnerability to environmental changes and they can respond differently (Moore et al. 2007; Sarkar et al. 2006). The issue of death or migration in the extreme scenarios may occur when organisms are exposed to pollution. A reduction in the ability to reproduce and enzyme that suppresses metabolism is some responses of organisms to pollution (Chapman 1992). Zooplankton species are on the increase as a result of pollution and eutrophication and they cause limiting oxygen thereby affecting fish species which are principal components of coastal waters (Hassan 2008; Xie et al. 2008; Khan 2003). Fisheries' biodiversity is also decreased when there is a disruption in the food chain/webs as a result of biodiversity loss. The abundance of fish species in the Nile has decreased as presented in Table 13.1.

- Pollution from agricultural, industrial and sewage discharges was observed to reduce fish species in the River Nile from Aswan to Cairo (Fishar and Williams 2006; Fishar et al. 2003).

Table 13.1 Fish species abundance in Egyptian Nile

Coastal areas	Fish species abundance	Period	Reference
Egyptian Nile	85	1899–1902	Boulenger (1907)
Egyptian Nile	71	1997	Bishai and Khalil (1997)

- Lake Manzala has suffered changes as a result of pollution which has affected fisheries biodiversity. The environment is very dynamic and vulnerable to pollution effects (Fishar and Williams 2006). The southern part of the lake is exposed to wastewater with high organic content from Bahr El Baqur drain (Rashad and Abdel Azeem 2010) and this differentiates it from the northern side of the lake (Ahmed et al. 2006). Fish species have been deformed in their morphology due to increased eutrophication in the lake from increased domestic and industrial waste discharge (El Mansy and Shalloof 2015). Benthic macrofauna is also affected by these pollutants (Ismail and Hettiarachchi 2017).

There are diverse pollutants in the environment and they affect biodiversity in various ways. For instance, a case was reported in 1992 where heavy metals originated from affected aquatic biodiversity (Naidoo et al. 2006; Schindler and Scheuerell 2002). About 50% of the wastes originated from metallurgical industries, while about 30% resulted from industrial wastes from weaving and dyeing. In Egypt, about 250 industries were established in Cairo and 35% of the total activity discharges about 40% of heavy metals into the water. About 150 industrial facilities release 25% of heavy metal in streams. In Alexandria, 175 facilities are represented and released 25% of total industrial discharges and 10% of heavy metal discharge into streams in Egypt (El Bouraie et al. 2010).

- Some commercial fish species along the coast of the Mediterranean Sea were investigated for the effects of heavy metals such as zinc, copper, lead, cadmium and mercury. Their concentration is high and had significant effects on the fish species (Shreadah et al. 2015).
- Microbial contamination caused by excreta from livestock is very dangerous in the water. These parasites are harmful to all living organisms (WHO 2012; FAO 2006). Pathogens such as *Clostridium botulinum*, *Campylobacter* spp., *Salmonella* spp. and *Escherichia coli* can affect public health. Parasitic protozoa such as *Microsporidia* spp., *Cryptosporidium parvum* and *Giardia lamblia* can cause numerous infections to organisms (Christou 2011).
- Lake Qarun in Egypt is poised with increased discharge of crude oil, agricultural wastes and domestic and sewage discharges which contain an increased concentration of heavy metals. This condition causes a breakdown in the immune defense mechanism in fish species thereby predisposing them to different infections (Naeem et al. 2016). *Vibrio alginolyticus*, *Aeromonas hydrophila* and parasitic *Isopoda* sp. were identified in the lake and reported to cause serious diseases in fish (Elgendy et al. 2017).

13.4.4 Threats to Coastal Biodiversity

The major threats to global aquatic biodiversity as reported by Naeem et al. (2016), Harrison et al. (2014), Mace et al. (2012) and Tilman et al. (2014) are grouped into six (Fig. 13.2).

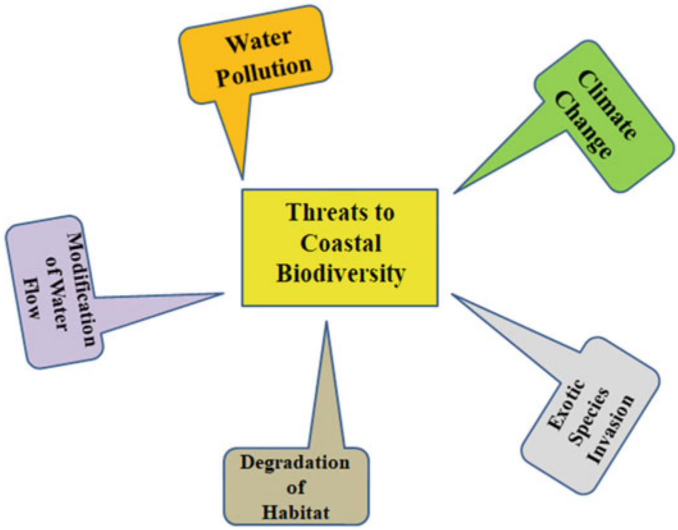

Fig. 13.2 Threats to coastal biodiversity

13.4.4.1 Water Pollution

The contamination of water from physical, chemical, biological and radioactive activities which originates from activities such as mining, industrial discharges, agricultural run-off and sewage are the major threats to water biodiversity in coastal regions (Malmqvist and Rundle 2002; Meffe 2002; Rahel 2002). Pollution can be caused by temperature change (Revenga et al. 2005) and causes many deaths in the world most especially in Asia and Africa. Radioactive matter pollution may also occur from nuclear power plant wastes (Munir et al. 2016; Sechrest and Brooks 2002). Pollutants in water can either be from point or non-point sources (Hallouin et al. 2018; Richardson et al. 2007; Helmer and Hespanhol 1997) and problems of pollution are seen as a pandemic in some areas and developed countries have worked out processes in reducing water pollution which is a threat to water bodies (Carpenter et al. 1998; Master et al. 1998). Overfishing is affecting the ecosystem biodiversity (Moss 2008; Kalff 2002); like the over-exploitation of eel and cod species in UK waters (Colburn et al. 1996).

13.4.4.2 Climate Change

It is the alteration in atmospheric, biogeochemical and hydrological cycles in the environment (Smith 2003). Observable alterations are daily variations in average temperatures and fluctuations in periods of rain, carbon cycles and solar radiation which impact directly on biodiversity. Presently, temperatures have risen by 0.6 °C when compared with the last centuries and it has declined the coral reef populations in the coastal regions (Schmid et al. 2009; Moore 2006). These regions may also be submerged due to an increase in sea levels with estimated 0.1–0.2 m when compared with the last century. There is variation in species due to their different responses and how they can adapt to these changes.

13.4.4.3 Exotic Species Invasion

The invasion of these species has caused an increase in human impacts on ecosystems. These species invade waters that are already modified by human activities affecting their physical and chemical composition (Smith et al. 2011; Baum et al. 2003). For instance, the crayfish plague in Europe, salmonids in the lakes and streams of the Southern Hemisphere and *Lates niloticus* invasion in Lake Victoria are some direct cases (Naeem et al. 2016) and their invasion have been projected to spread at a rapid rate (Frederiksen et al. 2013). Some indirect impacts are noticeable on some terrestrial plants (*Tamarix* spp.) by changing the soil water regime and altering the flow of streams in Australia and America (Engelhard et al. 2014).

13.4.4.4 Degradation of Habitat

This refers to the breakdown in the arrangement of the environment and reactive factors in which its impacts may be directly on the aquatic environment or indirect which may be from drainage basins (Merz and Moyle 2006; Allan et al. 2005; Tharme 2003). For instance, the alteration of surface run-off originates from the removal of trees which increases loads of sediments thereby changing the coastal habitat. This may be caused by shoreline erosion, blocking the river bottoms, floodplains and coastal habitats (Dudgeon et al. 2008).

13.4.4.5 Modification of Water Flow

In running waters, the modification of flow occurs ubiquitously (Bunn and Arthington 2002) although the flow may differ in type and speed. The need for water by humans is highest in areas with extremely variable water flow zones and there is a dire need for flood protection and water storage. Dams were identified as a solution because they can retain as much as 10,000 km^3 of water (Koehn 2004). Of recently, dryness was observed in some longest rivers in the world and it was traced to water abstraction on a large scale (Sala et al. 2000). Fish biodiversity has been impacted by the modifications of water flow, and there is a dire need for conservation because the issues are becoming severe (Nilsson et al. 2005; Tickner et al. 2001).

13.5 Coastal Ecological Communities and Biodiversity Loss

The decreased relationship in loss of biodiversity, the ability to capture resources that are biologically important to ecological communities and biomass generation is not proven. It was reported in 2005 that gene number, species and groups of organisms that are active decrease, and resources are converted to biomass (Xenopoulos et al. 2005; Postel and Richter 2003; Dudgeon 2000; Nilsson and Berggren 2000). Various groups of organisms have different impacts across trophic levels and ecosystems (Balvanera et al. 2006). Some groups may dictate the ecosystem functions while some may present various ways of exploring the boundaries that may constrain the effects of biodiversity (Cardinale et al. 2011; Stachowicz et al. 2007).

13.5.1 Stability of Ecosystem Processes and Biodiversity Functions in Coastal Regions

The stability of coastal ecosystems may be described in many forms and there is no evidence that coastal biodiversity can be established to be stable in different forms (Flynn et al. 2011). The temporal stability of biodiversity is supported at different stages of life by a combination of data and theory of all biomass. The various ecosystem functions can be affected by time variations, and the production biomass of the ecosystem is stable in different communities (Jiang and Pu 2009; Srivastava et al. 2009; Ives and Carpenter 2008; Cardinale et al. 2006). The changes in environmental interactions between various life forms and environmental responses dictate life processes (Hector et al. 2010; Campbell et al. 2011; Cottingham et al. 2001). The level at which biodiversity can alter the functions of an ecosystem cannot be quantifiable and more research is needed in investigating the significance of these processes (Loreau 2010; Gonzalez and Loreau 2009; Doak et al. 1998).

13.6 Conclusion

Water is a resource that must be available in the right quantity and quality for the sustenance of all forms of life. The issue of water pollution is a danger to the environment and measures to enact its management should be paramount. This issue is a principal occurrence in coastal areas due to the potential resources it proffers. It is a direct source of employment and revenue generation for communities around these regions. The rate of industrialization and population increase has resulted in intense human pressure on the environment, most especially the rich coastal regions in Africa. As elaborated, it has resulted in income generation in countries of the world such as Egypt, Africa and different coastal regions in the world.

Pollution is one of the challenges that humans are facing within the twenty-first century and it is a major issue in coastal environments thereby causing health issues for humans and organisms. Anthropogenic activities are the major activities that cause alteration in the natural environment. Activities such as transportation in the ports and marine environment, waste disposal, urban settlement, transportation and agricultural activities; all of these release various pollutants in the water. Also, activities such as dredging, oil exploration, aquaculture and agriculture are some intense activities in coastal regions. It is therefore important to strike a balance between development and conservation of the coastal regions due to the importance that biodiversity can proffer; some of which are supportive roles, regulatory roles, cultural roles and supply roles.

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Chapter 14
Impacts of Climate Change on Aquatic Biodiversity in Africa

Adams Ovie Iyiola, Berchie Asiedu, Emmanuel Oluwasogo Oyewole, and Akinfenwa John Akinrinade

Abstract The climate change phenomenon is an issue which has posed serious threats to the environment and the economy of developed, developing and under-developed countries of the world. The concept of global warming was prominent in the post-industrial era, sequel to that the issue of global cooling was the case during the pre-industrial era. The climate change issues can be of natural occurrence which may be from sources such as eruption of volcanos, respiration by living organisms and decomposition by micro-organisms or man-made occurrence which are from anthropogenic activities such as emission discharge from industries, burning of fossil, agricultural activities, transportation and various commercial activities. The greenhouse gases such as methane, carbon dioxide, nitrous oxide and fluorinated gases are released from both natural and man-made sources into the atmosphere, and accumulation over time in the atmosphere can lead to depletion in the ozone layer. Countries where inhabitants do not comply with environmental emission laws are

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highly vulnerable to increased greenhouse gases. This affects fish species, coral reefs and nursery and breeding habitats for fish species are eroded and the source of livelihood and economic returns of the fish farmers are affected. Fish species may also migrate when the water temperature exceeds the tolerable range. Several measures such as afforestation and awareness of the dangers of this phenomenon can go a long way in mitigating these effects. Conversely, it is expedient to know and understand the concepts of climate change, how it can impact life most especially in the aquatic ecosystem as elaborated by SDG 14—Life below water—and the necessary strategies to fight the impacts of climate change as elaborated by SDG 13 (Climate action). All of these will be explained in this chapter.

Keywords Greenhouse gases · Aquatic habitat · Climate action · Sustainable development goals · Anthropogenic activities

14.1 Introduction

Climate change which results from increased greenhouse gases from human activities mostly occurs as a result of non-compliance of state and individuals to necessary laws and policies on their activities. The plant and animal biodiversities which are components of the natural environment are at the receiving end of these effects. The natural environment is very dynamic and the conditions at any time will affect the presence of biodiversity because they are directly connected to it. These species' biodiversity depends on the environment for all necessary support for all live processes. Pollutants can get into the environment from either point (direct sources such as dumping) or non-point sources (indirect sources such as run-off from land). As the terrestrial animals depend on land for survival, the aquatic environment in turn depends on the terrestrial for most of its activities in terms of quality and quantity. The aquatic environment is a sink for all inputs from land, and it can be said that the condition of the aquatic environment is dictated by the activities on the land (Iyiola and Iyantan 2021).

The inconsistency in the definition of biodiversity was reported by DeLong (1996) although the word "Biodiversity" was coined in 1986. It has been viewed from different perspectives by researchers and various authors such as Adams (1994), Cloudsley-Thompson (1993), Landers (1992), Trauger and Hall (1992), Cooperrider (1991) and Noss (1990) and this has led to diverse definitions for the word "biodiversity". The difficulty in having a single definition for the word "biodiversity" arises from the variability and complexity of biological processes and entities (Sarkar 2002). Aggarwal et al. (2000) stated that the word "biodiversity" was coined by Walter G. Rosen in 1986 at the National Forum on Biodiversity in Washington, USA. The term has gotten a wide usage since its invention. However, Sarkar (2002) pointed out the problems of definition and measurement as a common limiting factor among conservation biologists. In search for a more rounded definition, DeLong (1996) noted that "a generally accepted fundamental definition of biodiversity is imperative for effective communication and cooperation within and among different countries, government agencies, disciplines, organizations, and private landowner". However, Beattie (1996) emphasized the need for synergy among the key players as a necessary tool for the conservation of biodiversity.

In recent research, giving a widely accepted definition for the word "biodiversity" involves creativity from various researchers. Maclaurin and Sterelny (2008) submitted that answering the question, "*What is Biodiversity?*", which is a fundamental question to be attempted creatively and timely. The authors explained the biodiversity types and composition, emphasizing its importance in the theory of evolution, biological development, ecology, morphological development and general taxonomy. The assumptions that biodiversity is majorly attributed to or with richness of species, abundance and species composition in a particular region were argued, and its concepts were related to theories (Economic inclusive). They also submitted how important it is in understanding the concepts of biodiversity before making decisions based on conservation approaches. Rands et al. (2010) argued that biodiversity should not be limited as environmental agencies work but it should be treated as a general concern, with responsibility for its conservation integrated across sectors of society and government. They also advised on the implementation of policies to help integrate biodiversity conservation and decision frameworks for resource production and consumption.

Purvis and Hector (2000) gave a nearly simple definition to biodiversity splitting the words combined. "The term 'biodiversity' is a simple contraction of 'biological diversity'". They therefore defined it "*as the sum total of all living variation genes' level to ecosystems*". Rao (1999) also referred biodiversity to biological diversity and defined it as "the Earth's variety of life and the natural patterns it forms". He pointed out the inclusion difference in genetic make-ups within species and the variety of ecosystems in biodiversity. The accelerated loss of biodiversity globally with its envisioned long-term effect on the earth is according to Loreau and Kinne (2010). They defined biodiversity as a broad concept that encompasses the variety of life in all its manifestations. They pointed out the study of the existing biodiversity to know the extent of the various changes that have occurred over time and to confirm the need for serious management.

14.2 Aquatic Biodiversity

14.2.1 Aquatic Biodiversity and Sustainable Development Goals

The global concern on "cases of hunger, disease outbreak, gender inequality and the degradation of the environment" among others led to the unified mobilization to fight for a common social priority globally (Sachs 2012). All the perceived issues were simplified into the creation of eight sets of goals. With a specific time frame and measurable objectives, MDGs were used for 15 years to stimulate global awareness, political accountability, improved metrics, social feedback and public pressures amidst the nations of the world. Furthering on the MDGs, recent development has modified into SDGs. According to Hák et al. (2016), Sustainable Development

Goals [SDG] comprises 17 goals and 169 specific targets with 330 indicators. Most are continuation of Millennium Development Goals [MDG], while others are newly incorporated ideas. They argued for a conceptual framework for the selection of target indicators. Their argument was to reduce or remove totally any ambiguity in conveying messages to users both for policy- and decision-making, and to the public. They also point out that experts should always look out for "indicator–indicated fact" relation and its relevance. They however didn't stop with pointing out the various issues but also recommended a more conceptual framework in laying a strong foundation for the development of the final indicators' framework.

Stafford-Smith et al. (2017) in reporting on the invention of SDGs pointed out the goals as a key point for sustainable development in nations that are interested in the growth of their economy, social inclusion and protection of the environment. Advocating for synergies across each link, they advised paying close attention to interlinkages across sectors in the economy such as the financial, agricultural, energy and transport sectors, societal actors such as the local authorities, agencies of the government, civil society and private sectors, and relationship between the countries having low, medium and high income. They postulated several recommended ways in improving the interlinked goals which are the finance, capacity building, technology, partnerships, coherence in policy, monitoring and accountability of data. In finance, Stafford-Smith et al. (2017) gave their opinion that "*there should be adequate links across all sectors and countries by providing incentives at an early-stage development of markets for the long-term investment in lower income countries, especially for products and services that contribute towards sustainable development*". They further submitted that the success of SDGs is hanging on "an approach that includes growth, and can instigate sources for innovation for financing while eliminating investments that are not sustainable in their activities in all countries". They also emphasized the important of technologies transfer from developed to less-developed nations.

14.2.2 Aquatic Ecosystem and Sustainable Development Goals

Forio and Goethals (2020) opined that aquatic ecosystem is one of the most vulnerable and highly threatened ecosystems in the world and it is evident by the noticeable decline in composition of aquatic biodiversity worldwide. They encouraged constant monitoring and evaluation of aquatic ecosystems for their protection. In their work, they pointed out that monitoring "*provides insights into the changes in the aquatic ecosystem over a long period of time and assessment indicates the status of these ecosystems*". They also elaborated on the developed methods of assessment to support the sustainability of water and its contribution to SDG implementation. Models (integrated socio-environmental models) monitoring of all communities was tipped as the new way to link various communities to the SDGs realization.

Ait-Kadi (2016) submitted on how important the Inclusion of the Water Goal is in the overall sustainable development. He tipped it as a major concern for all the other sectors, pointing out that its management is solely resting on the water and water-using sectors. Though all the sectors are important, Ait-Kadi (2016) argued that the success of all the goals is pending on that of water. He advised that "governments must accept and embrace interconnectedness and take an integrated approach to water management" across the nations while pointing out the challenge of how best the government would be able to put up an integrated approach. The Sustainable Development Goal 14 is focused on the life below water. It elaborates on the use of the seas, oceans and marine resources in a conservative and sustainable approach with the target of development in a sustainable approach (UN 2015). As argued by Griggs et al. (2013) that the United Nations targets must not only be able to combat poverty and protect human well-being, planetary stability must be integrated to make it wholesome. In their argument, they stated, "*the protection of Earth's life-support system and poverty reduction must be the twin priorities for SDGs*".

According to Tigchelaar et al. (2021), aquatic foods are not only important to global nutrition but also critical to its health, livelihoods, economies and culture inclusive. They pointed out climate-related hazards as a major limiting factor to its potential. In their work, they submitted that if not properly monitored, social, nutritional, environmental and economic outcomes would be a climate hazard with emphases on capturing fisheries in the wild ecosystem of Africa, South and Southeast Asian countries and Small Island Developing States. In meeting the Sustainable Development Goals, Tigchelaar et al. (2021) suggested that "it is important to stimulate and promote the aquatic and terrestrial ecosystem resilience for food production and provides investments which yields a high return which is a process of system-level interventions which addresses dimensions such as governance, poverty and gender equity".

According to Yang et al. (2020), choosing between environmental protection and well-being of humans has constituted a major hindrance to implementation of SDGs. In a quest to bridge the gap between the two, they reported that countries or regions with special priority for basic needs and environmental conditions like zero hunger (SDG 2), no poverty (SDG 1) and clean water (SDG 6) take the SDGs with greater concern. On a global scale, linkages between SDGs include SDGs 14 and 15 (Life under water and Life on land), SDGs 5 and 10 (Gender equity and Reduced inequality) and SDGs 1 and 2 (No poverty and Zero hunger). Based on ecosystem services (ES), SDG 14 and SDGs 6, 13 and 15 were reported to be closely related (Fig. 14.1). Bangladesh with other countries of the world enjoys various benefits from the coastal and marine ecosystems (Islam and Shamsuddoha 2018). Natural and anthropogenic sources of pollution have challenged the ecosystem of the country over the years. They reported the involvement of the country in enhancing the ocean-based blue economy in achieving sustainability in the marine and coastal environment, through the development of comprehensive strategies towards conservation. With more researchers calling for more synergies between the engineering systems (i.e. traditional and ecosystem-based), it is important to yield solutions that are cost-effective in water and its biodiversity management (Iyiola and Asiedu 2020;

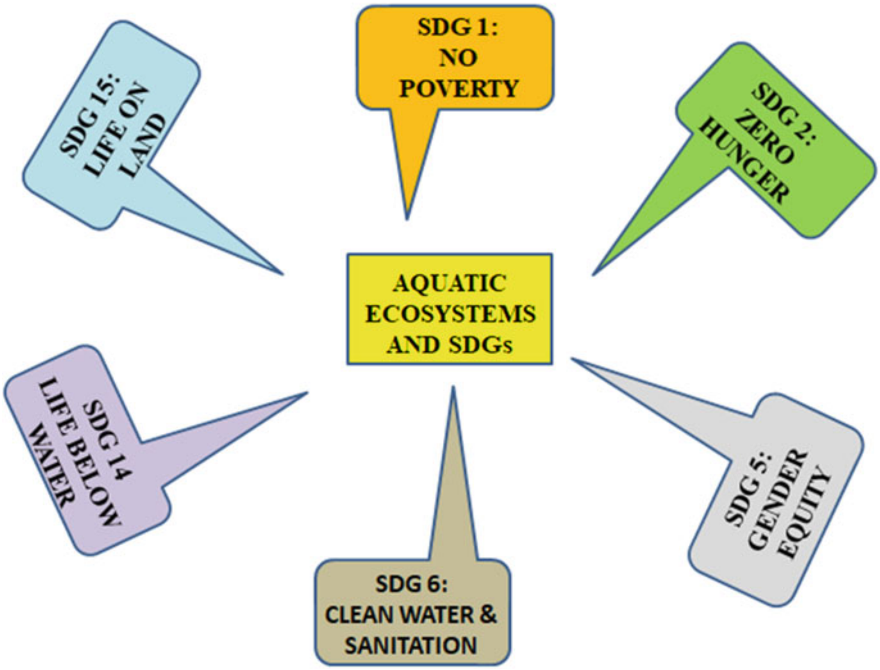

Fig. 14.1 Aquatic ecosystem and sustainable development goals

Vörösmarty et al. 2018). The global threats identified on endangering the sustainability of reservoirs and lakes as identified by Ho and Goethals (2019) are biological invasions, changes in climate, intensification in usage of land and depletion of water. They however postulated that the development of a view on the protection and sustainable exploitation of reservoirs and lakes should be multidimensional. This is essential to contain the threats from human and natural elements. Commending the crucial roles that reservoirs and lakes play in the global well-being of the world, the uses are provision of drinking water, production of food (via aquaculture, fisheries and agricultural land irrigation), recreation, provision of energy (via hydropower dams), treatment of wastewater and control of flood and drought. Other SDGs in relation to environmental dimensions (6, 13, 14 and 15) have positive links with the sustainability of lakes and reservoirs. They both however noted their conflicts with SDGs 1, 2, 3 and 8 which are related to social and economic dimensions.

The enforcement and actualization of SDGs by the aquatic sector of many countries have been achieved by creation of programmes to ensure these procedures. Project like Ambassadors for Biodiversity (EmBio) of the Portuguese western Atlantic coast is a prototype of project in ocean literacy which was developed to improve literacy on marine and coastal biodiversity by ensuring the promotion in conservation of resources in the coastal and oceanic areas and the sustenance of the Portuguese western Atlantic coast values which may be natural and cultural (Ferreira et al. 2021). This research compared project EmBio and the SDGs. They identified connections of 11 out of 17 goals with 31 targets from the 169 with emphasis on the SDG 14—Life below Water. The results pointed out the relevance of the project for the accomplishment of the SDGs.

14.2.3 Aquatic Biodiversity and Sustainability

Jenkins (2003) reported that significant changes will occur in the services of biodiversity and ecosystem by 2050 with more species extinction. Considerable changes are expected with our forest resources. The aquatic environment is not left out in the effect of the incautious behaviour of man. Both marine and freshwater ecosystems would suffer a tremendous reduction in their biodiversity with few large predators. They linked these possible changes to the adverse effect of human behaviour. They however finalized that these changes may likely in themselves threaten human survival. Sala et al. (2000) reported that visible changes in environmental elements like concentration of carbon dioxide in the atmosphere, climatic changes, vegetation and land use with their evident results on biodiversity can be used to forecast the possible effects in the long run. Identifying the major sources of alteration like land-use change, having the largest effect on terrestrial ecosystems. They argued biotic exchange as the most important for aquatic ecosystems. Other issues like changes in climate, deposition of nitrogen, exchange in biotic processes and increased concentration of carbon dioxide were listed. The key driver of most aquatic environments (river and floodplain wetland ecosystems) is the flow regime. They further submitted that the species diversity is also dependent on the natural flow of the water body.

14.2.4 Challenges of Biodiversity

Pearce and Moran (2013) reported that biodiversity loss is major resource problem nations are facing in the world today. They both worked on the application of economic tools in determining the extent of exploitation and how best to manage such. Ecologists are now seeking to improve the outcome of biodiversity with most of them developing tools that can assess better and can recommend the important restrictions and areas of enforcement in curbing the various biodiversity challenges (Walker et al. 2009). Burton et al. (1992) called for a conscious and coordinated form of action towards protecting the ecosystems and landscape. They emphasized the importance of maintaining our various biodiversities in order to aid future sustainability. "*. . . because we cannot always identify which individual species are critical to ecosystem sustainability, nor which species may be useful to mankind in future*", a line in their work, showing the importance of all the known and unknown species to the sustainability of the earth, also agreeing to the work of Takacs (1996).

14.3 The Climate Change Concept

Climate change can be seen as a long-term change in the average pattern of weather factors that can dictate the local, global or regional climates of the earth. These changes in weather factors have a wide range of effects which are observable and that are synonymous with the term. Human activities are the major causes of observable changes in the Earth's climate in the twentieth century, which increases the greenhouse gases in the atmosphere thereby elevating surface temperatures. The increase in temperature resulting from human activities is commonly referred to as global warming and can also be contributed by natural processes. Global warming is caused by certain greenhouse gases and results in a long-term increase in the temperature of the world's surface. According to the United Nations Framework Convention on Climate Change (UNFCCC), climate change is defined as an alteration in climate which is connected either directly or indirectly to human activities. These activities can modify the components and composition of the global atmosphere and these are observed in addition to natural climate variability over a long period of time (Boadu 2016). Scientists on climate change reported that the planet will suffer from drought, reduced rainfall patterns and increased sea-level rise in coastal areas (David 2014). This will affect the supply of water and production of food thereby making millions of people migrate in search of survival (Klare 2008). Climate change will alter the patterns in rainfall and reduce the availability of fresh water by 20–30% in some regions (European Commission 2008).

Changes in climate have various causes. Apparently, all these have their concomitant effects on the earth and human beings at large. The causes are widely divided into natural and human causes leading to the global effect of global warming. The earth's climate is influenced by both human and natural factors, but the observed trend in the past century can be attributed to the effects of human activities on the weather system. According to IPCC (2013) report, human activities have been said to be the most dominant and increasing cause of climate change when compared with any other causes. The dynamics behind the climate system of the earth is a very simple process. When there is transfer of energy between the sun and the earth (which results mostly by clouds and ice), or when the atmosphere releases energy to the earth, the planet cools. When the earth absorbs the energy from the sun or the greenhouse gases interfere with the energy transfer, the heat radiation is released into the space by the earth (the greenhouse effect); this results in the planet warm-up.

14.3.1 Causes of Climate Change

Natural resources have been exploited with no consideration for the effects on the environment. Activities such as deforestation, land degradation, desertification, oil pollution and spillage, urbanization, industrialization and degradation of aquatic

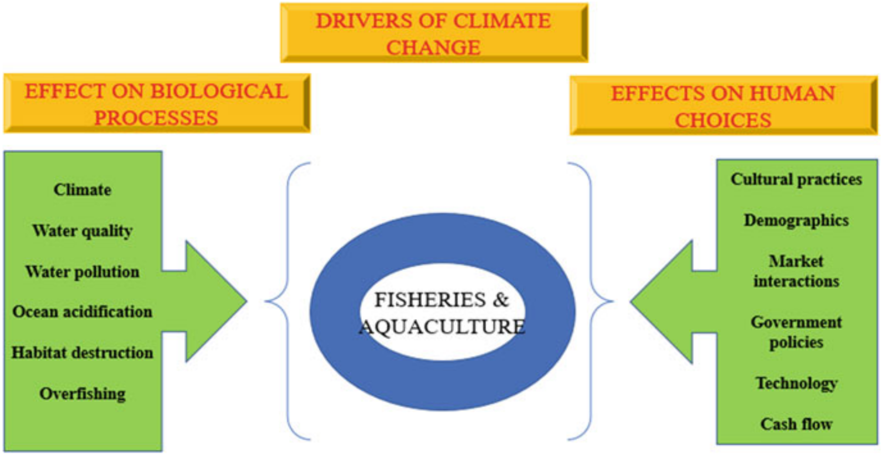

Fig. 14.2 Factors and effects of climate change on biodiversity

habitats have resulted to decrease in natural resources and the destruction of the environment. These issues are mostly felt in the developing countries in which conflicts may arise between the communities and the natural resources (Osibanjo 2009; Ozor and Nnaji 2011). It is essential for sustainable development approach to address the present needs of the environment notwithstanding the contribution of various anthropogenic activities on the natural environment. The environmental system in Nigeria is observed to have a lot of features which are vulnerable and very fragile and susceptible to changes (Asiodu 2013). Apart from the natural effects, anthropogenic activities have been reported to have various impacts as illustrated in Fig. 14.2. Some activities are as follows:

- **Urbanization and growth of population:** This phenomenon has been noticeable in Nigeria in the last decades with an increase in population in urban areas by 60% projected in 2015 from 43.3% in the year 2000. Based on this, a lot of pressure has been put on the forest ecosystem thereby looking for spaces for agricultural production while aquatic lands have been filled and converted to residential spaces.
- **Deforestation:** It is the process of removing the cover of the forests thereby exposing them to severe environmental problems. This activity results in a lot of changes in the natural environment and activities such as bush burning, oil exploration and overgrazing.
- **Erosion:** It is very crucial in the environment and occurs at an alarming rate. It is dictated primarily by the activities on land such as burning of bush, construction activities, overgrazing by animals and pressure from humans.
- **Desertification:** This is a serious issue in the African continent with a lot of land under serious threats to as high as 50–75% in states in northern Nigeria. Human activities and land use activities have increased the extent of desertification.

14.3.2 Natural Causes of Climate Change

Long before the existence of humans, the earth has encountered phases of warming and cooling. Forces which include the intensity of the sun, erupting volcanos and various changes in greenhouse gas concentrations that are naturally occurring can contribute to the process of climate change. It is reported that climatic warming observed in the world today, especially since the mid-twentieth century is at an increased rate and natural causes cannot be the only reason for this rapid increase. According to NASA, the natural causes of climate change are still in play today, but their influences are not significant and their rate of occurrence is too slow to present the rapid warming observed in recent decades.

14.3.2.1 Changes in Earth's Orbit and Its Rotation

The observed changes in orbit and the rotation of the earth axis have impacted the climate regimes in the past. For instance, the past climatic cycles observed in the ice ages were caused by the orbit changes in the Northern Hemisphere of the earth, in which extended cold temperatures were observed (ice ages), and interglacial regimes (periods between ice ages) which are characterized by warmer temperatures were shorter. During the last period of the coldest regime in the ice age (the last glacial period), the average global temperature was about 11 °F colder than it is today. During peak periods in the last interglacial period, the global temperature on the average was 2 °F warmer than the condition experienced in the atmosphere today.

14.3.2.2 Solar Activity Variations

The various changes observed in the energy output from the sun have a direct impact on the sunlight's intensity that gets to the earth's surface. As these changes can dictate the climate of the earth, variations in solar radiation have played little role in the observed changes in the climate regime observed in recent decades. The amount of energy received on the earth from the sun has been monitored and measured using satellites since 1978. The results have however shown that there has been no net in the radiation output from the sun, even an observed increase in global surface temperatures has been observed.

14.3.2.3 The Human Causes of Climate Change

The leading causes of changing climatic issues in the world today are the activities by humans which generate greenhouse gases. Although, greenhouse gases are important in ensuring that the earth is habitable by keeping it warm but the quantity of these gases has rapidly increased in recent decades. Indeed, the atmosphere's

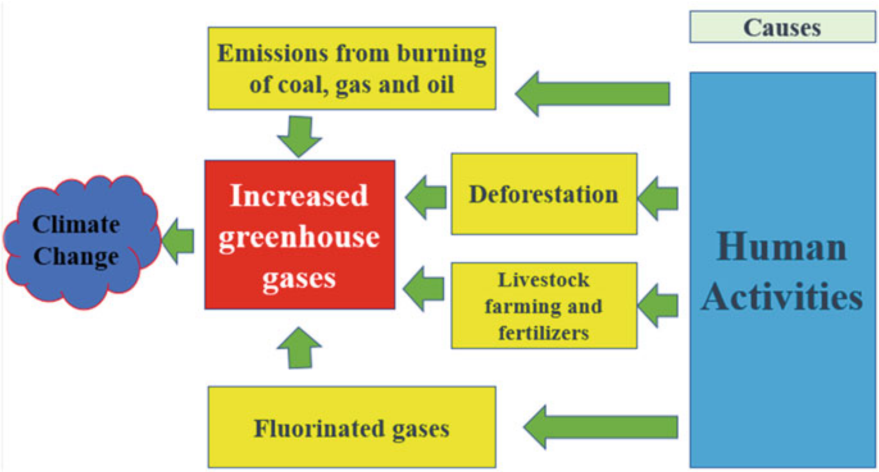

Fig. 14.3 Concept of climate change

share of carbon dioxide has risen by a high percent since pre-industrial times. The greenhouse effects are the major drivers of changes in climate. In the earth's atmosphere, there are some gases that may act like glass in a greenhouse to some extent, which has the ability to trap heat from the sun and obstruct it from being reflected to the space which results in global warming. Most of these greenhouse gases are naturally occurring, but their concentrations are dictated in the atmosphere by intense human activities. The major gases are carbon dioxide (CO_2), methane, nitrous oxide and fluorinated gases.

Human activities are the largest contributors of carbon dioxide in global warming and are the contributors of other greenhouse gases which occur in smaller quantities. Methane has a short lifetime when dispersed in the atmosphere and it is more powerful than CO_2. Nitrous oxide stays in the atmosphere for longer periods like CO_2, and it can accumulate in the atmosphere for periods ranging from decades to centuries. These greenhouse gases are released into the atmosphere through various sources as illustrated in Fig. 14.3. The burning of coal, oil and gas can release nitrous oxide and carbon dioxide into the atmosphere. The cutting down of forests (deforestation) in terrestrial ecosystems which function in climate regulation by sequestering CO_2 contained in the atmosphere. When there is increased deforestation, the rate of carbon absorption is reduced and the carbon stored by the trees is released which results in the greenhouse effect in the atmosphere in the long run. The increased rearing of livestock such as cows, sheep and goats can produce methane to a large extent when their food is digested. Loads of concentrations are released in the faeces as well. The use of nitrogen fertilizers can produce the emission of nitrous oxide. Fluorinated gases are emitted by facilities and equipment that use fluorinated gases for their basic operations. These gaseous emissions have a strong warming effect on the environment and can be up to 23,000 times greater than the effect of CO_2.

14.4 Climate Change in Africa

The global phenomenon which has been reported by IPCC (2007) has cut across various spheres of life, affecting production, maintenance and sustenance of all life processes. To this end, statements from researchers have been reported so as to raise awareness on the importance of sustainability and smart use of the environment. Africa is majorly composed of countries categorized as underdeveloped with few developing and very few categorized as developed. The vulnerability of underdeveloped countries is very high because they lack adequate strategies to tackle the effects caused by changes in climate. It was reported by Collier et al. (2008) that Africa is more vulnerable to these climatic changes because it is agriculture-dependent and its capacity to adapt to these changes is limited. Crop yield will be greatly affected leaving a whole work for the countries' governments in policies making to curb the possible effect. Toulmin (2009) also submitted that changes in change as a principal threat to African countries. Strategies in reducing vulnerability by most African countries are being advocated as this may widen their horizon in terms of fighting environmental, resource and economic perturbations. With the light contribution of Africa to changes in climate, the continent would suffer most from it. There is a need for proper sensitization on the possible effect of changes in climate and constant review of the status of international climate agreements related to adaptation, mitigation and compensation (Nkomo et al. 2006). It is observable that the rainfall and temperature variables have changed and are predicted to increase with increasing anthropogenic activities (Rodney et al. 2021).

Issues relating to climate issues have been debated decades ago. Hulme et al. (1995) reported about the clear uncertainty surrounding the future effects of changes in climate in African nations and possible adaptive strategies. They considered the African societies, their response to changes in greenhouse gaseous emissions in the climate system, and the extent to which ecosystems and economies will adapt to changes in climate. Hope (2009) agreed with other authors on the occurrence or the negative impacts of changes in climate in Africa; however, he was more bothered about the less report on the possible devastating impact on the socio-economic development and the policy measures available to Africa for adaptation. Brown et al. (2007) submitted the effect of policies and programmes in curbing or averting the effect of changes in climate with possible consideration of existing social, political and economic tensions in African nations. They referred to changes in climate as more than just an environmental issue but also as a security issue in Africa. Challinor et al. (2007) reported the impacts of changes in climate in Africa. They further submitted how important the policies of the government are in curbing the effect of changes in climate in Africa. All these reports had predicted the issues happening in the continent today, ranging from political issues to inadequate funding for combating the climate change effects. The aquatic systems of today have had their share of the impact of changes in climate, however, there is little research into its effect on the system in general (Morrongiello et al. 2012). The use of fish, molluscs and some coral hard parts have the potential of being used as ecological indicators for measuring the climate change impacts on the aquatic environment. Most African nations depend on their water for food (Mali on Niger), hydroelectric supply (the case of Akosombo dam which depends on River Volta in Ghana) and transportation. A drop in water level resulting from changes in climate can result in crisis in the economy. The various effects of changes in climate across Africa are drought, flooding, changes in rainfall patterns, melting of glaciers, receding and drying-up of rivers.

There have been occurrences of climate changes over the years; however, the current rapid changes are notable and of great concern in the earth's history. Tracing to earlier reports on changes in climate, Houghton et al. (1990) in their report on assessment of changes in climate observed at that time that there were changes in climate (post-industrial era) when compared with what was observed in the previous century (pre-industrial era). The conclusion at that time was attributed to human activities with an observable increase in sea level resulting from changes in climate. Change et al. (2006) opined that the ultimate cause of changes in climate is human activities and the impacts are noticeable in all sectors of the economy. From a viewpoint of an ecologist, Thuiller (2007) recommended the climate and biodiversity assessment due to rise in the global temperature with its adverse effects on precipitation patterns. Urry (2015) agreed with other authors that there are much doubts from scientists on the issue of climate change despite the established concepts.

14.5 Effects of Climate Change on Aquatic Systems

14.5.1 Rise in Sea Level

It was reported by IPCC (2007) that the range of global projected level of sea rise is uncertain. It is reported that evidence on the level of accelerated rise in sea level, and only the high-climate sensitivity case was considered. This acceleration led to a range of 49–59 cm in global rise in sea level at the end of the century. It is posited that global warming has contributed significantly to the observed sea-level rise through terminal expansion of water in the sea. Many coastal cities around the world may be submerged due to the rising sea level and it is expected to rise two to four times faster in this twenty-first century. A rising sea level will put thousands and millions of people as environmental refugees. Globally, the sea level on the average has been increasing at a rate of 1.8 mm/year on the average since 1961 (Church et al. 2004; Miller and Douglas 2004; Douglas 2001). This is due to overstretching the capacity of the glacier ice absorption of heat which leads to change in the state of ice to liquid. All coastal ecosystems are vulnerable to rise in sea level and more direct impact of anthropogenic activities, especially coral reefs and coastal wetlands (including salt marshes and mangroves) (Barange and Perry 2009). This implies that the food web of the ecosystem coupled with breeding site will be destroyed.

14.5.2 Increased Salinity

Salinity changes in the oceans are an indirect but potentially sensitive indicator of a number of processes in changes in climate such as rainfall, evaporation, run-off of rivers and melting of ice. Salinity changes have been observed in the ocean, with the waters close to the surface in areas that are exposed to increased evaporation are posed to increasing salinity in almost all basins of the ocean, and decreased salinity is observed in high latitudes due to greater precipitation, increased run-off and ice melting (FAO 2008). Salinity changes will definitely affect the natural physiological adaption techniques of the fish to its environment as more energy will be spent on osmoregulation to the new changes in their environment and the more unstable the environment becomes the more stressed the fish will be, leading to fish migration, disease and fish kill (Kolawole and Iyiola 2018).

14.5.3 Floods

Floods have been reported to be the most common natural disaster in the world (European Environment Agency 2004), resulting in economic losses such as damage to infrastructure, lands for agricultural activities and other losses that are not directly within the flooded areas and beyond. The trends in damages caused by flood have increased over the last decade and have been attributed to increased socio-economic factors (Barredo 2007). The issue of global warming is predicted to increase as well as increased rainfall and flooding.

14.5.4 Drought

The nature and changing pattern of rainfall especially low rainfall leads to drought in Africa and other parts of the world. Drought is of various types:

- Meteorological drought which occurs when precipitation is well below average based on recommended standards
- Hydrological drought which is attributed to river flow and the low levels of water in lakes, rivers and of groundwater
- Agricultural drought which is related to low soil moisture

- Environmental drought which combines the metrological, hydrological and agricultural droughts

The interaction between the natural environmental conditions and the human factors such as changes in the use of land, its cover and water demand are termed as the socio-economic impacts of drought on the environment. Excessive withdrawal of water from the environment can increase the impact of droughts (Institute of security studies 2010).

14.5.5 Effect on Water Supply and Quality Leading to National Security Issues

The effects of changes in climate which is observable in water resources in Africa include flooding, drought, rainfall distribution changes, drying-up of rivers, glacier melting and the receding of bodies of water. Water is a very important resource and it is needed everywhere that even the poor and the rich need it. No community or continent can survive without water, but changes in rainfall patterns affect and reduce the water supply and the quality of the water. Drying-up of water bodies means they can no longer support plant life as most plants will die due to lack of water. The impacts of climatic change on the environment are enormous; it has the potential to increase the issues of national security and numerous international conflicts in an environment. Conflict is a survival instinct of life and it occurs over the use of already limited natural resources, grounds that are fertile and over the use of water. Access to a dependable and constant source of water is greatly demanded in many African regions. However, the fluctuation and changes in the pattern and timing of rain have affected the availability of water in the environment. This is a major course of conflict in an environment over this limited resource (IPCC 2014).

14.5.6 Change in Rainfall Pattern

Considerable numbers of lakes in Africa have experienced a reduction in size and composition. Increased temperature affects rainfall pattern and in turn modifies the run-off pattern with a resultant effect on the quality and quantity of life in the ecosystem. Precipitation which is a source of water for most aquatic environments is affected by climate change. The food security of the continent would be affected which may lead to more unrest in the African nations. The drought reported between July 2011 and mid-2012, affecting Eastern Africa, was said to be the worst of it in more than 50 years.

14.6 Effects of Climate Change on Biodiversity

14.6.1 Effects on Fish Species

14.6.1.1 Coral Bleaching

Around the globe, coral bleaching and damage to reef ecosystems are caused by high sea temperature (World Fish Centre 2007). The high-temperature impacts are directly felt in the process of stock recruitment in the open ocean, the coral reef assemblage and the breeding grounds thereby reducing its biodiversity. The combined interaction of ocean warming and coral reef habitat degradation is expected to reduce the yields from coral trout fisheries significantly (Johnson et al. 2018). These impacts are felt in the changes in resources capture, cost involved in production and marketing of products, changes in prices during sale, and possible increases in risks of damage or loss of infrastructure and housing (FAO 2008). Massive fish kills were reported on the Coral Coast of Fiji and in Vanuatu by Welch and Johnson (2017). The temperature of water on the reef flat was consistently over 30 °C and was as high as 35 °C in Fiji. Johnson et al. (2018) linked the situation to the influence of higher water temperatures on oxygen concentrations as oxygen has an inverse relationship with temperature. Low recruitment will definitely have its impact on the fish stock and on the fish price because supply will reduce due to low catches by the fishermen meanwhile the demand for fish is not getting lower but higher due to constant increase in population. This increase will pose more pressure on the little available resource, and can simply be termed as the demand getting higher and supply getting lower.

14.6.1.2 Sea Warming

Fish are poikilothermic animal; this implies that any alteration in the aquatic environment will have direct impact on their physiological process. Any changes in the temperature of habitats will influence the metabolism of species significantly and, hence, their growth rate, total production, seasonality of reproduction, reproductive efficacy, and susceptibility of animals to various diseases and toxins (FAO 2008).

14.6.2 Effects on the Environment

14.6.2.1 Agriculture and Food Security

Climate change has become a major factor determining or affecting rainfall patterns across the globe by either increasing or decreasing the patterns in various regions or continents. Rainfall can be torrential leading to loss of lives and properties such as the tornados currently happening in different parts of the world. It can also lead to low rainfall leading to droughts as all these affect agriculture and invariably food production. With reduced rainfall, it can lead to famine and malnutrition.

14.6.2.2 Change in Distributions Pattern

Rahel and Olden (2008) reported the effect of changes in climate on the abundance and distribution of the aquatic organisms with the complexity of their various reactions. Migration of invasive species into a new environment would distort the natural flow of energy or change the interactions in such environment (Parmesan 2006; Jackson and Mandrak 2002). This may also lead to seasonal shock in fish species (Sharma et al. 2007). Rahel and Olden (2008) concluded that a decline in composition of native species and loss in biomass population are other effects associated to changes in climate.

14.6.3 Effect on Health of Human Beings

The changes in climate have a range of complex interlinkages with health (Costello et al. 2009). Managing the health effects of climate change includes the direct impact on human beings such as illnesses related to increase or decrease in temperature and extreme weather events. There are also indirect impacts on human beings such as issues that cause water- and food-borne diseases, diseases by vectors or the scarcity and shortage of food and water. The relationship between mortality and temperature is a direct one and temperature can differ based on climatic zones and geographical locations (Menne and Ebi 2006). Heat strokes and illness can result from high temperature (e.g. cardiovascular diseases); however, increasing temperatures can reduce the occurrence of death in winter periods. The empirical relationship between mortality caused by heat or cold is based on the mortality and temperature effects (Ciscar et al. 2009).

14.6.4 Ecosystem Effects

The effects of changes in climate have impacted fresh and marine ecosystems in Eastern and Southern Africa, while the impacts in southern and western parts of Africa are on terrestrial ecosystems. The weather extremes have also affected some parts of South African ecosystem. Species in terrestrial and marine environments have been affected by changes in climate and their migration patterns, geographic cover and seasonal activity are being shifted as a result of climate change as well as interaction and distribution of species (IPCC 2014).

14.6.5 Effects on Vulnerable Population

The most vulnerable people to the climatic change impacts are women, children and the elderly across Africa. The scarcity of water is a burden on women in Africa, as they trek for several hours and sometimes days to get water (IPCC 2014). The children and the elderly are vulnerable to infectious diseases (such as Malaria), limited mobility and reduced intake of food, while the elderly are vulnerable to physical danger and death due to loss of water, heat stress and wildfires. Children mortality may result from issues such as malnutrition, starvation and flooding.

14.6.6 Effect on Tourism

The tourism sector in Europe is a major economic sector, with one out of every six tourists in the world are from either Northern or Southern Europe. Climate change can alter the potential of tourism in Europe by inducing changes in destinations and demand based on the structure of the seasons. In Africa where there are good tourist places, most people from other parts of the globe visit especially places like Kenya and South Africa, but because of the change in weather conditions due to climate change, it has affected the tourist sides or even distracted the time of visit, therefore disenabling tourist.

14.7 Conservative Strategies of Fish Species to Climate Change

The survival of fish species depends on many factors in which climate is not an exclusion. Beginning from the early stage of fish development up to its adulthood, climate plays either a direct or indirect role in fish development. Significant threats to fisheries are posed by changes in climate change and many other concurrent pressures such as overfishing, degradation of habitat, pollution, introduction of new species and so on (Brander 2010). Changes in climate and its effects on the fisheries need to be appraised just as it has been done to other sectors in the world because climate is a major prerequisite to the flourishment of the world ecosystem and any alteration or fluctuation in this abiotic factor will definitely affect the general ecosystem in which fish is not excluded. It may be argued that the possibility of detection in generalities of the response of fish population to changes in climate is slim because the factors that influence fish population are very numerous and fish species vary in their response to changes (Rijnsdorp et al. 2009). But according to a law that states “to every action there must be a reaction and this reaction”, most of the times responses, are in an opposite direction.

The reproductive ability of fish is greatly affected by changes in water temperature, and other impacts on cueing, egg production, larval distribution and survival are noticeable (Potts et al. 2014). Natural climatic fluctuations have always affected fisheries as well as their management performance (Garcia and Rosenberg 2010). Climate change will directly affect abiotic factors that are connected with fish population distribution, and the biotic changes dictated by climate will likely differ between the Open Ocean, shelf seas and coastal waters (Lehodey et al. 2006; Walther et al. 2002). Studies from basic principle show that fish generally have their low and optimum range for survival even though this varies from species to species, but there is a range that will affect the fish community in general. For instance, fish needs dissolved oxygen to survive so anything that will cause the oxygen to deplete below the tolerance of even the hardiest species will result in many things such as migration, death or even extinction and dissolved oxygen has an interaction with the temperature which is a direct function of the climate.

14.7.1 Adaptive Strategies

It is evident that humans through their activities started a global war with nature and it seems that the nature has started its own fight back and is also set to take more revenge for the damage that has been done unto it and the fisheries sector is receiving its own blow big time. Studies have clearly shown that increase in anthropogenic activities will only worsen the standing situation. So here are some adaptive measures that could be taken to help slow down the impact of the change in nature of fisheries resources.

- Reducing the use of the aquatic environment as dispose centre of thermal waste as this is also another source of heat that can be controlled when compared to the climate that can't be controlled directly.
- Anthropogenic activities should be cautioned totally because the water is ready to react to anything due to its increase in temperature and this can be a major cause of acidification.
- Proper awareness concerning changes in the ecosystem should be made to people.

Aquaculture can be a bail out for declining fisheries resources, so more research should be done to increase the biological knowledge of more fish species so as to increase the number of fish species that can be cultured as this could be a way out of the extinction of many species that are currently endangered.

14.8 Climate Change and Ecosystem Services

Biodiversity is the variety of life on earth comprising ecosystems, species and genes. It is essential to economic prosperity, security, health and other aspects of our daily life. Biodiversity loss can undermine and threaten efforts to improve economic, social and environmental well-being in the EU, and worldwide (EU Biodiversity Policy 2006). Decline of any aspect of biodiversity to threshold when they cannot contribute to ecosystem servicing can have dramatic impacts on the importance of ecosystem services upon which people depend. Due to changes brought by climate and ecosystem services, plants (including aquatic plants) and other species are also responding to it to enable them to survive the turbulent weather changes and the environmental changes which eventually affect the productivity of aquatic ecosystems.

14.8.1 Responses of Biodiversity

14.8.1.1 Shifts in Species Distribution

The broad conclusion of literature results shows that migration of species has increased to other areas in response to changes in temperature and precipitation regimes, generally poleward, towards higher elevations. Groffman et al. (2014) reported a movement of plants and animals in terrestrial environments towards higher elevations at the rate of 0.011 km per decade and moved to higher latitudes at the rate of 16.9 km per decade. Changes in climate have resulted in a shift in distribution of East African species and ecosystems. Climate change and ecosystem are significantly altering Africa's species diversity (Iyiola et al. 2020, 2019, 2017). An example is the endemic Ethiopian wolf (*Canis simensis*) which is struggling to adapt to the dry periods which have appeared to be longer and the reduced availability of water and other resources. Ecological specialists are particularly vulnerable and react strongly to changing resources due to their relatively narrow diet. The land use pattern in many African countries can limit animal species from changing routes of migration. For instance, the spread and expansion of agriculture on huge scale has disrupted the migratory journeys of animals thereby leading to decline in population of large mammals.

14.8.1.2 Demographic Responses

Loss of natural habitats and shifting habitat ranges to more suitable ones as a result of climate change can have significant effects on the population size and distribution of species (Erasmus et al. 2002; Walther et al. 2002). *Canis simensis* has already changed its geographical range and moved towards higher elevations; this is a way of adapting to the increasing changes in temperature and rainfall regimes. These shifts might likely bring about new assemblages of species, cause novel, interspecific interactions, and in the worst-case scenarios, result in some extinction (Barnosky et al. 2011; Butchart et al. 2010). Additionally, this relationship could be exacerbated if climate change restricts the range of a species to just a few key sites and an extreme weather event occurs, thus driving up a population decline and extinction of the species in the future (Ipinmoroti et al. 2018). Species ranges will probably not shift in cohesive and intact units and are likely to become more fragmented as they shift in response to changing climate (Barnosky et al. 2011; Walther et al. 2002). For biodiversity conservation, it is important to understand how species and their ecosystems can change under varying changing scenarios.

14.8.1.3 Phenological Shifts Response

Changes in phenology or the seasonal timing of life events have been observed in Africa in response to variations in temperature, precipitation and photoperiod. Phenological events include changes in leaf growth, flowering and blooming in plants, and shifts in the timing of spawning, reproduction and migrations in animals (Dawson et al. 2011; Doak and Morris 2010). Issues of extreme weather can affect biodiversity in a complex pattern; for instance, African elephants (*Loxodonta africana*) breed all year round, but the male species that are dominant mate in the wet season and the subordinate males breed during the dry season. Subsequently, changes in the intensity or duration of rain can alter their relative rate of breeding, and, hence, genetic structures in these populations. As food crop production is the main agricultural activity in Africa, lengthened growing seasons would also mean increments in costs of production of crops. Besides, current research is starting to explore the role of epigenetic responses, wherein environmental drivers alter gene expression and can be passed to future generations, occur between generations, and are considered intermediate responses (Jeremias et al. 2018).

14.9 Conclusion

Changes in change have become a challenge and global threat in our time. The causes of these changes can be of both natural and human origin and the economic, social and biological impacts of changes in climate cannot be waived. Biodiversities are components of the environment and are the direct recipient of these changes and the complexity can result in migration and even mortality in extreme cases. The human survival and sustainable development of the environment are at risk due to climate change regimes. The health of ecosystem which is an indicator of biodiversity is declining to an unprecedented level. This in turn affects aquatic ecosystem, food and nutrition security, employment and decent living. We must all reduce our footprint and tackle climate change to sustain the present and future generations as elaborated in the Sustainable Development Goals. The concept of climate change must be understood by countries and necessary stakeholders in decision-making towards sustainable development. The goals evolve around sustainability and they all at one point or the other may be affected by these climatic changes. Urbanization, population growth, desertification, deforestation and land activities must be checked to reduce the stress on the environmental system. The greenhouse gas emissions must also be reduced by safe livestock farming, precise farming activities, afforestation, reduced burning of fossil fuels and shift to green fuels. This will go a long way in preserving the ozone layer in the atmosphere. The vulnerability of African continent which is a result of the agricultural dependence must shift to a precise agricultural farming practice. Most African countries are categorized as developing and they lack incentives to tackle the effect of climate change.

Finally, the aquatic ecosystem which is the recipient of all land-based activities must be maintained. They are affected by floods, erosions, changes in rainfall patterns, water use and human activities on and around the water ecosystem. The fishery resources are greatly depleted if the aquatic system is not in the adequate quality and quantity. To this end, conscious efforts must be geared towards protecting climate-smart land-based activities for good and healthy environmental system.

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Chapter 15
Anthropogenic Restructuring of Fiddler Crabs (*Uca tangeri*) Communities: A Solid Wastes Perspective

M. Moslen, C. A. Miebaka, and P. K. Ombo

Abstract The constant increase in human populations and its associated activities has become a stress factor for ecological communities of the aquatic ecosystem/environment. The aquatic environment/ecosystem particularly, the intertidal zones, mangrove forests and wetland ecosystems serve as a refuge for a diversity of organisms including fiddler crabs (*Uca tangeri*), with habitation and protection often coming in the form of extensive mudflats/sandy beaches and dense vegetations. This study evaluated the effect of anthropogenic activities on fiddler crabs (*Uca tangeri*) population particularly, on the fragmentation/loss of their habitats due to impact from solid wastes. Habitat fragmentation and loss due to solid wastes along the intertidal zone could eventually lead to biodiversity loss. The decapods (fiddler crabs) are among the common burrowers found in the intertidal and wetland zones of the coastal environment in the Niger Delta, Africa and other parts of the world. They are in the family Ocypodidae and have a number of features (size and shape of eyestalk, antenna, carapace, pairs of walking legs with chelipeds, body colour and sexual dimorphism) that could easily distinguish them from other crabs. They play very important ecological roles and interactions that sustain their ecosystems, serving as prey and predators in the ecological food chain/web. Fiddler crabs actively participate in bioturbation and organic matter degradation which has significant effect on ecosystem health/processes and so contributes to ecological diversity. Therefore, the impact of solid wastes due to anthropogenic activities is a menace of concern to the ecology, activity and life of fiddler crabs. The domination of solid wastes on the intertidal zones of our estuaries and coastal system had caused serious habitat degradation and loss for fiddler crabs and other organisms. Review of studies within the Niger Delta (Iwofe, Eagle Island and Ibeto) in Africa indicated serious threats to the habitats and existence of fiddler crabs due to the menace of

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solid wastes, indicating they are endangered. Significant variation in fiddler crab holes between different sites suggested population density variation across the sites. This was attributable to the influence of solid wastes that had taken over and fragmented the habitats of these intertidal dwelling crabs. This also suggests the level of anthropogenic activities (municipal wastes from run-off and direct discharges into the aquatic environment) impacting fiddler crab habitats by blocking fiddler crab burrows and occupation of available shoreline space, dislodging the crabs from their habitats. Increasing population and change in consumption pattern are responsible for increased waste generation in surrounding towns and cities. Other factors related to anthropogenic activities such as dredging/land reclamation, urban development, waste from urban run-offs and direct disposal, exploitation of mangrove resources and commercial boat activities further fragmented and degenerated the ecology of this very important species. These anthropogenic impacts could lead to a decrease in available refuge for such intertidal dwellers (fiddler crabs) and further endanger them, which could expose the crabs to increased predation, mortality rate and an overall reduction in population and consequent biodiversity loss. Sequel to the important ecological roles of fiddler crabs, alteration of their population and behaviour may have an adverse effect on the habitat and ecosystem. This may lead to biodiversity loss and eventual loss of important ecosystems such as intertidal environments, salt marshes, mudflats and mangrove forests.

Keywords Fiddler crabs-*Uca tangeri* · Anthropogenic activities · Solid wastes · Impacts · Conservation

15.1 Introduction

The natural environment is made up of the biotic (living) and abiotic (non-living) components that are constantly interacting to sustain the various ecological systems. Increase in human population and associated anthropogenic activities are major stress factors for various ecological communities/systems that make up the environment. This has led to unsustainable exploration and exploitation of natural resources in the environment with far-reaching negative impacts and consequences—*ecosystem degradation and biodiversity loss*. Issues of climate change and global warming driven by greenhouse gas emissions due to human activities are still topical and of very great concern making world leaders to gather at the recently concluded COP26 (United Nations conference) in Glasgow, Scotland, from 31 October to 13 November 2021. This was to proffer mitigations/solutions to the mirage of challenges faced by mother earth due to the activities of man. The impacts of anthropogenic activities have a global facet but in Africa, the Niger Delta region is one of the most impacted environments due to the decades of oil and gas exploration and exploitation activities in the region. Various studies by researchers in the Niger Delta have reported different degrees of impact due to industrialization and other human activities leading to environmental degradation, ecosystem/habitat damage and biodiversity loss (Moslen and Aigberua 2018; Moslen et al. 2018; Moslen and Miebaka 2017a;

Moslen and Miebaka 2017b; Nwoha et al. 2019; Moslen et al. 2019; Okolocha et al. 2020). It is also very pertinent to state that urbanization, industrialization, agricultural practices and most importantly, changes in lifestyle and consumption pattern have led to the generation of different kinds of wastes particularly solid wastes (Moslen et al. 2015). The indiscriminate disposal and improper management of volumes of solid wastes generated by the ever-increasing population remains a critical concern particularly in developing countries of the world. Such wastes eventually are drained to the aquatic/coastal environment (creeks, rivers and seas/oceans) where they constitute an environmental/ecological and economic menace to the society. One of the most impacted environments is the fragile and sensitive aquatic ecosystem/wetlands that house the intertidal zone. The intertidal zone/wetland is habitat and home to great diversity of organisms particularly, the fiddler crabs (*Uca tangeri*) that play a key ecological role in the intertidal ecosystem. Fiddler crabs have proven to be very important in intertidal/wetland environment in various ways such as aerating the soil, soil drainage and soil decomposition operations. This zone is one of the most studied and researched zones in the aquatic environment due to its easy accessibility and interface with contaminants and other harmful wastes dumped into the area. It is also one of the most impacted zones in the aquatic environment being in the frontline of receiving contaminants and solid wastes flowing into the rivers and seas. Huge volumes of solid wastes have taken over the intertidal zones/wetlands and natural stretches of mudflats that provide habitats for great diversity of organisms in such sensitive ecosystems. Wetland ecosystems so far have served as a refuge for many species such as fiddler crabs, with protection often coming in the form of dense vegetation. The implication is that of habitat fragmentation/damage and eventual ecosystem loss if not checked. A change in fiddler crab population and behaviour can have an adverse effect on the habitat and could lead to the loss of important ecosystems such as salt marshes, mudflats and mangroves. This is because key ecological phenomena like breeding/nursery activities and food chain processes that sustain the entire coastal ecosystem might be heavily impacted or even lost completely. Again, the livelihood of human populations depending on such rich ecological zones would be in jeopardy. This makes the consequences of the impact of solid wastes on the intertidal zone far-reaching. This chapter, therefore, sought to review and evaluate the impact of anthropogenic activities on organisms like the fiddler crab—*Uca tangeri*—of the intertidal zone with particular reference to solid wastes and possible conservation options for these endangered species of a sensitive coastal ecological zone.

15.2 Biology of Fiddler Crabs (*Uca tangeri*)

The West African fiddler crab (*Uca tangeri*) is a very important organism in the mangrove ecosystem. They are commonly seen on river banks, beaches, swamps, mangrove forests and stretches of mudflats along coastal ecosystems of lagoons and brackish waters. Understanding the biology of this very important species is the key due to the impacts of anthropogenic activities on the fiddler crab populations. Generally, the physiology and metabolism of the fiddler crab may not seem too different from those of other similar decapods. Taxonomically, the fiddler crab is classified as follows:

Classification

Kingdom	Animalia
Phylum	Arthropoda
Subphylum	Crustacea
Class	Malacostraca
Order	Decapoda
Infraorder	Brachyura
Family	Ocypodidae
Genus	*Uca*
Species	*tangeri*

It is also pertinent to mention that there are other species of these fiddler crabs both in Africa and other regions of the world. Such species of the same genius include *Uca thayeri*, *Uca lacteal*, *Uca pugilator, Uca rosea, Uca perplexa, Uca rapax, Uca vocans, Uca iranica, U. annulipes* and *U. sindensis.*

*15.2.1 Morphology of Fiddler Crabs (*Uca tangeri*)*

The fiddler crab is one of the most noticeable organisms on marshes, lagoons and estuarine beaches. They constitute one of the most important preys in salt marsh habitats (Wolff et al. 2000). Fiddler crabs are in the family Ocypodidae, they could easily be identified and differentiated from other crabs by their smaller eyes placed on longer stalks which are set close together (Teal 1958). The antennae of the fiddler crabs are longer but with shorter legs (Rothschild 2004). These antennae serve mainly for communications with the crab's surrounding environment and responses to different stimuli. The fiddler crabs possess four pairs of walking legs with a most anteriorly fifth pair improved into clawed limbs called chelipeds used mainly for protection and feeding. Crabs of the family Ocypodidae are distinguished by their sexually dimorphic claws where the major claws of the males are quite larger than the minor claws but both the claws of the females are same in size (Levinton et al. 1995). The colour of the body of the fiddler crab is mainly dull to grey, tending more greenish-blue around the anterior region of the carapace and eyestalks. According to Moruf and Ojetayo (2017), the carapace of the fiddler crab has violet to black colour but sometimes yellowish in female species and the appendages also appear yellowish-brown in colour. The abdomen is small, highly reduced and carried permanently fixed below the cephalothorax where it fits tightly within a shallow depression. The movement of the smaller claw of the male from ground to mouth during feeding depicts the crab's common name where it appears like the crab was

Fig. 15.1 Fiddle crab [A-male] and [B-female]

playing the larger claw like a fiddle (Levinton et al. 1995). According to Carlson (1935), colour is controlled by the blood-gland of Hanstrom which is located at the mid part of the eye-stalk of the crab. Colour variation during the day and at night is also characteristic of the fiddler crabs where they appear darker during the day and lighter at night. The black pigment spots (melanophores) of the crabs are open while the white pigment spots (leucophores) close during the day and the opposite takes place at night, which makes the crab lighter in colour. The carapace of the fiddler crab narrows towards the anterior, but the frontal view appears comparatively wider. The upper orbital margins of the crabs are characteristically composed of two edges that are sharp, making an eyebrow that is inclined and nearly vertical. The fiddler crabs also characteristically have short hairs on the adaxial part of the first and second pairs of walking legs and the big claw of the males (Crane 1975; Thurman 1979; Rothschild 2004). Sexual dimorphism is a morphological feature of the fiddler crab with one of the male claws bigger than the other but are similar in size for the female species. Activity of the male claw is very pronounced during courtship for the attraction of the female species. The large claw of the male is also used in territorial protection (Allen and Levinton 2007), species-specific displays and threats to intruders. Figure 15.1 shows male and female fiddler crabs in their habitat.

15.2.2 Reproduction

Fiddler crabs like *Uca tangeri* are a good model example of sexual selection particularly depicting how males display and burrow ornamentation influence the choice of female mate behaviour (Pope 2000; Christy et al. 2003). The reproductive system and reproduction in fiddler crabs may show variations between different species which could be related to structural morphology, behavioural patterns, different adaptations and evolutionary attributes though, similarity still exists in their reproductive physiology. The reproductive organs gonads are testes and ovaries for the male and female crabs, respectively. In terms of behaviour, courtship is highly pronounced in the fiddler crabs. This is demonstrated by the complex waving signals and rhythmic movement of the larger claw of the males in a bid to attract the females as part of their reproductive process. This action is observed in mass on the intertidal zones and stretches of mudflats at low tides with most males showing territorial integrity around their holes and breeding burrows. Salmon (1987) reported that receptive females select their mate and enter the male's burrow to enable copulation in the burrow. Mating system in most of the fiddler crab species is resource-based because male breeding burrows are areas used by females for ovulation and incubation of their clutches. Reproduction is higher during spring and summer relative to winter. It is also important to state that mating could also take place outside the holes/breeding burrows, therefore, mating could be on the surface or underground. Spawning of females does not only take place in the male breeding burrows but female could also breed and spawn in their own burrows. Nakason and Murai (1998) in their studies reported that 31% of surface-mated female species of *Uca lactea* spawned in their own burrows and not of the male while 96% of underground mated female species oviposited in the burrows of the mated male (Murai et al. 1987; Goshima and Murai 1988). Underground pairing of copulating crabs could also differ between species with the male or female entering the hole/burrow first with mating period varying between a few days. Fiddler crabs pass through different developmental stages from hatching of the eggs through juvenile to adult stage with moulting also observed in between. The larval form (zoea) after hatching is a free-swimming planktonic form like that of other decapods that develops to the Megalopae, the final larval stage before the adult stage of the crab. The average incubation period of *Uca lacteal* is 15.4 days (Yamaguchi 2001). Fiddler crabs exhibit seasonal growths with higher growth rates during warmer seasons relative to colder seasons. Males of fiddler crabs also show higher growth rates than their female counterparts possibly due to more commitment of energy by the females during reproduction years. Considerable reduction in growth rate may also coincide with maturation which reflects distribution of energy to gonadal development (particularly in females) and other processes associated with reproduction such as waving demonstrations and constructions of hood by males (Mokhtari et al. 2008). This may vary with respect to species in different environments and regions.

15.2.3 Food and Feeding Habits

The fiddler crab, a semi-terrestrial dweller of the intertidal zone feeds during the low tide and enters its burrow at high tide. The fiddler crab is a detritus feeder taking sediments with plants and animal remains which can lead to changes and modifications of the surrounding environment. In other words, fiddler crabs are mud eaters where they also take up contaminants small enough to be ingested. The sediment is taken up to the mouth opening using the claw. Movement of their mouthparts enables uptake and push-in of mud and water, where they separate the organic content (food) of the sediment from the inorganic content (sand) which are eventually discharged to form pellets around feeding grounds near their burrows. They swallow the food and spit the sand back out in little balls. In a study to examine feeding (particularly quality and size of food) of the fiddler crab *(Uca tangeri)*, Wolfrath (1992) reported that all particles smaller than 250 μm were ingested irrespective of the chemical composition of the particle. The study further showed that *Uca tangeri* mainly feeds on microalgae that are extracted from the sediment in addition to vascular macrophytes, macroalgae, detritus and dead remains of fish and other organisms. Saher and Qureshi (2014) observed that the foraging distance away from the burrow, and the shape of the radiating paths of fiddler crabs were specific to each species and correlated positively with the diameters of burrows. Saher and Qureshi (2014) further reported that the percentage content of the mud in the stomach was significantly different among the four species of crabs examined. According to Saher and Qureshi (2014), stomach contents of crabs had also shown plant debris, interstitial organisms, their eggs, spines and animal tissues but *Uca urvillei* was observed to be a predator species. Availability of food has been said to depend on the productivity of the ecosystem, microbial activity, substrate texture and tidal action (Twilley et al. 1995; Moura et al. 2000). A key digestive gland in the crab is the hepatopancreas which plays a role in absorption of digested food and separation of digestive enzymes after the food is broken down in the stomach. Summarily food is taken up by the claws in its filter-feeding style where the digestive glands release enzymes that digest the food before absorption of nutrients and eventual elimination of wastes through the anus. Fiddler crabs can feed and store reserves particularly with respect to seasons. During unfavourable seasons, they remain inactive and survive on stored food until conditions return favourable.

15.2.4 Excretion in Fiddler Crabs

Excretion which is the removal of wastes from an organism is also synonymous with osmoregulation. This is a very important phenomenon in the life of aquatic organisms due to the fact that it helps to maintain body fluids of the organism. The main excretory organ of the fiddler crab is the antennal gland. It is also very important in osmoregulation in view of the fact that the crabs live in a saline environment which is quite challenging. The antennal glands contain cells that can regulate salts or ions between the animal's body fluid and the surrounding fluid in the environment. The antennal gland as described by Tsai and Lin (2014) is positioned at the base of the eyestalk within the suborbital area. It is about 3–5 mm long and 2–3 mm wide for an average individual having carapace width of 35 $\pm$ 5 mm. This excretory gland is very delicate with posteriorly and anteriorly axis and laden with connective tissues looking pale to yellow in colour. Fiddler crabs in different habitats may have differences in their processes of osmoregulation, particularly with regard to physiology and structure of their excretory organs. Tsai and Lin (2014) reported the important roles of the antennal glands of the fiddler crab in osmoregulatory activities of the organism. The general process of osmoregulation comprises intake or removal/excretion of ions between the body fluid and the environmental medium via organs of osmoregulation, like antennal glands, gills and the gut in decapods like crustaceans (Freire et al. 2008; Chung and Lin 2006). Antennal gland performs a major function during the movement of anion in order to regulate the loss of ions from excretion in urine (Holliday and Miller 1984; Péqueux 1995; De Vries et al. 1994; Morris 2001; Freire et al. 2008). The gland of the antennal also performs a key function in marine crabs during the removal and excretion of nitrogen and a lesser part during the regulation of ions (Freire et al. 2008; Holliday and Miller 1984; Péqueux 1995).

15.2.5 Circulatory System and Respiration in Crabs

The circulatory system in crabs is quite more complex than imagined with a heart, arteries and capillaries. The heart located in the basal region like in other crabs is the main pumping station of the circulatory system. Just like other aquatic organisms, crustaceans like fiddler crabs essentially use gills for breathing by filtering water to absorb oxygen. The gills are highly vascularized and able to absorb dissolved oxygen from the aquatic environment. The gills have gill rakers that are used to enable moisturization of the gills to prevent them from drying. They are morphologically and physiologically adapted for air and water breathing. The moist epibranchial surface is used as lungs by fiddler crabs (Eshky et al. 1996). The absorbed oxygen diffuses through the membranes into the circulatory system of the crab to reach the cells and tissues. This is then used for internal respiration or cellular respiration to release energy (ATP) for other metabolic and physical activities. Oxygen extraction and consumption rates among species of fiddler crabs may also vary relative to temperature and location along the intertidal zones. The distinct distribution of fiddler crabs along vertical zonation of the intertidal region could also affect oxygen extraction from air and water. Fiddler crabs like *U. tetragonon* and *Uca vocans* do inhabit the low intertidal regions with longer times of submersion, while *Uca crassipes* dwells in upper intertidal zones with relatively long period of emersion time (Jimenez and Bennett 2005). The gills of the fiddler crabs are also kept moist during air-breathing by retaining some water in the epibranchial apertures. Gill morphology and development may also vary between species of fiddler crabs.

15.2.6 Nervous System

The ability to respond to stimuli both internally and externally is a very important biological characteristic. Fiddler crabs also possess this quality which makes them adapt favourably to their unique environment. The fiddler crabs also have the ability to detect behaviourally useful signals like mate attraction and also dangerous signals in the environment. Their response to stimuli could also be related to their good nervous system. Application of substrate borne vibrations is utilized by fiddler crabs to accomplish such activities like courtship. Fiddler crabs have the ability to convert substrate borne signals into electrophysiological signals that are then used by the neural network of the crab (Beazley 2013). They have compound eyes on the stalks which are well adapted to responses in the environment where they live. The eyes of the crabs work more with gravity associated with visual horizon compared to speed, size and shape of potential predator (Lawrence 1998). Due to use of gravity to assist positioning, the crab can retain its eye level even without a visible horizon line to enable it to distinguish between friends and dangers. Therefore, anything higher than this horizon is handled as a predator while those things appearing below it would be perceived as a member of the same species and possibly ignored (Lawrence 1998). In other words, the fiddler crabs are able to effectively coordinate and respond to stimuli in their environment using their nervous systems.

15.3 Habitat and Ecology of Fidler Crabs

Fiddler crabs dwell along the shores of tropical and subtropical zones of the world where they dig simple dwelling holes in the intertidal zones. The cohabitation of different species of fiddler crabs on the shores makes it difficult to distinguish by mere visual inspection the exact habitat of each species. Fiddler crabs adorn marshy intertidal zones, mudflats and sandy beaches with their cylindrical holes and burrows. They burrow more actively in the presence of few other species. The burrows of fiddler crabs appear simple, deep with gradient, but diameter changes lengthways tending horizontally downwards with no branches observed. The depth of such burrows averages about 0.5 m depending on sediment characteristics. They inhabit brackish water areas and wetland marshes, estuarine reaches and intertidal or littoral zones. These crabs hardly move farther than 1–2 m from their burrows. Fiddler crabs (*Uca tangeri*) are semi-terrestrial organisms and prefer areas with moderate salty marshes. They have the ability to tolerate salinity range of 5–35 psu with bigger individuals seen more at the lower ends of the environments particularly, with smaller ranges of sediment particle size having lower clay content (Levin and Talley 2002). Most species (*Uca lactea annulipes*) are diurnally active, coming out during low tides as the tide ebbs (Backwell and Christy 2000; Skov and Hartnoll 2001; Macia et al. 2001). Re-entry and plugging of burrow entrance suggest the end of surface activities particularly, at high tide. Plugging of burrow can also be at night and during hot days characterized by dry sediment (Crane 1975; Macintosh 1988).

Fiddler crabs are among the commonest burrowing decapods. These crabs are important in ecosystem feeding relationships and are vital connects between primary detritus at the bottom of the food web and consumers of the upper feeding levels. They are one of the most common intertidal organisms used to study and express behavioural, sensory and ecological processes for better understanding. The conventional demonstrations, exact visual tasks, relatively simple environment and lively social relations have put them as an ideal structure for identifying the sensory pattern contribution to many types of behaviours in their ecology, for example, tracking conspecifics (Land and Layne 1995), finding burrows (Hemmi and Zeil 2003a, 2003b), neighbour and species recognition (Detto et al. 2006) and also attracting mates (Christy 1995). Ecological behaviour like burrow formation and signalling for mate attraction and defense is quite characteristic of the fiddler crabs in addition to colouration features. Such attributes are very useful in ecological community interactions. Visual signalling in fiddler crabs is an imperative aspect of intraspecific communication and sexual selection in such crabs (Latruffe et al. 1999). The production of mudballs around the burrows of the crabs is another major ecological feature of the fiddler crabs. Their ecological roles remain very important with good turnover and production rates under favourable conditions. The distribution style of fiddler crabs is the outcome of interaction between physiological stress, predation risk, feeding preference and social behaviour (Hogarth 2008). Different predators like fishes and birds feed on these fiddler crabs in the mangrove forests ecosystem. Fiddler crabs escape such predation and survive by hiding in their burrows in areas where burrow digging is possible due to sediment characteristics.

Unlike other crabs such as soldier crabs, fiddler crabs are more landwards preferring to remain close to their holes. Their burrowing and feeding activities are limited to periods of low tide for effective operations. This is because as the tide and water level rise on the intertidal shore and mudflats the crabs go into their holes/ burrows and block their entrance with available mud or sand particles. Some fiddler crabs stay under mangrove trees to enable them to get shades which reduce desiccation of the organism. This also explains the low-temperature tolerance of some species of fiddler crabs.

Salinity is also an important factor in the habitat and dwellings of fiddler crabs but this also depends on species as some have a wide range of distribution at the lower and upper ranges/zones of the intertidal mudflats. Some species like *Uca forcipata* prefer habitats close to mangrove trees, possibly due to the likelihood of finding sediments rich in carbon and organic matter composition (Mokhtari et al. 2013). Mangroves, crabs and bacteria are related in the form of positive feedback loop, where a rise in the activity of one contributor will tend to rise the activity of the rest of all (Mokhtari et al. 2008).

Some fiddler crabs have widespread distribution, dominating the benthic crab population in the estuarine and mangrove forest ecosystem. Fiddler crabs especially *Uca (Afruca) tangeri* (Altevogt, 1835) is the only one that inhabits the eastern coasts of the Atlantic considering the hundreds of species described (Rosenberg 2001). The geographical distribution of *Uca tangeri* spreads from the south-western axis of the Iberian Peninsula lengthwise to the west coast of Africa having a southern border on the shorelines of Angola (Levington et al. 1996). However, the distribution of *Uca tangeri* in Europe is limited to the Andalusian coastal region of the Atlantic around Spain and the coastlines of Algarve in Portugal. In Spain, the fiddler crab *Uca tangeri* was included as an exposed and susceptible species in the Red Book of Invertebrates of the Andalusia (Barea-Azcón et al. 2008). The major factors that affect the distribution of benthic communities including those that harbour fiddler crabs are sediment heterogeneity and quality, recruitment and predation. These factors can change with respect to adult and juvenile crabs leading to change of habitats particularly for juvenile species according to their own habitat requirement (Ribeiro et al. 2005). In the intertidal ecology, fiddler crabs are not the only occupants and burrowers found, though their burrows are quite conspicuous seen either in more densely or less densely pattern. It is a community made up of other organisms living and interacting together. Other crustaceans, gastropods, polychaetes and insects also feature in bioturbation and vertebrates including birds, reptiles and some mammals also play roles in the intertidal ecology.

15.4 Roles of Fiddler Crabs in their Ecosystem

Bioturbation is one of the phenomena that plays a key role in the sediment ecosystem. It is due to the activities of living organisms that produce sediment particles or pellets that could physically alter the original structure of the sediments. So, it actually has to do with the displacement of particles by organisms during their natural activities such as feeding, defecation and respiration in their sediment habitats. Bioturbation activities have deep effects on the ecosystem and the environment at large and are considered to be one basic contributor to biodiversity. Therefore, deposit feeders like fiddler crabs are actually involved in this ecosystem role. Bioturbation structures could be seen in the form of tracks, trails or burrows of sediments that contribute to the aeration of the sediment layers which is also beneficial to other organisms. The Encyclopedia of Ocean Sciences (Shull 2009) explains bioturbation as the biogenic transport of particles of sediment and interstitial or pore water which affect the stratigraphy of the sediment and also alters the rate of chemical reaction and sediment–water exchange which lead to the modification of the physical characteristics of the sediment like particle size, permeability and porosity. Fiddler crabs like *Uca tangeri* are actively involved in bioturbation as part of their roles in the ecosystem. In the mangrove forest ecosystems, leaf litter falls gather as organic carbon on sediment surfaces and produce anoxic sediment zones beneath the surface. The activities of fiddler crabs, via digging of holes and burrowing, transmit oxygen into the anaerobic zone and promote aerobic respiration, nitrification and iron reduction (Mokhtari et al. 2016).

During the course of gathering and harvesting of sediment as well as removal of the waste material rejected from sediments, male fiddler crabs only use their smaller claws but the females use both. Movement of these fiddler crabs leaves behind 3–4 mm long bits and capsules of sediments in rows which are related to the scraping marks exhibited by claws and circular depressions given by ambulatory pereiopods. These are noticed as radiating pathways from the entry points of burrows and form sinuous pathways in an irregular pattern (Gibert et al. 2013). The female shows traces of two symmetrical rows from the scratch of their two claws with evidence on both sides of the sediment capsules or balls but the male pathways show just a single line of scratches on one side. This unique characteristic may not be quite clear and altered in such densely populated intertidal zones and mudflats with mass movements. Fiddler crabs are also considered benthic organisms by virtue of their dwelling place on/in the sediments of the intertidal zone, also affecting the benthic community structure. In the course of contributing to bioturbation, they affect the benthic community structure of the intertidal ecosystem in so many other ways. The densities of suspension feeders in muddy sediments appear to reduce via bioturbation by the activities of deposit feeders. Conveyor-belt bioturbation can dislodge surface-dwelling benthic organisms. The depth distribution of organic matter can be affected and changed by bioturbation which could improve the record and quality of food for deposit feeders in sediments of the ecosystem. Bioturbation activities can increase nutrient fluctuations thereby improving and increasing the rates of microbial productivity and primary production of benthic fauna. Additionally, higher nutrient recycling between overlying water and sediments helps to continue water-column productivity in estuarine ecosystems and other shallow-water habitats in the marine environments (Shull 2009).

The burrows of fiddler crabs in the ecosystem increase the circulation of oxygen particularly in the anoxic zones of mangrove sediment. This also enhances reduction of iron and nitrification process over reduction of sulfate in subzone sediment leading to the promotion of the rate of decomposition under aerobic and anaerobic environments. The oxidation-reduction potential and iron pools differ at layers oxidized around burrows, but the porosity of sediment, water and organic component may not vary between mudflats that are burrowed and those not burrowed (Mokhtari et al. 2013).

The effects of environmental parameters on the local distribution of fiddler crabs (*Uca forcipate*) and crab burrows on sediment properties reveal that *Uca forcipata* prefers to live on open mudflats shaded with mangrove trees (Mokhtari et al. 2013). Some of the very important factors influencing the presence of the crabs were sediment porosity, texture, organic matter component, moisture level, temperature and carbon component (Mokhtari et al. 2013). The physical characteristics of mangrove sediments may not be effectively changed by the oxidation produced by the burrowing action of *Uca forcipata*. Fiddler crabs have good tolerance to differential salinity, reduced oxygen and increased temperature (Hogarth 2008).

These crabs dominate the macro-invertebrate fauna on mudflats of mangrove forests in tropical and subtropical regions (Hogarth 2008) creating burrows and tunnels on beaches and the mudflats to dodge predation and reduce desiccation due to high temperatures. The excavation of tunnels and burrows leads to effective oxidation of anoxic sublayers of sediments. The effects of oxidation of burrows effectively enhance the rate of decomposition of organic matter and recycling of nutrients in the mangrove ecosystem (Kristensen 2008).

The importance of benthic organisms like fiddler crabs in energy recycling and overall maintenance of biomass cannot be overemphasized. Herbivorous crabs (Sesarmidae) gain from the volume of primary production but takes in just a fraction of the obtainable energy, so the remaining energy goes to sustain the microbial circle in the detritus compartment promoting nutrient supply for the deposit-feeders like the fiddler crabs. Three advantages from the activity of these crabs and bacteria are (1) nutrients are reserved in the ecosystem by herbivorous crabs instead of being transported to the subtidal zone via the action of tides, (2) remineralization of nutrient is improved in the ecosystem by crushing of the organic leaf materials and the huge grazing pressure put on microorganisms and (3) the soil is aerated by the burrowing and feeding activities of the crabs, which prevents the formation of phytotoxins such as H_2S in the sediments (Hogarth 1999; Botto and Iribarne 2000; Koch and Wolff 2002). The outcome of such positive feedback process and close connection between mangroves, crabs and bacteria give improved primary production in the mangrove ecosystems. Such pivotal activities performed by the crabs make Hanim et al. (2020) describe them as keystone species due to their high impact on mangrove forest ecosystem. The workings and performance of a feedback circle can be perturbed by tampering or removing any of the constituents (Koch and Wolff 2002). The consequential impact is gradual or immediate loss of ecosystem functions and eventual biodiversity loss. Activities that are capable of tampering with or eliminating any of the ecosystem components are mainly anthropogenic in origin and would be mentioned in detail in the following subchapter.

15.5 Anthropogenic Activities

Anthropogenic activities are human or man-made activities that may in one way or the other interfere with the natural environment, in most cases negatively. They are human activities and not natural processes that are capable of impacting the environment including air, water and soil. Most of these anthropogenic activities are driven by the quest to satisfy human needs and comfort due to the ever-increasing population of humans. These anthropogenic activities begin to manifest as fallouts of urbanization and industrialization where they directly or indirectly impact the immediate or remote environment. Such activities are responsible for the transportation of solid, liquid and gaseous wastes and pollutants to remote parts of the globe. Anthropogenic activities involve a lot of processes like smelting of ore, mining, coal firing, release of industrial effluents and wastes, burning of fossil fuel, application of heavy metal-laden water for irrigation and agriculture, use of heavy metal-laden pesticides, herbicides, and fertilizers for agricultural purposes that ultimately contaminate the land. Anthropogenic activities and natural processes pollute both soil and aquatic environments with huge amount of organic pollutants or materials like pesticides, solvents, halogenated compounds, petroleum hydrocarbons and phthalate esters (Bali et al. 2021). Anthropogenic activities have caused the degradation of nearly one billion hectares of land worldwide either due to industrial or agricultural processes. This has led to the deterioration of many ecosystem services across the world, posing serious threats to livelihoods which have led to socio-economic instability (Jones and Rowe 2017). Such human activities no doubt will also influence the intertidal zones and mudflats that serve as habitats for diversity of organisms including fiddler crabs. There is, therefore, the need to re-establish such degraded environments in order to restore ecosystem functions and services. Anthropogenic activities create different ecological problems that trigger different abiotic stressors such as extreme turbidity, temperature, dissolved solids and salinity which are capable of impacting aquatic organisms and their biodiversity. Anthropogenic activities, like urbanization, industrial processes, aquaculture activities and alterations of watercourse, remain as major dangers to the sustainability of freshwater bodies (Ho and Goethals 2021) and other aquatic environments. Anthropogenic activities including change in lifestyle and consumption pattern have led to increased generation of wastes and pollution of the environment. Solid waste generation is a major challenge to the aquatic ecosystem (Moslen et al. 2015). Anthropogenic sources like industrial and domestic wastewater effluents, agricultural and urban run-off, hydrocarbon fuel combustion, depositions from the atmospheric pollutants and antifouling paints from ships (especially tin and copper) increase metal concentrations in marine environments to higher than normal levels capable of impacting marine organisms. Other types of wastes and pollutants include pesticides, herbicides, persistent organic pollutants (POPs), fertilizers (organic wastes/pollutants) and heavy metals (Fe, Cd, Cu, As, Zn, Hg and Pb). Anthropogenic activities like industrial processes, combustion of fossil fuel and wood, agricultural activities, demolition and construction activities, and dust from road construction activities into the air also impact seriously on the environment.

15.6 Solid Wastes and the Aquatic Environment (Intertidal Zone)

All activities of man generate one form of waste or the other. The generation and management of solid wastes is a major challenge confronting the world particularly in developing countries. RCRA (2014) defined solid wastes as any refuse or garbage, sludge from a wastewater treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, resulting from commercial, industrial, mining and agricultural activities, and even from community activities. The sources of these solid wastes are commercial, industrial, residential and even institutional operations and may be classed as hazardous or not. Refuse and garbage from municipal solid wastes, construction and demolition wastes, electronic and computer wastes, wood, glass, metal, plastic, leather, cloth and other materials are some examples of these solid wastes. The generation of solid wastes is on the increase and constitutes one of the most discernable environmental challenges in many urban areas and metropolitan cities. This is attributable to urbanization, industrialization, increase in population and modifications in consumption pattern, and the eventual end for most of these solid wastes is the intertidal shorelines and rivers/creeks around the metropolis (Moslen et al. 2015) as seen in Fig. 15.2. The ecological functions of most creeks and aquatic ecosystem in the Niger Delta have been significantly altered and impaired due to the immense quantity of wastes

Fig. 15.2 Solid wastes gradually taking over the creeks and coastal zones in the Niger Delta (Moslen et al. 2015) with permission to reproduce from the publisher

discharged into the shorelines and creeks which finally get their way into nearby rivers and seas (Moslen et al. 2015). Solid wastes in the aquatic environment interfere with ecosystem functions and greatly reduce services rendered by the ecosystem.

The intertidal zone is the shoreline of rivers and seas that are exposed at low tide and covered at high tide. It is otherwise the meeting point between the sea and land at low or high tide periods. It is a very unique environment due to its emersion and immersion. Emersion and Immersion phenomena expose the intertidal zone to varying degrees of temperature and dehydration effects. The intertidal zone, therefore, houses a unique community of organisms that have adapted to the varying degrees of abiotic factors and associated biotic factors. Depending on sediment characteristics, the bottom substrate of the intertidal zone varies from rocky to sandy to muddy sand bottoms. This in turn greatly influences the community of organisms particularly fiddler crabs inhabiting such areas. Organisms living in the intertidal zone have a very variable and hostile environment to cope with, and have developed various adjustments and adaptations to manoeuvre and survive such hostile environment. One clear feature of the intertidal environment is vertical zonation, where the environment is divided into distinct vertical zones with particular species seeming to dominate each subzone. The ability of species to survive abiotic factors related to drying and desiccation governs their upper limits, while biotic relationships like predation and competition with other species regulate the lower limit species occupy. The intertidal zone is habitat to numerous organisms including plants and animals. Most of the animals found there are invertebrates comprising a diversity of organisms. Some of the invertebrates found in the tide pools of the intertidal zone include crabs (fiddler crabs inclusive), barnacles, urchins, sea stars, mussels, sea anemones, snails and limpets. The intertidal region is also habitat to some marine vertebrates (fish, gulls and seals) that feed on other intertidal organisms. Terrestrial predators also make incursion into the intertidal zone to feed at low tide. The intertidal zone, therefore, is a very important zone in the food chain/

food web that connects the terrestrial (upper intertidal) and aquatic (lower intertidal regions) for the proper functioning and service provision of the aquatic ecosystem.

Streams of solid wastes find their way to the aquatic environment from different point and non-point sources. The intertidal zone is one of the worst affected parts of the aquatic environment due to solid waste depositions. Many cities are not able to manage the huge volumes of solid wastes generated because of poor regulatory, technical, institutional, financial frameworks and public participation shortcomings (Visvanathan and Glawe 2010). These wastes eventually end up in the rivers and creeks particularly, the intertidal shorelines causing more harm to aquatic life including fiddler crabs.

Change in consumption pattern and cultural shift towards the use of disposable plastics and nylon/polythene bags have increased household waste generation on a daily basis. Such polythene bags and plastics make up a substantial part of waste generated due to their daily use in transactions in markets and other business places (Moslen et al. 2015). These wastes (plastics and polyethene bags) are xenobiotic and non-biodegradable, thereby creating serious problems in the environment. Indiscriminate disposal of wastes makes our creeks and rivers the ultimate sink for these wastes. Even in rural areas, open dumping particularly, into the rivers/creeks is now a common practice putting more pressure on the aquatic ecosystem. Exposed mudflats and intertidal beaches are no longer adorable and befitting sites for recreation but carry stretches of different wastes, creating an ugly sight (Moslen et al. 2015). Estuaries and streams that are being polluted also pollute and impact the coastline, where many people enjoy recreational activities (Couch 2007). It is obvious that our creeks and rivers are stretched, beyond their carrying capacities and may be compromised.

15.7 Anthropogenic Impacts and Effects of Solid Wastes on Fiddler Crab Population and Habitats

The environmental degradation caused by improper and indiscriminate disposal of waste cannot be overemphasized, spawning grounds and other fish habitats are aggressively being taken over by non-biodegradable wastes. Fishing activities are also being impaired as a result of waste-laden water bodies leading to reduced catch and loss of aesthetic recreational sites (Moslen et al. 2015). Xenobiotic and non-biodegradable types of wastes from domestic, industrial and small-scale business outfits dominate the intertidal shorelines. Waste types like plastic bags, bottles, metal cans of various industrial products and polythene bags including ‘pure water’ sachets suggested the dominance of wastes coming from small- and medium-scale business outfits and domestic activities. Other types of wastes clogging the intertidal shores of the coast include scrap metals and used tyres from mechanics/artisanal workshops around city centres (Moslen et al. 2015). The significant negative impacts of such wastes on the aquatic ecosystem are numerous including loss of natural and beautiful recreational sites with high aesthetic value, alteration of hydrodynamic flow rates with siltation that clog water ways, impairment of fishing activities, destruction and alteration/fragmentation of aquatic habitats, as well as direct burial of benthic and shoreline organisms. Our rivers, creeks and coastal/intertidal shorelines have no doubt been stretched beyond carrying capacity and limits as a result of the humongous amount of waste discharged into them. This has further led to the deterioration of marine habitat and aquatic ecosystem quality. The damage and alteration of basic ecological processes on coastal shorelines of the aquatic ecosystem pose serious danger and threat to aquatic biodiversity that ultimately impact ecosystem functions ecologically, economically, culturally and socially. The wastes that settle on the shore due to hydrodynamic conditions and submerged ones whose density could not support their floatation and so sink down to the bottom of the rivers and creeks and settle in/on the sediments are the ones that mainly impact the intertidal organisms and fiddler crabs.

The activities of the fiddler crabs in terms of burrow-making on sandy beaches and mudflats make them to be described as ecosystem engineers. Proximity of the intertidal zone to terrestrial ecosystem makes human incursion and impacts inevitable on the lives and activities of shore dwellers like fiddler crabs. Human activities greatly impact the width and surface area of fiddler crab burrows (Numbere 2020). The need to accommodate the ever-increasing human population has led to increased dredging activity in recent times, putting pressure on the coastal system of the Niger Delta. Dredging of shorelines and intertidal zones has humongous impacts on the organisms of the intertidal zone including fiddler crabs. Impacts ranging from direct burial of the organisms and crabs to fragmentation of their habitats as well as permanent dislocation and dislodgement of the organisms are quite disturbing. Such effects in most cases lead to impairment of ecosystem functions and complete loss of ecosystem services and biodiversity. The implication here is that the numerous organisms like fiddler crabs that dominate intertidal shorelines/zones are endangered and gradually eliminated from such sensitive natural and productive ecosystems. Anthropogenic activities greatly impact the ability of fiddler crabs to construct burrows and perform their ecosystem functions and services. A study carried out at high impact locations (George et al. 2010) reported that juvenile fiddler crabs were living in shells of snails. The crabs could be using the shells as a shelter and protection in response to a reduction in vegetation in highly impacted areas.

The Niger Delta part of Africa over the years has been host to hydrocarbon (oil and gas) exploration and production with the consequential events of oil spills. The huge barrels of hydrocarbons spilled into the aquatic environment particularly, the intertidal zones create humongous problems for coastal and intertidal organisms like fiddler crabs due to their toxicity and physical effects. Some of the impacts of oil spills on fiddler crabs are reduction of the number and abundance of fiddler crabs, direct killing of the crabs by smothering and poisoning and changing the species of fiddler crabs in their habitat/marsh overtime after oil spills (Zengel et al. 2017). The change in fiddler crab populations due to anthropogenic impact may also affect other parts of the ecosystem, including marsh plant growth, soils and predators of the fiddler crabs. Ombo and Moslen (2020) demonstrated that Eagle Island and Ibeto areas of the Niger Delta, Nigeria had lower number of fiddler crab holes compared to Iwofe area with less impact. This was due to anthropogenic impact on the ecosystem (salt marshes, mudflats and mangroves) particularly the overwhelming presence of solid wastes that plugged, fragmented and dislodged the fiddler crabs in their habitats.

Coastal estuaries are often situated in areas appropriate for human development, leading to multiple sources of environmental contamination (Lamparelli et al. 2001; Abreu-Mota et al. 2014). The pollution of estuarine coasts due to the presence of heavy metals can also be an added pressure and stress on estuarine organisms like fiddler crabs, which may show limited capability to adapt their regulatory activities to maintain physiological homeostasis. The contamination of habitats of fiddler crabs by heavy metals causes bioaccumulation and induces biochemical and physiological variations in the crabs (Capparelli et al. 2016). Solid waste effects are not the only impacts from anthropogenic activities. Overharvesting of mangroves for fuelwood, charcoal making, construction and other uses, dredging for building of roads is a vital disturbing threat to the ecosystem which directly or indirectly affects fiddler crab abundance (Vanessa et al. 2016).

15.7.1 Conservation and Sustainability of **Uca tangeri**

The aquatic ecosystem is a natural habitat with different resources that is constantly being depleted, therefore, there is the urgent requirement for conservation for sustainable provision of such resources. Conservation is the practice of protecting earth's natural resources for immediate and future generations. Ecological conservation is the practice of protecting, maintaining and restoring the natural environment to functional capacity in order to deliver requisite ecosystem services. Conservation practices are also aimed at protecting species of organisms from going into extinction particularly, endangered species. Each organism or species has its natural habitat that provides support and enablement for the organism to feed, reproduce and manoeuvre predation for survival. Protection of various natural habits translates to protection of the organisms or species living in that habitat. The aim is to ensure availability of natural resources for immediate generations without compromising those of future generations—*Natural Resource Sustainability*.

Mangroves are exceptional ecosystem of high ecological value that provide numerous ecosystem goods and services including coastal protection against sea erosion, water purification and mitigation of climate change via carbon sequestration, aesthetic beauty and provision of habitat and shelter for organisms like fiddler crabs. Studies have shown that globally, mangrove ecosystems function as important carbon-sequestering systems (Donato et al. 2011; Ray et al. 2011; Murdiyarso et al. 2012). Resources from mangrove ecosystem also provide livelihood for numerous coastal populations. Some of the threats facing mangrove ecosystems include indiscriminate logging of mangrove trees for timber and energy production (charcoal), increased aquacultural usage, dredging for land reclamation and development, mining activities and pollution from other anthropogenic activities. The rapid rate at which the mangrove forests are disappearing also accounts for the exposure and threats posed to the mangrove ecosystem organisms like fiddler crabs including *Uca tangeri*. Humans also directly exploit fiddler crabs for food as it is a delicacy in certain parts of the world. In southern Portugal (Ria Formosa), the bigger claw of the fiddler crab (*Uca tangeri)* is a local delicacy as fishermen break off the big claw of the male fiddler crab and send back the crab into its habitat to redevelop a new claw (Oliveira et al. 2006). Such predation by humans affects the populations and reproduction of fiddler crabs and consequence poses a threat to survival and existence of the crabs.

The fiddler crab (*Uca tangeri*) dwells on sandy beaches, mudflats and salt marshes of coastal estuaries and mangrove forest ecosystems. These are very sensitive and vulnerable environments that require protection and sustainable management in view of the array of anthropogenic activities that impact such environment and their inhabitants. The protection of the mangrove environment automatically translates to a conservation and sustainable status for inhabitants of the mangrove ecosystem including fiddler crabs like *Uca tangeri.* This is supported by the fact that mangrove forests provide thermal shelter and huge organic litter/deposits that support fiddler crabs as organic/detritus deposit feeders. Protection and conservation of fiddler crabs and other organisms in the mangrove and coastal ecosystems cannot be achieved in isolation because such systems work as a wholistic and integrated unit for optimum productivity. Conservation and sustainable exploitation of mangrove ecosystem resources will ensure protection and conservation of fiddler crabs. Such conservation practices also ensure that ecosystems are not stretched beyond their functional/carrying capacity in order to continue to deliver the desired ecosystem services.

Conservation of mangrove ecosystem is mainly targeted at preventing devastation of mangrove ecosystems, in order to increase mangrove forest cover. A major problem is not just destruction but degradation of mangrove ecosystems, via pollution, siltation, variation in salinity and biodiversity loss.

Some conservation and sustainability measures include awareness campaigns on indiscriminate exploitation of mangrove resources including mangrove crabs, this is key in order to drive home the basic understanding of appropriate and sustainable exploitation and management of natural resources. This has to be achieved by all stakeholders, including the local people who are directly involved in mangrove resource exploitation.

Putting in place appropriate legislative frameworks and enforcement measures by the authorities concerned is a key to sustainability and conservation practice. Effective conservation and sustainability practices cannot be achieved without requisite laws and enforcement of the law. Equivalent rainforest guards (mangrove forest/coastguards) can also be introduced for effective monitoring and implementation of laws governing sustainable harvesting of mangrove forest and coastline resource.

Provision of alternate sources of livelihood and energy is also a key measure towards effective implementation of conservation practices. Natural resources are not replenished at the same rate of removal by the increasing population.

Government and other concerned authorities should as a necessity create alternative livelihood forms to minimize additional pressure on natural resources and support fiddler crab habitat conservation practices, e.g. provision of alternate source of energy would reduce the incessant harvesting of mangrove wood for fuel energy. This would create the enablement for a balanced ecosystem that supports inhabitant organisms including fiddler crabs.

Minimal dredging activities with issuance of environmental permits before dredging: Indiscriminate dredging has caused major destructions to the mangrove forest and intertidal zones. Regulation and enforcement of appropriate environmental laws towards dreading would greatly support conservation efforts towards protection of fiddler crabs.

Appropriate waste management systems particularly solids and other harmful wastes that get into the aquatic ecosystems are key to conservation and sustainability of aquatic organisms including fiddler crabs. These crabs suffer from habitat fragmentation and destruction due to poor waste disposal and management particularly in developing countries.

Regular monitoring and cleaning/remediation of impacted aquatic ecosystems would also enhance conservation and sustainability measures for aquatic organisms like fiddler crabs.

Scientific approach, climate change, social and ecological factors specific to sites must all be integrated together from the planning stage in order to have an effective conservation and sustainable management of fiddler crabs and other aquatic resources.

15.8 Conclusion

The aquatic ecosystem is a very sensitive environment that is under threat due to the impacts of anthropogenic activities. The salt marshes, stretches of mudflats, sandy and muddy sand beaches are parts of the intertidal zone of the aquatic ecosystem that accommodates diversity of organisms including fiddler crabs like *Uca tangeri*. Most of the solid wastes generated due to urban, municipal, development and industrial activities find their way to the aquatic environment particularly the intertidal zones that provide habitats for diversity of organisms including fiddler crabs. The impacts of such wastes on the fiddler crabs in particular include habitat destruction/fragmentation and even death of crabs in addition to other physiological problems created by the presence of these wastes in the organisms. Anthropogenic activities that constitute generation of solid wastes and the improper/poor management of these wastes are, therefore, major menace that endangers the survival and existence of fiddler crabs including *Uca tangeri*. Such anthropogenic influences no doubt contribute to biodiversity loss in the aquatic environment. This is due to the fact that fiddler crabs are part of the intertidal food chain and disturbance or elimination of such key players of the ecosystem could have consequential effects on other organisms and the entire environment. Effective control and management of solid wastes, protection and conservation of the mangrove forest ecosystem including the intertidal zones are strongly recommended to save our vulnerable and endangered ecosystems by providing habitats for diversity of organisms including fiddler crabs such as *Uca tangeri*.

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Chapter 16
Aquatic Biodiversity Loss: Impacts of Pollution and Anthropogenic Activities and Strategies for Conservation

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Abstract Human activities pollute water, air, and soil, which has a negative impact on the environment. Despite the significant efforts made in recent years to clean up the environment, pollution remains a serious issue that presents continuous health hazards. Despite the fact that water covers 71% of the Earth's surface, just 0.3% of it is suitable for human use. Furthermore, the quality of freshwater in ground and surface systems is a major problem, since consumable water must include a certain amount of minerals. Natural and human activities both have an impact on the quality of ground and surface water in rural and urban areas. As a result, water is becoming more limited as the world's population grows, particularly in Africa**.** This chapter discusses sources of water pollution, aquatic pollution and biodiversity, the main threats to biodiversity, effects of anthropogenic factors on water quality, biodiversity loss and its conservation.

Keywords Environmental pollution · Anthropogenic activities · Aquatic biodiversity · Conservation

16.1 Introduction

Pollution of the environment, especially as a result of human activity, has become a worldwide problem. A pollutant is a substance that has the incorrect number of elements at the wrong place at the wrong time. Plants and animals, including people, may develop infections and allergies, and even die as a result of it. As a result, environmental pollution is today regarded as one of the most serious global concerns confronting both rich and developing countries, having a significant impact on

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people's environmental health across the globe. Continuous population expansion, increasing economic movements, as well as climate change, all contribute to the depletion of natural resources, endangering biodiversity and the whole ecosystem. The most heinous problem is that nearly primitive ecosystems are among those on the verge of extinction. Biological diversity refers to the variety of living species found in various environments, including, but not limited to, terrestrial, marine, and other aquatic ecosystems.

Water is a renewable resource that is necessary for all kinds of life, food production, economic growth, and overall health. It is impossible to replace for most of its functions, difficult to decontaminate, and costly to transport, and it is certainly a one-of-a-kind gift from nature to humans. Water can be diverted, transported, stored, and recycled, making it one of the most controlled natural resources. All of these characteristics contribute to water's high value for humans. Agriculture, hydropower generation, animal production, industrial operations, forestry, fisheries, navigation, and recreational activities all rely heavily on the country's surface and groundwater resources. The world's freshwater ecosystems cover just around 0.5% of the planet's surface area and have a volume of 2.84×10^5 km^3. Rivers make up a small percentage of the land surface (0.1%). River channels contain about 0.01% of the world's water. Despite such small numbers, flowing waterways are very important (Wetzel 2001).

The demand for freshwater has risen dramatically in recent decades as a result of high population expansion and the quick pace of industrialisation (Ramakrishnaiah et al. 2009). Most agricultural development operations endanger human health, especially when it comes to excessive fertiliser use and filthy circumstances (Okeke and Igboanua 2003). Water quality has deteriorated in many regions of the globe as a result of anthropogenic activities such as significant urbanisation, agricultural practises, industrialisation, and population growth (Mian et al. 2010; Wang et al. 2010; Baig et al. 2009). In addition, limited water supplies have hampered efforts to reduce pollution and enhance water quality (Bu et al. 2010). Water contamination has been a subject of government and scientific inquiry. As a result of chronic water pollution and worldwide shortage of water resources, safeguarding river water quality is critical.

Inland water biodiversity is critical to the ecosystem's long-term viability. Inland water biodiversity is also significant for its economic significance as a home for commercially valuable species. Despite the fact that aquatic ecosystems are among the most diverse and abundant environments in terms of species richness and abundance, the Millennium Ecosystem Assessment (MEA) reported in 2005 that biodiversity decline in freshwater systems occurs at double the rate of other ecosystems. As a result, their capacity to provide ecosystem services deteriorates, posing a threat to human health (MEA 2005).

The relationship between pollution and biodiversity will be discussed in this chapter, including the value of biodiversity and its relationship to ecosystems, as well as the key threats to biodiversity. It is necessary to determine the effects of biodiversity on ecosystems and communities, as well as the conservation problems that biodiversity faces.

16.2 Sources of Water Pollution

Water contamination may come from two different sources. The sources are: point and non-point sources. Pollution with a direct identified source is referred to as a point source. Pipes linked to factories, oil spills from tankers, and effluents from industry are all examples. Wastewater effluent (both municipal and industrial) and storm sewer discharge are examples of point sources of pollution that primarily impact the region around them. Non-point sources of pollution, on the other hand, are those that come from a variety of sources and arrive in the environment in a variety of ways. For example, contaminants can enter groundwater or surface water through a variety of routes and arrive in the environment from a variety of non-identifiable sources. Run-off from agricultural fields, urban trash, and so forth are examples. Pollution introduced into the environment in one location may have an impact hundreds or even thousands of kilometres distant. This is referred to as cross-border pollution. The radioactive waste that goes over the seas from nuclear reprocessing facilities to neighbouring nations is one example. There are two types of water pollutants: organic and inorganic.

1. Insecticides and herbicides, organohalides and other chemicals, bacteria from sewage and animal farms, food processing wastes, pathogens, volatile organic compounds, and other organic water contaminants are examples of organic water pollutant.
2. Heavy metals from acid mine drainage; silt from surface run-off, logging, slash and burn practises, and land infill; fertilisers from agricultural run-off, including nitrates and phosphates; and chemical waste from industrial effluents are all examples of inorganic water pollutants.

16.3 Aquatic Pollution and Biodiversity

Most aquatic creatures are very sensitive to changes in their environment and they react to pollution in a variety of ways. Death or migration to another environment constitutes the most extreme reactions. Reduced reproductive capacity and inhibition of specific enzyme systems required for traditional metabolism may be among the fewer reactions (Chapman 1992). The role of zooplankton and macrobenthic components in trophic dynamics in freshwater environments has been acknowledged. Such creatures not only control aquatic production by occupying a middle level in the food chain but they also provide information about the state of the environment throughout time (Xie et al. 2008). Furthermore, their variety has grown in relevance in recent years as a consequence of their specific species' capacity to detect any worsening in water quality as a result of pollution and eutrophication (Hassan 2008; Khan 2003). Any food chain disturbance caused by loss of variety or degradation resulted in a drop in fish populations at the top of food webs. Boulenger (1907) observed 85 fish species residing in Egyptian Nile waters between 1899 and 1902;

however, Bishai and Khalil (1997) recorded only 71 fish species, 22 of which were detected in the capture and 49 of which were unusual. The River Nile from Aswan to Cairo shows signs of diminished taxonomic richness, as well as heavily polluted areas caused by sewage drains, industrial, and agricultural sources (Fishar and Williams 2006; Fishar et al. 2003). Lake Manzala is a highly dynamic aquatic system that has been exposed to a variety of contaminants (Ahmed et al. 2006). Manzala lake is also affected by pollution, which has a significant impact on aquatic biota. Between the northern and southern sides of the lake, there is a significant divergence. The lake's southern side gets wastewater effluent with high organic matter concentration from several drains, including the Bahr El Baqur drain (Rashad and Abdel-Azeem 2010).

In terms of biodiversity, both fish and bird species have seen significant declines in the lake over the previous several decades. With the exception of the north-western basin, where a dam has resulted in a negative water balance, hypersalinity, and a loss of species diversity, the reduction in water salinity may be the most important effect. Water pollution and high eutrophication in the south-east basin have resulted in the extinction of countless aquatic species. Pollutants from waste-water discharge have harmed the benthic species in a few locations of the lake (Ismail and Hettiarachchi 2017). Fish deformation has been recorded in recent research, with numerous varieties of fish exhibiting anomalous shapes, which might be linked to pollution caused by significant eutrophication of the lake owing to high domestic and industrial waste flow, as well as predation (El Mansy and Shalloof 2015).

Different aquatic contaminants prevalent in the environment had a significant impact on biodiversity, which manifested itself in a variety of ways. Heavy metal contamination, for example, has a negative influence on all aquatic species. A survey released in 1992 said that the metallurgical sector accounts for 50% of industrial waste, while weaving, dyeing, and spinning account for 30% of industrial waste. In Egypt, over 250 industrial firms in Greater Cairo account for about 35% of total industrial activity and 40% of heavy metals loads deposited in water. In addition, roughly 150 industrial sites are responsible for nearly a quarter of the total heavy metals burden in water streams. While Alexandria has over 175 facilities, accounting for roughly 25% of Egypt's entire industrial activity, it only trades about 10% of heavy metals total loads in natural streams (El Bouraie et al. 2010). Heavy metals (Zn, Cu, Cd, Pb, and Hg) were studied in a variety of commercial fish species gathered along the Egyptian Mediterranean sea coast. There were no significant changes in certain metal concentrations, such as lead, when referring to the age or size of the fish caught (Shreadah et al. 2015).

Furthermore, microbial pollution is one of the most harmful contaminants in water streams, whether they are freshwater or marine. Excreta from livestock include zoonotic bacteria as well as multicellular parasites that are toxic to all living things (WHO 2012; FAO 2006). *Clostridium botulinum, Campylobacter spp., Salmonella spp., and Escherichia coli* O157:H7 are among the microorganisms that influence public health in livestock. Parasitic protozoa, such as *Microsporidia spp., Cryptosporidium parvum,* and *Giardia lamblia,* are very major pathogens that may cause hundreds of thousands of infections each year in a variety of species (Christou 2011). Lake Qarun in Egypt gets a massive combination of heavy metal-laden agricultural, domestic, and sewer effluents. Unfavourable circumstances in the lake cause fish immunological defence mechanisms to be inhibited. As a result, fish are more susceptible to diseases. In lake Qarun, *Vibrio alginolyticus, Aeromonas hydrophila,* and parasitic *Isopoda sp.* have been discovered, posing a major threat to the fish population (Elgendy et al. 2017).

16.4 Importance of Biodiversity

The word biodiversity is well-known to have a broad definition. The United Nations Convention ion Biological Diversity defines biodiversity as follows: "Living species variations from a variety of places, including terrestrial, marine, and aquatic environments, as well as the ecological groupings to which they belong: including species diversity and ecosystem diversity" (UNEP 1992). As can be seen, biodiversity encompasses a wide spectrum of species, genetic variation, and ecological variation. It underpins the majority of biotic ecosystem activities, such as production and degradation. Only around two million species have been described out of a total number of species believed to be between 5 and 30 million on the planet (MEA 2005). Humans profit from ecosystems because they provide several economic advantages to the surrounding civilisation. The Millennium Ecosystem Assessment (MEA) summarises some of the functions of biodiversity in the ecosystem service: (1) Supporting—It increases the compositional, structural, and practical variety of ecosystem. (2) Regulatory—It concerns the influence of biodiversity on productivity, consistency, and the resilience of ecosystem. (3) Cultural—It consists of the spiritual, artistic, and recreational benefits of biodiversity to humans such as providing both direct and indirect job opportunities of food delivery, as well as freshwater provision.

Furthermore, apart from any other advantages, biodiversity has certain significant values that cannot be assessed (MEA 2005). It is critical to properly conceive the relationship between biodiversity (traits, species, and genes) and human well-being as society strives to move towards more sustainable development options (wealth, security, and health). Data analysis of earlier literature revealed that the phrases biodiversity, human well-being, and sustainable development are becoming more popular in the public sphere, but only as standalone terms. Some scholars have stated that a suitable paradigm for sustainable development should explicitly include biodiversity as a set of internal factors that both influence and are influenced by human well-being (Seddon et al. 2016).

16.5 The Main Threats to Biodiversity

Major risks to global aquatic biodiversity may be classified into the following categories: Climate change, pollution, overexploitation, alien species invasion, habitat deterioration, and flow alteration are factors to be considered (Naeem et al. 2016; Tilman et al. 2014; Harrison et al. 2014; Mace et al. 2012).

16.5.1 Climate Change

Changes in atmospheric, biogeochemical, and hydrological cycles are referred to as climate change. Variations in average daily temperatures, the length of rainy seasons, the carbon cycle, night-time temperature, and solar radiation may all have an impact on biological life. Temperatures have risen by around 0.6 °C in the twentieth century compared to previous centuries. Tree ring and ice core research provided the scientific evidence required to support the trend of rising temperatures. Some marine coral reef ecosystems have suffered as a consequence of climate change. The sea levels are expected to rise by 0.1 to 0.2 metres at the end of the century. This fast rise may cause coastal areas to be swiftly flooded. This is thought to be disastrous for certain species as well as varied populations in the ecotone. Due to species' varying capacity to adapt to climate change, historical climatic variations resulted in ecosystems with a diverse species makeup.

16.5.1.1 Impact of Climate Change on Biodiversity

The slightest shift in climatic pattern has a significant influence on biodiversity, affecting species habitats and posing a danger to their existence, putting them at risk of extinction. According to the Millennium Ecosystem Assessment (MEA), global climate change is the primary threat to biological diversity and ecosystem health (Anonymous 2007). Climate influences the distribution of species (biogeography), as well as the distribution of ecosystems and plant vegetation zones (biomes). Climate change may simply move these distributions, but plants and animals may be unable to respond for a variety of reasons, resulting in the extinction of certain species and ecosystems. This results in a loss of biodiversity (Kumar and Verma 2017). When a species becomes extinct, the species that are inextricably linked to it also go extinct.

Several plant species such as Berberisa siatica, Taraxacum officinale, Jasminum officinale, and others have moved to higher altitudes in Nainital as a result of rising temperatures. Teak-dominated woods are expected to supplant Sal trees in Central India, while conifers may be supplanted by deciduous species. According to Gates (1990), a temperature rise of 30 °C may cause forest movement of 2.50 km per year, 10 times the rate of natural forest movement. Climate change and global warming are major issues today because they have an impact on the natural ecology. Climate change is the term used to describe changes in the global or regional climate over time (Mandal and Singh 2020).

Animal species are wiped off as a result of minor climate changes, for example, climate change has resulted in the extinction of animals such as the golden toad and the Monteverde harlequin frog; polar bears are endangered due to a reduction in Arctic ice cover; and the North Atlantic whale may become extinct as planktons, its primary food source, have declined as a result of climate change. Though the full effect of climate change on India's natural resources has yet to be determined, preliminary research indicates that indigenous species such as the Nilgiri tahr are at danger of extinction (Sukumar et al. 1995). Furthermore, there are indications that some species, such as the Black-and-rufous flycatcher (*Ficedula nigrorufa*), are relocating their lower distribution boundaries to higher reaches, and that portions of Shola forests are dying sporadically as ambient surface temperatures increase.

Because of the high temperature, more female turtles are produced, the sex ratio of sea turtles is disrupted. Frogs, toads, amphibians, tigers, and elephants are among the endangered species that are susceptible to climate change's effects, such as rising sea levels and extended dry periods. Changes in ocean temperature and acidity may cause 95% of the Great Barrier Reef's live corals to perish (Anonymous 2007). Animal disease behaviour is also affected by climate change. Many amphibian populations are decreasing or extinct due to the fatal amphibian illness Chytrid fungus, which is likely worsened by rising temperatures.

Climate change may have a beneficial influence on biodiversity. The increased temperature and carbon dioxide, for example, are anticipated to be advantageous to many plants, resulting in an increase in biomass output. The temperate places with milder winters may enhance the survival of many presently vulnerable species. The increase in precipitation might also help certain plant groups and animals that rely on it. Furthermore, some studies have shown that climate change has a negative impact on biological invasions (Parmesan 2008).

16.5.2 Pollution

Contamination of water bodies by various contaminants (physical, biological, chemical, and radioactive) resulting from a variety of sources (mine, industrial effluents, residential sewage, and agricultural run-off) is seen as a serious danger to aquatic biodiversity (Rahel 2002; Malmqvist and Rundle 2002; Meffe 2002). Pollution causes a variety of ailments and even fatalities all throughout the globe, but it is more prevalent in Asia and Africa. Physical contaminants, such as temperature change, may create visual water pollution Revenga et al (2005); untreated sewage emits a variety of harmful contaminants; and nuclear power plants emit radioactive materials (Munir et al. 2016; Sechrest and Brooks 2002). Water contaminants are classified as either point sources or non-point sources, and both are caused by agricultural drainage and sewage (Hallouin et al. 2018; Richardson et al. 2007;

Helmer and Hespanhol 1997). It has been recognised that pollution is widespread, and several developed countries have taken steps to reduce water contamination from many sources, including industrial and home sources. Other pollution sources, such as chemical contamination, are becoming more prevalent, posing serious hazards to water bodies (Master et al. 1998; Carpenter et al. 1998).

16.5.2.1 Impact of Pollution on Biodiversity

Some marine coral reef ecosystems have suffered as a consequence of pollution. The preservation of current biodiversity and ecological balance are both essential for the mutual existence of all living things, including humans (Verma 2018; 2017). Air pollution has been a major issue in recent decades, with significant toxicological implications for climate change. Pollution in the air poses a severe danger to biodiversity. This brief focuses on the consequences of acidification, nitrogen fallout, and ground-level ozone, with sulphur dioxide, nitrogen compounds, and volatile organic chemicals as the main pollutants. The release of greenhouse gases is another potentially major concern. The greenhouse effect has caused an increase in tree species migration to higher elevations.

Alpine and boreal forests are projected to spread northwards and move their tree lines upwards at the stretch of low stature tundra and alpine ecosystems at higher elevations and latitudes (Srivastava et al. 2019). According to FAO (2006), around 9% of all known plant species are on the brink of extinction as a result of these changes. There are certain benefits of air pollution, for example, air pollutants induce the emergence of numerous aphids (Singh and Singh 2019). Other species are resistant to them and they proliferate to fill the void left by the extinction of more vulnerable species. Noise pollution has the ability to impair a variety of animal taxa's physiology, behaviour, and reproduction. Changes in foraging and reproductive behaviour, decreased animal fitness, increased predation risk, and lower reproductive success are examples of consequences (Maheshwari et al. 2020).

16.5.3 Overexploitation

Overexploitation (particularly overfishing) is wreaking havoc on marine vertebrates (particularly big vertebrates and predators such as sharks and tuna, which have been found declining) (Kalff 2002). Overfishing of target species at illegal levels may have a significant impact on ecosystems, especially when the biomass ratio is high or the species is linked to food webs (Moss 2008). Sand eel and cod populations, for example, have been overexploited in UK waters (Colburn et al. 1996), with the impact being exacerbated by the synergy of sand eel overfishing and the range shift of the copepod *Calanus finmarchicus*, which is a significant food source for sand eels (Smith 2003).

16.5.3.1 Impact of Overexploitation on Biodiversity

The increasing growth of humanity is placing tremendous pressure on our ecosystem. Humans continue to place a high demand on our planet's natural resources. The expansion of the human population places more demands on our already few resources. The depletion of natural resources and biodiversity, the generation of waste, and the destruction of natural habitat are all important issues that must be addressed if life on Earth is to be sustained for the next century. Overexploitation as a result of deforestation for fuel wood, overgrazing, agricultural operations, and industrialisation are the principal reasons that have contributed to the loss of arable lands, many (though not all) of which are linked to human development. Below are the respective percentages of overexploitation of some principal biodiversity services which includes overgrazing (35%), agricultural operations (28%), deforestation (30%), overexploitation of land for fuel wood (7%), and industrialisation (4%) (Mittal and Mittal 2013).

16.5.4 Invasion by Exotic Species

Alien species' extensive invasion and intentional submission has been proven to increase humans' chemical and physical effects on freshwater ecosystems, first and foremost because exotic species often enter habitats that have already been damaged or transformed by human activity (Smith et al. 2011; Baum et al. 2003). Many instances of significant consequences of exotics on indigenous species have been identified (the crayfish epidemic in Europe, salmonids in Southern Hemisphere streams and lakes, Nile perch, *Lates niloticus*, in lake Victoria) (Naeem et al. 2012), and such impacts are expected to increase rapidly (Frederiksen et al. 2013). Some indirect effects are also noticeable, such as the influence of terrestrial plants (*Tamarix spp*. (Tamaricaceae)) on riparian soil water regimes and stream flows in North America and Australia (Engelhard et al. 2014).

16.5.5 Habitat Degradation

Habitat degradation is a collection of reactive elements that might include direct or indirect effects on the habitat; in the aquatic environment, such as changes in drainage basins. Forest clearance, for example, is often associated with changes in surface run-off and increased river sediment loads, which may result in habitat changes such as shoreline erosion, coastal habitat strangulation, river bottom obstruction, or even floodplain aggragation (Dudgeon et al. 2006). Flow changes are a common occurrence in moving water basins (Bunn and Arthington 2002). They vary in kind and intensity, but they tend to be exceedingly aggressive, particularly in areas with highly varied flow zones. This means that people in these places have the greatest need for water storage and food security. Dams hold around 10, 000 km^3 of water, which is five times the world's total water volume (Koehn 2004). This explains the worldwide scale of human-induced changes in river flow. As a consequence of large-scale water abstraction, several of the world's longest rivers have recently become dry (Sala et al. 2000). The effects of flow changes on river biota, such as fish, are expected to be severe and should be taken into account in future studies (Nilsson et al. 2005; Tickner et al. 2001).

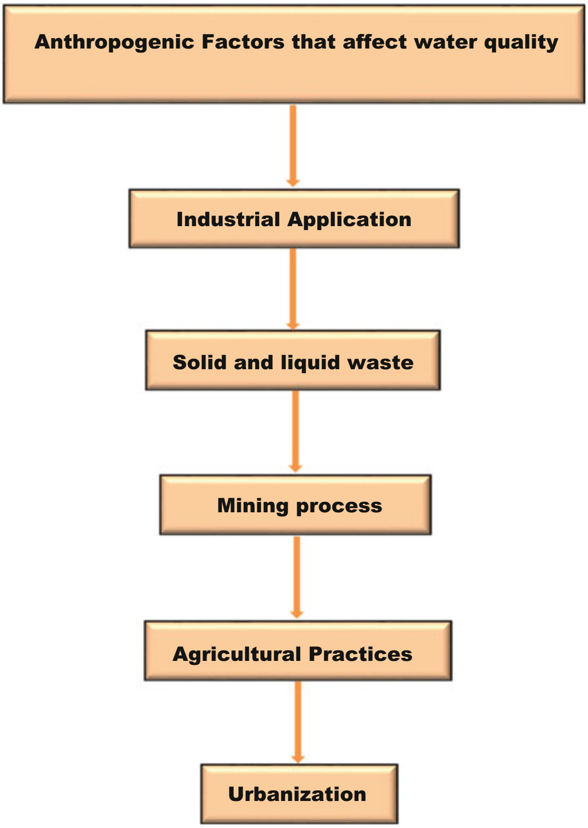
16.5.5.1 Impact of Habitat Degradation on Biodiversity

Habitat loss is a kind of environmental change in which a natural habitat becomes incapable of supporting the species that live there. Habitat fragmentation, geological processes, climate change, or human actions such as the introduction of exotic species or ecosystem nutrient depletion may all contribute to this process, which can be natural or man-made. The creatures that formerly utilised the location are moved or exterminated during habitat loss, lowering biodiversity. The second half of the twentieth century had human habitat degradation increase dramatically. Human activity often destroys natural environments in order to gather natural resources for industrial production and urbanisation. Habitat damage is mostly caused by clearing habitats for agriculture, mining, logging, and urban growth. Currently, habitat loss is the leading cause of species extinction across the globe (Okereke et al. 2016).

16.6 Effects of Anthropogenic Factors on Water Quality

Anthropogenic pollutants are compounds that are produced as a consequence of human activity, most often via land-use practices. Several human activities (agricultural, industrial, and urban migration) contaminate surface water and groundwater systems, and contaminants travel via several channels. Surface water varies from groundwater in that it may contain various dangerous substances as a consequence of human activities, making it highly polluted (Khatri and Tyagi 2014). Anthropogenic changes have a significant impact on each phase of the water cycle (leakages, irrigation, extraction, or wastewater), both in terms of changing the magnitude of existing circumstances and introducing new factors (Burri et al. 2019; Doble and Crosbie 2016). Furthermore, to take into account the natural context, local socio-economic elements in connection to present and past land-use practises, such as waste treatment methods and infrastructure, should not be overlooked (Seiyaboh and Izah 2017). The factors that affect water quality are illustrated in Fig. 16.1.

Fig. 16.1 Flow chart illustration of Anthropogenic factors that affect water quality



16.6.1 Industrial Applications

Industrial waste, mostly from mills, industries, and mining, pollutes the water supply. These industries have the potential to pollute water resources. Those sources are on the surface of the Earth, whereas industrial waste material flows into surface water, which then percolates directly or indirectly into groundwater. There are various efforts that have been undertaken in recent years in both developed and developing nations to identify these causes of water contamination. There are activities for monitoring and clean-up that have been established. Despite these obstacles, much effort need to be done to classify and store these sources, as well as to assess the consequences of the actions made. Industrial and urban uses, including mineral extraction exploration regions, are anticipated to occupy 3% of the land surface (Sagasta et al. 2017). Given the massive volume of liquid and solid waste emitted, these two main components of pollutants are the most often discussed in water resources literature.

Manufacturing businesses create more trash than urban and agricultural operations combined, notably mining operations, which produce the most waste globally

(Burri et al. 2019). The discharge into the environment of an ever-expanding and diverse assortment of waste products has left its imprint on the quality of water resources in recent decades, which has resulted from exponential industrial expansion in energy generation, raw materials, and technical applications (Khatri and Tyagi 2014). Wastewater of over 80% is believedito be dumped into the environment without treatment globally (Masi et al. 2017). Solid or liquid waste, mining methods, spills, and leaks are all potential major causes of water pollution due to industrial activity.

16.6.2 Solid and Liquid Wastes

Industrial waste refers to waste generated during the production process, which includes any waste products created in industrial activities such as factories and mills (Burri et al. 2019). Manufacturing businesses produce liquid, solid, and gaseous wastes that have negative environmental and human consequences; sulphur dioxide and nitrogen oxide emissions from chimneys and exhaust pipes contribute to acid rain (USEPA 2020;Masi et al. 2017). Industrial pollution may contaminate the air, soil, or local water sources, ultimately ending up in the oceans and rivers.

The existence, coverage, kind, and upkeep of infrastructure, such as landfills, may have been the most important determining factors for water quality and the danger of solid waste contamination from solid waste products (Han et al. 2014). Landfills (including tailings facilities) are the most common form of solid waste disposal worldwide, and they remain the most cost-effective choice, particularly for large volumes of industrial solid waste (Ferronato and Torretta 2019). Despite the fact that landfill leachate is a known source of groundwater contaminants, solid landfill liner is not irequired everywhere. Furthermore, landfills with insufficient or non-existent linings going back to the Industrial Revolution are common. Currently, areas without access to adequate preservation or disposal technologies must rely on shallow subsurface disposal of solid waste. Furthermore, solid trash includes a wide range of items such as plastic, cardboard, paper, scrap metal, packaging materials, wood, vehicle components, culinary waste, and any other solid waste that no longer serves its original purpose (Abdel-Shafy and Mansour 2018).

The term "wastewater" refers to industrial liquid waste. The presence of organic components (proteins, lipids, and carbohydrates) as well as dissolved inorganic pollutants in industrial fluids causes contamination (Elnasri 2003). The majority of industrial enterprises need large amounts of water, which might generate hazardous substances. Drainage systems, drains, septic tanks, and sewer networks are all part of the liquid waste infrastructure (Marszelewski and Piasecki 2020).

Centralised wastewater collection systems in conjunction with a properly working treatment plant employing contemporary treatment technologies and periodic maintenance are advised, because effluent is frequently better monitored for environmental protection. The other kind of infrastructure is the extensive gasoline storage and pipeline networks used in the industrial sector. These components have the potential to pollute nonaqueous liquids as a result of leaks or spills (Burri et al. 2019; Jackson et al. 2013).

Petrol stations, as well as extensive networks with above- and below-ground channels and pipes carrying petroleum compounds, may pose a major danger to groundwater quality (Corapcioglu and Baehr 1987). Spills and leaks in industrial product tanks and pipes may potentially pollute water supplies. Manufacturing environment products, chemicals, or hazardous waste (benzene, toluene, xylene, etc.) and their introduction into freshwater cause accidents (Holt 2000).

The use of injection and disposal wells, which degrade water resources, is a special issue in the industrial process. Industrial effluents and water for cooling and processing enter the groundwater system at the well's bottom or through well screens at disposal wells (Pichtel 2020). Chemicals and bacteria from these wells, especially from industrial waste, might directly pollute aquifers. Injection wells are often related with the disposal of hazardous waste in deep-seated rock formations that are not meant to interact with freshwater resources (VanDerGun et al. 2016). Brine, radioactive products, chlorinated hydrocarbons, and liquors for bearing steel are all examples of waste that may be dumped by injection wells.

The other issue in the groundwater system is improper well field design, which may alter local groundwater flow as well as chemical and biological conditions. This may result in the direction of groundwater flow being modified or reversed, as well as the hydrological chemistry of the subterranean aquifer and the redox potential (Michael and Voss 2009), for example, inappropriate well screening and sitting may alter redox values in iron-rich groundwater, resulting in iron, manganese, and slime precipitation in the groundwater, as well as in well screening and pumping (Zhang et al. 2020). The other example is inadequately screened wells in aquifer systems where human-induced contaminants such as pesticides, fertilisers, liquid and solid wastes are present (Ayilara et al. 2020). Furthermore, contaminant penetration via semi-constricting formations has the potential to degrade groundwater quality in deeper water aquifers and infiltrate well screens (Sheng 2005). This results in faulty well screening and sifting, exacerbating the effects of both human-made and natural pollutants, and may be considered a secondary pollution mechanism.

Chemical compounds are often used in industrial operations for pest control or to enhance substance qualities (Usta 2013). According to Burri et al. (2019), pest control products are often referred to as biocides. Chemical materials are employed both outside and inside in the industrialisation and urbanisation sectors; however, they are almost primarily used outdoors when compared to agricultural goods. Furthermore, outdoor contaminants may continue to flow via sewage networks, resulting in groundwater contamination, either as a point or line source (Hensen et al. 2018).

16.6.3 Mining Processes

Environmental consequences of mining may occur at local, large, regional, and global sizes through indirect and direct mining operations. Sinkholes, erosion, biodiversity loss, exploration of radioactive substances, salt, coal, phosphate, or chemicals discharged from mining activities are all examples of its consequences (Agboola et al. 2020). The excavation of solid waste, the high use of water in iore processing, seepage from tailings, waste rock impoundments, and water pollution from mining activities have serious impacts on groundwater and surface water systemsi(Jain and Das 2017). Furthermore, mining and iore processing activities mostly draw groundwater in open-pit mines, where groundwater infiltrates regularly, or in underground dewatering operations, where groundwater infiltrates frequently.

Observation wells, abandoned production wells, and boreholes drilled for exploration may act as vertical conduits for harmful contaminants (Rybicki et al. 2015). Acid mine-water discharge, which results in groundwater pollution from mining waste, such as tailings facilities is another source of contamination (Anawar 2015). Coal mining is the most common cause of this problem.

Disposal tailings facilities, which often retain significant volumes of by-products of host-rocks like pyrite, make up crushed waste rock and liquid (Burri et al. 2019). The oxidised material is diluted with water, resulting in acidic mine water. There is no typical component in mine-water drainage, although it generally contains high sulphate, iron, and other metal concentrations, a low pH, and a high acidity. Water used to decrease mining dust, cool equipment, wash it, and process it, among other things, may build up hazardous substances (Okore et al. 2021).

Nonetheless, prior data show that, depending on pH, soil types, and leachate amounts, heavy metal absorption from mine leachate may be quite effective in shallow and deep aquifers (Schwartz and Kgomanyane 2007). The lack of calcite or carbonate in the subsurface geology, as well as the discontinuation of lime addition to tailings facilities, reduces groundwater's capacity to tamp down mine wastewater. Soluble elements have occurred in higher amounts with just a small drop in pH. When the pH of the leachate and groundwater falls below 5, much larger quantities of aluminums and copper are detected in groundwater, posing a serious threat to the quality of surface water and groundwater, as well as the ecosystems that depend on them (Schwartz and Kgomanyane 2007).

16.6.4 Agricultural Practices

Agriculture is one of the most prevalent human activity that has an impact ion both surface and groundwater. Fish farming, agricultural cultivation, livestock, insecticides and fertilisers, cattle, and poultry farming are all examples of operations in this area. Because these activities take place on the surface of the Earth, contaminants may reach the groundwater via soil, vegetation, rainfall, surface, and irrigation water penetration. Forestry may have a negative influence ion iwater iresources ias iwell. iStockpiles iof ia ivariety iof iirrigation imaterials iand agricultural waste might potentially become point sources of contamination in subsurface water (Seiyaboh et al. 2017).

16.6.4.1 Pesticides

Pesticides are chemicals that are used in community gardens, agricultural regions, and other public spaces to eliminate unwanted species (Hassaan and El-Nemr 2020). The term "pesticide" refers to any substance that is used to kill or control pests. Pesticides were first recognised as environmental dangers in the early 1960s. Chemical controls have become a staple of agricultural expansion, as well as rising urbanisation and industrialisation.

Pesticide use has continued to climb since 1989, according to massive monitoring estimates, with up to three million tonnes used in 2007. (Burri et al. 2019). Pesticide usage has grown dramatically in the previous two decades, particularly in Europe and North America, and worldwide pesticide use is visible. Despite limits, pesticides are still a major risk for global groundwater resources.

Pesticides include iherbicides (herbs), fungicide (fungi), insecticides (insects), and rodenticides (vertebrate poisons). They are particularly important for food production, since they protect or boost crop yields and allow a plant to be grown on the same piece of ground many times each year (Kim et al. 2017). The mobility of pesticide products in the subsurface is complicated by variations in pesticide degradation and sorption rates (the two most important processes for controlling pesticide persistence) and their characterisation of sediment and groundwater media. Porous groundwater aquifers often increase pesticide filtration from underground; however, karstic aquifers are more prone to long-term pesticide contamination concerns owing to fast flow and poor sediment reactivity. Pesticides, as a result, may readily be transported over a large geographic area, polluting surface water and groundwater (Agrawal et al. 2010). Many pesticides are water soluble and are sprayed with water before being ingested by the target.

The more soluble a pesticide is, the greater the risk of leaching; residual herbicides, on the other hand, are generally less soluble to assist bind the soil (Šperl and Trckova 2008). Precipitation is another factor that effects pesticide water pollution; high precipitation rates increase the risk of pesticides contaminating the water. It might take decades to get toxic water out of the damaged wells, because of the sluggish flow of groundwater. Pesticides that have been used in the past but are now banned have been found as lingering compounds in groundwater. It is not always evident why this is the case.

There are presently few operational methods or strategies for tracking environmental harm or forecasting its long-term viability within water resources.

Time series for concentration, isotopes study for particular chemicals, and compound ratios for parent-to-metabolite are all traditional approaches for identifying the sources and paths of pesticide contaminants in water bodies.

16.6.4.2 Fertilisers

Fertiliser components that are not adequately regulated might end up in water bodies via run-off or leaching (Smith and Siciliano 2015). Nitrogen (N) and phosphorus (P) are the two principal fertiliser chemicals that are most dangerous to water resources. Nitrate poisoning of water bodies may be caused by improper or excessive fertiliser use. Organic or inorganic nitrogen fertiliser is physiologically transformed to nitrate, which is very soluble in water (Hallberg 1987). Furthermore, since soluble nitrate is very mobile and may be removed from soil with percolating water, it is inaccessible to crop absorption and build-up. Fertiliser nitrates may create major health problems when pollution reaches drinking water sources, especially for young cattle and newborns (Briški et al. 2020).

By lowering the blood's oxygen-carrying capacity, nitrates may cause methemoglobinemia (blue baby syndrome) in children. Another important component of fertiliser is phosphorus (Akhter and Hasan 2016). Phosphorus, in certain cases, may be readily transferred with the soil. Furthermore, 60 to 90% of phosphorus is carried through the soil. Phosphorus is the most common source of lake water quality problems across the world. If water sources are to be safeguarded from chemical contamination, proper fertiliser storage, handling, and application on farms or acreages is critical. This is mainly due to the fact that fertiliser rubbings in surface water may promote excess algal growth and fish death; to overcome this issue, safe permanent storage and mixing fertilisers from spills, leaks, or storm-water penetration are required.

According to previous research, many silage-making situations result in contaminated liquids with high BOD needs and the emission of phenols and sulphates (López-Pacheco et al. 2019). Agricultural nitrate is the most prevalent chemical pollution found in groundwater aquifers across the world. Agriculture in the United States of America is the leading source of pollution in streams and rivers, the second most important wetland, and the third most significant lake source (USEPA 2018). Agriculture in China is also responsible for a significant quantity of surface water and groundwater contamination caused by nitrogen (Sagasta et al. 2017). Chemicals such as insecticides and chemical fertilisers have been used extensively to boost agricultural output across the world. Nitrogen and phosphates in excess may seep into groundwater or be carried away by surface run-off into streams. Phosphorus is not as soluble as nitrate and because of it, it is absorbed into the soil and subsequently transported to the water resource via soil erosion.

16.6.5 Urbanisation

Urbanisation is a broad term for land-use and land-cover change that is quickly spreading over the world (Müller et al. 2019). It involves the conversion of croplands, wetlands, woods, pastures, grasslands, and other land cover types to commercial, industrial, residential, and transportation uses, resulting in an increase in impervious surface areas (Khatri and Tyagi 2014).

The impermeable surfaces, as a result, are quantifiable elements that are linked to increases in contaminated run-off sources, lowering the quality of water resources (McGrane 2016). River embankments, sluices, irrigation and drainage works, penetration galleries, water wells, dams, and reservoirs are all common construction projects. Major pollutants emitted from urban operations, such as municipal practises, land development, forestation, and deforestation, have been examined in this section.

16.6.5.1 Municipal Wastes

Municipal (home or domestic) wastes come from a variety of human activities and socio-economic sectors across the globe, and they may be liquid or solid, making them difficult to employ as raw materials (Abdel-Shafy and Mansour 2018). These wastewaters arise from our daily routines, such as meal preparation, washing, bathing, and toileting (Milla et al. 2012). Furthermore, grey and black water are discharged from private residences with piped water, as well as commercial properties and organisations in residential neighbourhoods such as schools and health institutions.

These types of liquid wastes, in conjunction with surface run-off, are referred to as sewage. Commercial wastewaters, which include businesses, shops, stores, open markets, restaurants, and cafés, are mostly identical to domestic wastewaters (Stuart et al. 2011). Liquid waste, such as urine, human faeces, and washing water, is dumped into shafts to prevent it from becoming a danger on the land's surface, as well as in the water table and contaminated water systems surrounding the site, if the liquid level is high (Lee et al. 2020). Septic tanks may harm local groundwater sources, especially in heavily populated metropolitan areas.

Furthermore, solid waste products, such as wood, plastics, metals, food waste, papers, inert materials, paint containers, yard trash, demolition materials, construction, and textiles, are very diverse, with varying physical qualities depending on their source (Khatri and Tyagi 2014). However, the majority of these sources are no longer expanding in terms of size and quantity of recyclables.

Water contamination from cemeteries has been a long-standing problem in the United States. During the breakdown of the human body, about 0.4–0.6 L of leachate with a density of 1.23 ig/cm^3 is emitted per 1 kg body weight. The leachate contains 10% organic components, 30% nitrogen ion salts, phosphorus, Cl, Na, and different metal compounds (Cr, Cd, Pb, Fe, Mn, andNi), and 30% water (Ziychowski and Bryndal 2014). The liquid has a strong conductivity, pH, and BOD value, as well as a pronounced fishy odour. Chemical substances used in chemotherapy and embalming treatments (arsenic, formaldehyde, and methanol), make-up (cosmetics, dyes, and chemical compounds), and a variety of other chemicals are examples of pollutants that originate in the body (Burri et al. 2019). Furthermore, these leachates include germs that might pollute groundwater (Ogamba et al. 2015).

The average daily traffic in urban regions is greater than in rural areas, and as a consequence, water pollution in urban areas is much higher. According to the EPA (2011), transportation has four direct effects on water quality:

(a) Because of greater rushes, reduced groundwater recharge rates, and increased erosion, road construction and maintenance, particularly impermeable surfaces, may have a negative impact on water quality.
(b) Pollutants such as oil, car exhaust, dirt, and de-icing chemicals are deposited in highways, causing dryness in streams.
(c) Oil spills, particularly those on the sea, have an impact on the water quality of interior waterways and coastal areas.
(d) Petroleum is released into groundwater by leaking underground storage tanks.

16.6.5.2 Livestock Productions

Most nations have a large number of livestock and poultry farms, with the United States having an estimated 1.2 million. This statistics also includes all operations that boost the production of beef or dairy cattle, pigs, and swine, including both confinement and non-containment (grazing and range-fed) cattle, hogs, and swine (Akinbile et al. 2016). Animal dung may also be used to fertilise plants and add/recover nutrients to the soil on farms. Nonetheless, developments in animal production, notably the expanding tendency towards animal husbandry in large feedlots, have resulted in more serious problems with animal waste consumption and disposal. Since animal husbandry has been denser and more spatially concentrated, the amount of manure nutrients has risen, notably in China, India, Australia, the United States, and South Africa, according to assimilative land production capacity on farms. Animal manure may be carried over the agricultural land surface and into nearby lakes, streams, and groundwater. As a result, waste from livestock feedlots that leaks into surface water, groundwater, soil, and the air seems to have a wide variety of environmental and human health consequences. Salts and trace elements, as well as antibiotics, insecticides, and hormones, are found in animal excrement to a lesser level. In addition, the principal contaminants in animal waste include nutrients (particularly phosphate and nitrogen), pathogens, sediments, organic matter, and odour/volatile chemicals (Polat and Olgun 2018).

16.6.5.3 Land Use Practices

Urban areas, since 2010, have been predicted to cover 3% of the world's available land. Cities can cause an even greater or equivalent risk of groundwater contamination than surrounding farmland regions due to their diverse land use, large population, development of transportation systems, heavy resource usage, and heavy waste disposal (Khatric and Tygagi). As a result, the ntensity and density of these occurrences are comparable to, but not greater than, those of industry and agriculture in terms of geographical area. Furthermore, land cover changes are often the initial stage in a region's development. It includes changes in vegetation, soil permeability or porosity, topography, and surface water characteristics, all of which have an impact on recharging and groundwater flow (Burri et al. 2019). Changing current terrain, adding to alien species of plants (typically for agriculture), wetland draining, soil tillage, diluting, and removing any vegetation cover are some examples of these consequences (Camara et al. 2019). Furthermore, changes in soil and vegetation are the primary cause of evapotranspiration rate fluctuation. Changes in the absorption or reflection of solar radiation, as well as the water needs of dominating species, may enhance or reduce recharge. The various land management practises result in topographic changes (Khatric and Tygagi).

Infrastructure, which includes building, pipelines, motorways, and roads, has an influence on water systems as well (EPA 2011). The conceptual framework of an anthropogenic water balance, in contrast to land-based changes, must be added to infrastructure-based man-made source and sink components. Significantly altered landscapes resulting from such components have the ability to alter the water balance, influencing solute mass fluxes and quality (Parris 2011; McGrane 2016). Manure spread, in addition to liquid pesticides, is a common agricultural technique that transports a variety of chemicals into the environment.

Concrete or compacted surfaces, such as highways, building sites, and park areas, are the most common elements of anthropogenic environment. Storm and snowfall run-offs are elevated, while diffuse input and evapotranspiration are significantly reduced, as is usual in urban and industrial settings (Burri et al. 2019). If we suppose, at the same time, that more than half of the world's population lives in cities, we have a continuous issue with waste treatment and wastewater. According to the UN World Urbanization Prospects 2018, this proportion is expected to climb to over 70% by 2050. (World Bank 2020). This poses a serious threat to city inhabitants who live near poorly managed garbage, as well as an elevated danger to urban water supplies.

16.7 Biodiversity Loss and Common Species

The majority of past research on biodiversity loss has concentrated on the consequences of species extinctions; nevertheless, biodiversity loss also includes decreases in common species populations and alterations in species dominance patterns (Hooper et al. 2005). Common species are thought to be the drivers of any ecological process (Schmid et al. 2009), and any loss might have negative consequences for the ecosystem's primary function, for example, dominant fish plays an important role in freshwater ecosystems, primarily by bridging the gap between the benthic and pelagic sections of the food web via their quick movement and adaptable foraging behaviours (Moore 2006). Dominant fishes span more trophic levels with lower species richness, because of this they are less likely to be replaced by other functionally identical fishes. Many instances of overharvesting of plentiful fishes leading to alterations in ecosystem function have been discovered (Schindler and Scheuerell 2002). The fall in migratory fish populations presents a slew of issues, since they often transport items across large distances with no effective substitutes available. Salmon fish, for example, move huge amounts of marine-derived nutrients across vast scales into freshwater and terrestrial environments, as well as redistributing nutrients to smaller sizes during spawning (Merz and Moyle 2006; Allan et al. 2005).

16.8 Conservation of Biodiversity

Over the years, Nigerian biodiversity conservation has gone through numerous stages. Indigenous peoples have long conserved biodiversity via cultural traditions and religious beliefs before the British established the forestry administration (Martin 1991). The inhabitants held the forest in great regard. The majority of people thought that the forest was home to ghosts and that one needed to be spiritually reinforced before venturing into it, as a result, only the most daring hunters and local medics ventured to penetrate the dense jungle (Aigbokhan 2016). The cutting of particular tree species, such as the Iroko (Milicia excelsa), which was regarded as the king's tree, was a terrible offence, according to an ethnobotanical inquiry conducted by informed respondents in Southern Nigeria. Plant species utilised as fuel forests were carefully chosen, with the majority of species being numerous and fallen trees. Hunting of animals was not done at random in the case of animals, only recognises the practise as being carried out by village hunters. Clearly, the people cared about biodiversity protection, and although while agricultural techniques were mostly defined by slash and burn at the time, the locals typically allowed some key tree species on fields, a system known as agroforestry.

The Europeans' introduction of civilisation led to the adulteration and degradation of some of the beliefs and traditions that aided in biodiversity preservation. The demand for tropical woods by Europeans, as well as the conversion of forest areas into rubber and oil plantations and the industrialisation of forest operations, had a major role in the loss of biodiversity in most West African nations, including Nigeria. The need for agricultural land for food production, the creation of communities, and the supply of other sorts of infrastructure has worsened the encroachment process, and most of these once treasured regions have lost protection (USAID report on Nigeria Biodiversity and Tropical Forestry Assessment 2008).

In the face of the existing reality, two primary approaches to biodiversity conservation have been adopted in Nigeria: in-situ and ex-situ strategies.

16.8.1 In-Situ Conservation

The on-site conservation, or the preservation of genetic resources in natural populations of plant or animal species, such as forest genetic resources in natural populations of tree species, is referred to as in-situ conservation (Ajayi 2019). The in situ conservation preserves not just a species' genetic variety but also the evolutionary adaptations that allow it to adapt to changing environmental circumstances, such as previous population and climatic fluctuations. It guarantees that as a by-product, hosts of other interconnected species are retained alongside target species. It is usually less expensive than ex-situ approaches (although not cheap), for example, for species of plants with resistant seeds, it may be the sole choice for conservation. Places in Nigeria, with a high level of biodiversity are designated as protected areas and maintained (Ejidike and Ajayi 2013). The natural peacefulness of these protected places, as well as the many plant, animal, and bird groups that live there, combine to make each one a unique destination (Sawe 2019). National parks, forest and wildlife reserves, and holy groves are the mainstays of *in-situ* biodiversity protection.

16.8.2 **Ex-Situ** *Conservation*

Ex-situ conservation refers to the protection of an endangered plant or animal outside of its native environment, such as by colony relocation, which involves moving a portion of the population to a less vulnerable region, or through human care techniques like zoos and botanical gardens (Okorodudu 1998). *Ex-situ* conservation is beneficialito man's attempts to preserve and safeguard our environment at the same time, it is seldom sufficient to rescue a species from extinction. *Ex-situ* cannot replicate the ecosystem as a whole and conserve the whole genetic variety of a species, its symbiotic equivalents, or those components that, over time, can assist a species adapt to its changing circumstances, it is generally utilised as a last option or as a complement to *in-situ* conservation. *Ex-situ* biodiversity conservation in Nigeria is characterised by home gardens, seed banks, botanic and zoological gardens.

16.8.3 Cost Efficiency Plans for Conservation

Freshwater conservation systems should ideally incorporate an explicit appraisal of conservation management costs in order to cope with the growing strong competition for varied water resources. Freshwater conservation objectives dentified based on social, biological, and economic costs allow for a more clear evaluation of the trade-offs between use and management, as well as a higher likelihood of commitment from decision makers and legislators (Dudgeon et al. 2006). More ideas concerning conservation costs were offered in the literature when it came to conservation area selection, including acquisition, management, and transition costs followed by opportunity costs (Moore et al. 2007). Examining conservation costs in freshwater communities is complicated because it incorporates the notion of expenses for protecting a specific location as well as accompanying costs dealing with the needed water to maintain such a region for a long time. This includes calculating the costs and benefits for the whole catchment. The environmental field flow assessment has a large variety of formal methodologies which emphasizes alternate water allocations within the watershed (Naidoo et al. 2006). Essentially, such techniques assess trade-offs in flow demands for water resource management that would support both biodiversity and human needs. Full integration of such conservation planning systems has enormous promise, but it has not been done yet. Multiple conventional decision-making techniques were also utilised in terrestrial conservation planning to help in the analysis of a desired scenario based on quantitative or qualitative biological, social, and economic considerations (Tharme 2003; Sarkar et al. 2006).

16.8.4 Recommendation

1. To guarantee long-term biodiversity use and conservation, two major players must take the lead. First, the government must incorporate sustainable development concepts into its laws and initiatives. Second, ecologists must work to ensure that policymakers have access to complete biodiversity data.
2. There must be widespread public understanding of the necessity of biodiversity protection, particularly in rural regions, where the majority of our biodiversity remains. The indigenous peoples should be encouraged to participate in conservation programmes that help them protect their biodiversity and offer them a feeling of belonging. Locals should be taught as tour guides and in administration so that they can manage a viable ecotourism business. Additionally, revenue generated from tourism should help the local economy grow, give an incentive to protect the environment, and finance the local health clinics and scholarships for local kids.
3. Because economic activities are the primary cause of biodiversity loss and destabilisation of the natural system, such activities should be penalised financially, while conservation should be rewarded. Economic activities that do not undermine the natural system will be favoured in this manner.
4. Finally, the majority of management science degree programmes should include courses in bioresource management, particularly in the area of conservation. This is the finest way to educate future graduates about the importance of biodiversity conservation.

16.9 Conclusion

Aquatic pollution is a major issue in both freshwater and marine ecosystems; it has detrimental consequences for human health as well as other creatures. Freshwater habitats, like other ecosystems, are regarded severely endangered due to their live biota. Climate change, overexploitation, pollution, habitat degradation, flow alteration, and alien species invasion are all challenges to freshwater biodiversity. Systematic conservation planning gives biodiversity conservation a strategic and scientifically sound foundation.

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Part IV
Trends, Scenarios and Governance in Relation to Biodiversity Conservation

Chapter 17
Traditional Methods of Plant Conservation for Sustainable Utilization and Development

Matthew Chidozie Ogwu and Moses Edwin Osawaru

Abstract Cultural or indigenous practices refer to long-standing traditions and ways of life of specific communities or locales. These practices are place-based and often location- and culture-specific. Plants are integral to livelihood especially in indigenous communities within the Global South. Ethnologists including ethnobotanists continue to enumerate the interface between nature and culture, which addresses the need to provide quality information for plant conservation and their sustainable utilization. Plant conservation is the wise use of plant resources by the present generation so that future generations can benefit. Traditional conservation ethics protect plant diversity and natural resources because local communities consider themselves as the major stakeholders. Globally, support for contemporary plant conservation approaches exists whereas none exists for traditional methods. Some traditional systems used for plant conservation through their utilization include taboos, totemism, rituals, domestication, reserves, secrecy, selective harvesting, sacred groves, etc. Totemism is the practice-based consciousness of the supernatural link that exists between people and specific objects including plant species, natural resources and or objects made from these items whereas taboo is the forbidden practice of using or consuming some plant species, natural resources and objects or their parts (totems). Sacred groves are described as patches of land considered sacred and conserved by indigenes through sociocultural, economic and religious observances and include traditional sacred groves, temple groves, burial and cremation grounds, etc. like the Asanting Ibiono sacred forest, Nigeria; Anweam sacred grove within the Esukawkaw forest reserve, Ghana; sacred Mijikenda kaya forest, Kenya; Kpaa Mende sacred grove, Sierra Leone; Thathe Vondo holy forest Limpopo, South Africa and Kwedivikilo sacred forest, Tanzania.

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These largely informal conservation and utilization practices have several ecological, sociocultural and economic relevance. They have contributed towards the protection of plant species like *Lippia javanica*, *Milicia excelsa, Adansonia digitata, Spathodea campanulata, Ziziphus mucronata* and *Ficus thonningii.* However, growing pressures from human population boom, reduced environmental quality, and neglect of sociocultural norms and traditional belief systems are undermining the relevance of these practices. Therefore, it is essential to document these practices, enlighten future generations of their importance and institute legal instruments to promote the sustainable management and application of these cultural heritage and natural resources for societal development.

Keywords Cultural practices · Ethnobotany · Plant conservation · Taboos and totems · Global South · Sustainable development

17.1 Introduction

Cultural or indigenous practices are traditional ways of life associated with certain regional, native or local communities for centuries and may include wisdom, practices, knowledge, understanding and teachings that move through generations like stories, ceremonies, value systems, legends, taboos, folklore, rituals, folksongs, ceremonies, native laws, etc. (Acharya and Shrivastava 2008; Dike and Obembe 2012). These cultural and indigenous practices are place-based because they are inextricably linked to specific locations wherein indigenous systems acknowledge the practices and develop the rationale behind them (Dike and Obembe 2012). Moreover, the intergenerational accumulation, observation, communication and experience on the knowledge behind most cultural or indigenous practices are pertinent to the evolution of indigenous systems and practices.

Traditional plant conservation practices refer to long-standing cultures that are native to a group of people for conserving plant genetic and associated resources. These traditional practices encompass the wisdom, knowledge and teachings of how natural resources present in a certain locale can lead to posterity. Some traditional plant conservation practices may include stories, legends, folklore, rituals, songs, etc. The traditional uses of plant resources may refer to the local use of plant resources whereas cultural uses of plants mainly focus on the native way of life and value systems as they relate to the crop. Indigenous plants and bioresources are the main sources of energy, food, shelter and medicine for rural communities and these interactions have culminated in the development of local management strategies for these resources (Rankoana 2016).

In the Global South (i.e. countries that are south of the Equator and most often used in reference to developing and underdeveloped nations), rural and suburban dwellers depend on plants for their subsistence more so than any other part of the world and indigenous plant use has been considered a haphazard activity (Blockhus 1994; Rankoana 2016). For instance, the Kalanga people (of Southern Africa) depend on the same native plant species for food, fuelwood, medicine and timber without any elaborate coordination and distinct organization process (Rankoana 2016). Therefore, plants as invaluable natural resources are integral to survival in diverse local communities (Sidigia et al. 1990). In the same vein, plant conservation is essential to maximizing the benefits of plants as well as contributing to their adaptation, resilience and sustenance, despite the ongoing mass extinction. Apart from serving as a source of building materials, animal feed and fodder, weapons as well as other commodities, several plant species are important as pharmaceuticals and medicines with the use of ca. 50,000 plant species documented in the literature (Akama 1999; Leaman 2004a; b; Chime et al. 2017; Ogwu et al. 2018). Specifically, within the Global South, ca. 80% of the population uses plant-based local medicine in the treatment and management of various diseases and ailments like malaria and typhoid fevers, stomach and other ulcers, skin infections, diabetes, reproductive problems, and aches and pains mainly due to sociocultural beliefs (Ajose 2007; Ogwu et al. 2017). In other parts of the Global South, traditional practices including sociocultural, spiritual beliefs, cosmologies, as well as economic considerations are deemed invaluable to the use and management of plant genetic resources for sustainable development. These practices continue to reinforce the preservation of these bioresources in their environment. According to Sasaoka and Laumonier (2012), local plant resource management is entwined into broad social and cultural contexts within local communities while spirituality underscores native people's survival outlook.

Historically, botanical ethnologists have continued to focus on the realm of sociocultural, economic and ecological importance of plants within a locale. However, these traditional trends are giving way to different foci due to changing cultural norms and biological extinction. This has necessitated action from ethnobotanists to review their position and research approach at the juncture of nature and culture, which is capable of making novel contributions in documenting pertinent information and evolving novel approaches for the conservation of plants and natural environments (Dike and Obembe 2012). Nonetheless, the new system adopts a use-based conservation approach that is similar to historical systems. Documenting existing traditional conservation systems is limited by a poor understanding of their development, change and evolution, and mode of transmission through time and space (Rim-Rukeh et al. 2013). In recent times, the availability and sustainable flow of renewable plant resources are disappearing due to pollution, urbanization, climate change, habitat modification and fragmentation, and invasive alien species both in cultivated and non-cultivated lands in rural, suburban and urban ecosystems (Ogwu et al. 2014; Ogwu 2019). More so, the proportion of human-managed ecosystems is increasing (currently about 75% of terrestrial surface area) whereas protected areas remain at a meagre 8% (McNeely et al. 1994). These artificial (human-created) ecosystems at best only contain segments of Earth's biodiversity but can significantly contribute to the maintenance of plant diversity and their sustainable conservation (Osawaru and Ogwu 2014a,b; Ogwu et al. 2014). According to Cary and Mooney (1990), massive loss and reduction in plant genetic resources and diversity was recorded in the twentieth century especially under cultivation, and has led to increased pressure and diminished the diversity in the diets, health, social equity, justice and cultural stability of rural people. Therefore, maintaining the synergy between sustainable development and plant utilization and conservation is pertinent in the long term (McNeely 1989).

This chapter will enumerate the importance of traditional plant conservation and utilization practices to the sustainable management of plant genetic resources and other bio and natural resources as well as their contributions to sustainable development in Africa and other parts of the Global South. The chapter will briefly discuss the guiding principles for plant conservation as well as some modern plant conservation practices. The high point of the chapter will be the presentation and discussion of some traditional systems for plant conservation through utilization as well as their ecological and socio-economic cum cultural relevance. Thereafter, the chapter will mention some challenges and threats to traditional methods of plant conservation and enumerate the benefits of a robust complimentary-based plant conservation strategy that incorporates modern and traditional considerations.

17.2 Guiding Principles for Plant Conservation and some Modern Plant Conservation Practices

Plant diversity is the variety of genes, species, subspecies and varieties found in a locale but considered as an asset of international, regional, national and local value and significant to the ecosystem in maintaining ecological processes, functions and systems. The economy of some nations is essentially dependent on their plant resources. No two nations on Earth have entirely the same plant resources. The enormous plant diversity and richness often reported from Africa and other parts of the Global South are attributed to the unique environmental conditions. The works of Osawaru and Ogwu (2013) and Govindaraj et al. (2015) suggest that plant richness and diversity can be captured and maintained as genetic resources in biorepositories such as gene and/or seed banks, DNA libraries, tissue cultures, and in vitro techniques, which have the capacities to preserve plant genetic materials for long periods and utilized them for crop improvement to meet both potential and actual, current and future food, economic and environmental needs.

Plant conservation is the wise use of the Earth's plant resources by humans so that future generations will benefit (Rim-Rukeh et al. 2013; Ogwu et al. 2014). On a broad scale, it also focuses on the management of invaluable natural resources and ecosystems such as timber, soil, forest and wildlife, watershed areas, landscapes, wilderness, wetlands, etc. that are derivable from or hold vital plant resources. There are several definitions of the concept of conservation, which essentially stress an anthropological root and focus as well as economic considerations but all these are not too far away from the basic guideline and approaches only embracing a multidisciplinary look. Usher (2000) defined the conservation of biological resources as the maintenance of their genetic resources, species and ecosystem diversity either outside of or in their natural location to maintain their relevance and intrinsic abundance. Also, Smith and Wishnie (2000) presented a definition of conservation that focuses on conscious actions to protect, prevent, adapt or mitigate biodiversity and ecosystem loss with special management systems that are designed, established and maintained specifically for it. From time immemorial, local people in diverse places across the globe have developed a variety of systems and practices for indigenous biological resource management, which continue to exist to date especially in Africa, Asia, South America, Oceania and some parts of the new world (Appiah-Opoku 2007a). Examples include the celebration of festivals with foci on these bioresources as well as the adoption of traditional approaches to regulate interactions and emergent properties within natural environments such as erosion, flood control and water purification. Simply, plant conservation is the wise use and maintenance of plant genetic and associated resources to prevent loss and provide for future use (Chaplin et al. 2000; Millennium Ecosystem XE "Ecosystems" Assessment 2005). In 1992, the Convention on Biological Diversity established strategic policies for sustainable biodiversity use and conservation as well as the preservation of associated traditional knowledge and practices (Sen and Bhakat 2021). These are entwined in plant conservation guiding principles, which include the following:

- Preservation of cultural heritage and plant diversity.
- Practice-based food and environmental security hinged on plant diversity should be sustainable.
- Keeping smallholder as well as large-scale farmers on the land to ensure plant diversity.
- Understanding and documenting plant diversity as a means of conserving diverse environments and the other bio and natural resources in them.
- Integrating conservation with sustainable utilization practices.
- Promoting the importance of plant resources through characterization works.
- Documenting current and potential threats to plant diversity.
- Conservation education is necessary to mitigate and adapt to loss in plant diversity.

Nonetheless, there is still an alarming loss of plant diversity occurring worldwide even though most have not been documented. Conservation scientists are alarmed at the progressive reduction in plant diversity and have started collecting seeds of displaced and endangered species. Some causes of plant genetic erosion are habitat alteration and fragmentation, over-exploitation, competition from exotics, changes in land use, population growth and climate change (Ogwu et al. 2014; Ogwu 2020).

Modern plant conservation continue to increasingly involve the use of new methods and technology for the survey, collection, rapid characterization, assessment, documentation and utilization of plant germplasm from gene banks in different programmes (Govindaraj et al. 2015). In situ conservation strives to modernize by ensuring effective and efficient plant management systems within these sites – farms, homesteads, sanctuaries, natural parks and bioreserves, botanical gardens, arboretums, national parks, etc. On the other hand, ex situ conservation is modernizing by incorporating the most advance biotechnological approach and efficient management practices. These methods incorporate novel biotechnological techniques for genetic manipulation and breeding with high precision albeit with little to no consideration given to environmental effects. Some authors even considered biotechnology as the backbone of contemporary plant conservation strategy including the assessment of the genetic materials (Cruz-Cruz et al. 2013). In the views of Cruz-Cruz et al. (2013), many plant species, subspecies and varieties have benefitted from contemporary approaches to plant conservation through providing a new avenue for the collection, duplication and multiplication for short- to long-term plant conservation, using in vitro culture techniques that depend on the plant species and availability of appropriate infrastructure like

- Maintaining cell and tissue culture techniques under aseptic conditions (short term).
- Medium-term slow growth in vitro storage from several months to several years.
- Cryopreservation (liquid nitrogen at −196 °C) for long-term conservation.

Globally, support for contemporary plant conservation approaches exists whereas none exists for traditional methods. This is in addition to the uneven spread of modern plant conservation facilities and infrastructures in many countries in the Global South especially in countries south of the Sahara Desert in Africa. This has resulted in the limited availability of crop wild relatives for performing crosses in breeding research and gene introgressions in sub-Saharan Africa as reported for sweet potato (*Ipomoea batatas*) and African cowpea (*Vigna unguiculata*) in Khoury et al. (2015) and Moray et al. (2014), respectively. Also, Catarino et al. (2021) correlated the absence of modern conservation strategies in Africa to poor knowledge of the diversity of native germplasm and their geographical structure. Other topical issues include prioritizing exotic crops, poor knowledge of plant distribution, non documentation of utilization patterns, duplication of plant identity and lack of access to database for pre-breeding activities (Govindaraj et al. 2015). Moreover, there is a gross lack of information on species that are threatened and/or require urgent conservation efforts for most traditional locales within Africa and some parts of the Global South. Specifically, this might translate into the increasing loss, modification and fragmentation of habitat, which in addition to the effects of global climate change translate to difficulty in conserving some key plant species on traditional lands (Sharrock 2020). However, through modern plant conservation practices, significant progress has been recorded in the recovery and conservation of rare, endangered and threatened plant species as well as crop relatives like ornamental, medicinal and planted forest species, especially for non-orthodox seeds and plants that are propagated by vegetative means (Cruz-Cruz et al. 2013). Also, some collaborative efforts such as the Global Biodiversity Information Facility and Consultative Group for International Agricultural Research have increased the connection between people and plants (Pearce et al. 2020).

17.3 Traditional System of Plant and Natural Resource Conservation

On local plant taxa, Rappaport (1972) concluded, "that their survival is contingent upon the maintenance, rather than the mere exploitation, of the larger community of which they know themselves to be only parts". This view is supported by several other studies (Moller et al. 2004; Saj et al. 2006) wherein they reported on the effectiveness of traditional ecological knowledge and practices to protect and maintain natural resources. The roles of traditional practices in the conservation of plant resources relate to available plant diversity and their use-value, which dates back to the creation or origin of the local community (Berkes et al. 2000; Turner et al. 2000; Shastri et al. 2002). Traditional conservation knowledge and practice-based ethics protect biodiversity in particular and in turn the environment within local communities where they are found and will likely continue to play these roles as long as indigenes identify and act on their stakes in the ownership of these resources (Rim-Rukeh et al. 2013). Also, traditional knowledge systems are often infused with traditional conservation practices, concepts and modes of living, teaching and learning that can be directly and indirectly linked to resource stewardship and conservation at various scales.

In a study of the importance of traditional practices in plant conservation in the West Usambara Mountains of Tanzania, Msuya and Kideghesho (2009) recorded nine traditional cultural practices that contribute to the conservation of wild plants including plant domestication, beliefs in sacredness of trees, beliefs in sacred forests, respect for cultural forests, protection of plants at the burial sites, selective harvesting, secrecy, collection of dead wood for firewood and the use of energy-saving traditional stoves. These were mainly documented through botanical surveys of cultural sites like sacred, forbidden and cultural forests, farms/homesteads and burial sites, with a total of 1518 wild plants belonging to 100 species were identified. The authors concluded that these traditional management practices contribute significantly to biodiversity conservation in Tanzania.

In another study focused on the Mantheding community, Limpopo, South Africa, the traditional plant conservation management approach was highlighted as having a mainly in situ approach. Here, it includes the direct restriction on harvesting of crops such as the harvesting of whole plants and/or certain parts of the plants during certain seasons as well as seed propagation and control of plant used by the local chief and other informal systems (Rankoana 2016). Local communities partake in the sustainable use and management of indigenous plant materials since time immemorial and these communities have devised strategies to manage their cultural resources using local indigenous knowledge and practice systems (Richmond et al. 2013; Keitumetse 2014). According to Berkes et al. (2000), approaches to conserve plant diversity that relies on cultural and religious values are often more sustainable than those based only on legislation or regulation from external bodies and have the potential to contribute towards local societal development and sustainable use and conservation of plant genetic resources.

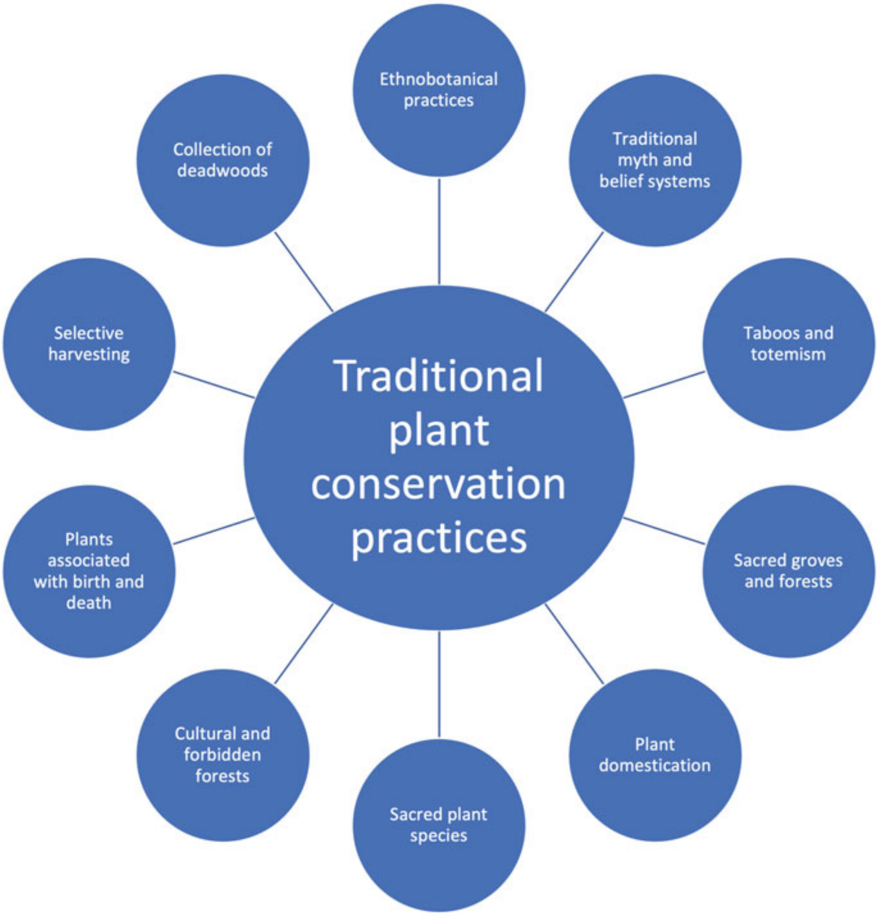

Fig. 17.1 Some traditional plant conservation practices

Broadly, traditional practices used for plant conservation incorporate in situ and ex situ considerations and include the following (Fig. 17.1):

- Ethnobotanical practices.
- Traditional myth and belief system.
- Taboos and totemism.
- Sacred groves and forests.
- Rituals, ceremonies and customs.
- Plant domestication.
- The sacredness of certain plant species and/or their parts (sacred species).
- Respect for cultural and forbidden forests.
- Protection of plants at the burial sites and the location of childbirth.
- Selective harvesting and use of plant or certain plant parts.

- Secrecy (including herbalism, wizardry and witchcraft).
- Collection of dead wood for firewood.

Some of these are discussed below.

Ethnobotanical practices. Ethnobotany uses multidisciplinary approaches to discuss the interrelationship between plants and humans in a particular environment. Indigenous people are custodians of traditional knowledge and practices that deal with plants in their daily life (Panigrahi et al. 2021; Osawaru and Ogwu 2014a,b; Ogwu et al. 2016). Ethnobotany remains an emerging field with structural origin in anthropology and sociology integrated with other fields of study. It is the backbone of traditional plant conservation because it is based on how plants are used and the need to retain them in the environment for future generations to benefit, for instance, the traditional knowledge, practices and beliefs related to specific plants are passed on through the word of mouth by the elderly people. More often than not, indigenous knowledge and practices are not documented in scripts or modern-day mediums but transferred verbally despite the attendant challenges such as inaccuracies. More so, since ethnobotany adopts the same categorization of plant conservation status, i.e. endangered, threatened, vulnerable, critically endangered, susceptible, rare, invasive weeds and plant species, etc., it can help present the conservation problems associated with native plant species as well as contribute towards the mitigation of habitat loss and other environmental challenges related to the plant. In addition, sustainable management and conservation efforts need to include local communities and their traditional knowledge systems as these are evident in plants produced and sold in rural markets (Sen and Bhakat 2021; Osawaru and Ogwu 2020).

The analysis of ethnobotanical data to reveal their relevance to plant diversity and conservation includes the use of qualitative and quantitative ethnobotanical indices to compare the knowledge system, uses and mode of transmission between many regions, statistical analysis performed by categorizing in various groups, relative popularity level, fidelity level, cultural importance index, relative frequency citation, use-value, informant consensus factor, rank order priority indices, etc.

Traditional myth and belief system. Even though the existence of traditional myths and belief systems does not guarantee the sustainable harvest of natural resources, it promotes the persistence of the plant resources in the vicinity (Chacon 2012; Krech 2005). Traditional religion and cultural practices in the Global South are mostly environment-friendly and sustainable with an innate capacity to ensure resource conservation and sustainability (International Institute for United Nations 1992). In parts of Africa, the traditional belief system ascribes metaphysical and superhuman abilities to objects like plants where gods and goddesses are believed to reside. The latter is the major tenet of the practice. Hence, the belief that the abode of the gods and goddesses is located within the plants found in a locale and the practice of choosing followers through elaborate rites of initiation conducted by messengers considered that the mouthpiece of the gods and goddess is an immemorial practice (Rim-Rukeh et al. 2013). The belief system and in turn system of plant conservation evolve around the notion that gods or goddesses protect the community from harm, famine, barrenness, impotence, drought, disease epidemics, war, etc. In the same vein, it is believed that the gods can vent their anger on whoever omits or commits any flaw that the system holds in very high esteem (Shastri et al. 2002). These beliefs are passed on through oral transmission to believers. Most often, the men are considered custodians and are initiated into these community cults or sects, which are often enshrined in religious or cultural beliefs and superstitions and enforced by taboos. The taboos and beliefs may or may not have legal backing but are held in high esteem within the community due to religious and cultural sentiments (Cox 2000). Therefore, the role of indigenous myths and beliefs in the protection of natural resources including plants is reflected in a variety of practices entwined in cultural and religious systems with social reflections. For example, in several communities around the world, particular patches of forests are designated as sacred groves under customary law and are protected from any product extraction by the community (Rim-Rukeh et al. 2013). Such forests maintain local biodiversity wealth including in some cases many rare, threatened and endangered plant species like herbs and medicinal plants. In their study, Tiwari et al. (2008) revealed that belief systems contribute to the maintenance of ca. 514 species in undisturbed, relatively dense and open forests. In Orhoakpor, Ethiope Southern Nigeria, the mighty Okpagha and Ogriki trees are highly revered and occupy a conspicuous position in the cultural landscape of the people because it is believed that trees belong to the Aziza spirit (god of the woods) who himself found enlightenment under Okpagha tree (Rim-Rukeh et al. 2013). Therefore, the groves of these trees are sacred and no axe may be laid on the tree nor can any branch be broken from it. Similar practices exist in communities around the Asanting Ibiono sacred forest, Nigeria; Aravalli Hills, India and Fengshui forests, China.

Taboos and Totemism. Some tribal people believe that they are linked with a particular species of plant and other natural- and bioresources in the form of the totem (Panigrahi et al. 2021). This belief system evolves over many years and is culturally passed along generations through cultural means especially socio-cultural-economic-religious aspects but also to conserve plant diversity in their surroundings. The tribal communities of Urhobos, Nigeria hold the belief that environmental conservation is equivalent to religion and has many totems – the belief in the metaphysical connections between natural materials or inanimate objects and people. In Urhobo land, it is considered taboo to use certain plant totems (Tonukari 2007). These taboos represent a class of informal institutions that govern human behaviour. They are also guided to human conduct and overall attitudes towards and exploitation of natural resources. However, the singular role played by these informal systems in biodiversity conservation has not been accorded its due importance (Rim-Rukeh et al. 2013).

Sacred groves and forests. Some examples of sacred groves and forests include Asanting Ibiono sacred forest, Nigeria; Anweam sacred grove within the Esukawkaw forest reserve, Ghana; sacred Mijikenda kaya forest, Kenya; Kpaa Mende sacred grove, Sierra Leone; Thathe Vondo holy forest Limpopo, South Africa and Kwedivikilo sacred forest, Tanzania. Sacred groves are patches of land where natural and bioresources are conserved by indigenous people through informal sociocultural and religious practices (Udeagha et al. 2013). These practices, in most cases, have existed for ages and ensure the continued proliferation and protection of rich native biodiversity—flora and fauna (Khumbongmayun et al. 2006; Khan et al. 2008). Culturally protected forest fragments considered sacred are often relics of original forests mostly within the Global South and have cultural and spiritual significance (Ormsby 2012; Khan et al. 2008; Salick et al. 2007). Indigenous people within these locales have developed a variety of useful practices to maintain these sacred sites that exist in Africa, Asia, South America and other parts of the world (Appiah-Opoku 2007a; Ray 2011). However, globalization and changing socio-economic conditions have started transforming these forest patches leading to degradation (Anthwal et al. 2006; Udoakpan et al. 2013). The works of Eneji et al. (2012), Ormsby and Edelman (2010) and Appiah-Opoku (2007a) emphasized that indigenous belief systems and knowledge form a fundamental part of traditional knowledge which serves as a very effective and important tool in protecting sacred groves which have become victims of development and population pressure. Furthermore, Appiah-Opoku (2007b) opined that those indigenous beliefs are not just a relic of the past instituted by our ancestors but something that is needed today and in the future for the conservation of local natural resources. The concept behind sacred lands is interlinked with the traditional knowledge system for maintaining and protecting biodiversity through fetish beliefs and taboos that serve as incentives (Khumbongmayun et al. 2006). Ormsby and Edelman (2010) affirmed that sacred forests are becoming vulnerable to the changing values and practices of the people around them. Eneji et al. (2012) noted that it is unfortunate that all these important strategies for natural resources conservation and management based on these traditional religious belief systems (sacred forests or groves) and sociocultural practices have almost been completely eroded from the acculturation and enculturation of communities within the Global South. The conservation of these natural resources is of utmost importance for the survival and sustenance of mankind (Pruthi and Burch 2009). Most recently, the protection of nature for religious purposes has gained attention in conservation literature (Ray 2011; Rao et al. 2011; Eneji et al. 2012). This is due to the urgent need for the sustainability of forests to preserve their regulating, supporting, provisioning and social/cultural functions in the face of present environmental changes.

Traditional rituals, ceremonies and customs. Native religion, culture, ceremonies and customs involve elaborate activities that are performed in a specific way, time and seasons and often required certain materials like plants and other natural resources and inanimate objects. These traditional rituals, ceremonies, culture, customs and religion dictate the attitude, behaviours, gestures and actions towards the plants and other natural resources that are required for them to occur. In the opinion of Geng et al. (2017), the long-term use of local flora and participation of natives in these rituals and customs contribute to the understanding and conservation of vulnerable plant species and landscapes within local communities where they are found. Therefore, these traditional rituals, ceremonies, religions and customs are important conservation tools even though, for example, in Dongba culture (China), live ritual ceremonies and the beliefs of residents within the community have maintained the plant diversity and entire forests despite the lack of elaborate support infrastructure from government and other external sources (Geng et al. 2017). This has led to the conservation of *Olea Europa* subsp. *Cuspidate, Pistacia weinmanniifolia, Hypericum forrestii, Acorus gramineus, Quercus pannosa* and *Juniperus chinensis* by the Naxi people of north-western China. Dafni (2007) highlighted the prevalence of tree worshipping practices in Israel to suggest the importance of ritual and customs to plant conservation as these trees have attained the sacred status and cannot be fell with consequences. This is also supported by the findings of Kanlaya and Poolsap (2016), wherein they reported that the Akha and Don Pu Ta indigenous people of Thailand do not cut trees because of their relevance to religious rites and worships. Therefore, these trees live for centuries. However, the rich knowledge about these local festivals, feasts, rituals and religious and cultural practices does not directly translate into efficiency in the conservation of these plant resources but their persistence from one generation to another might be a key to future incorporation of sustainable conservation techniques. Some of the traditional rituals and customs that contribute to plant conservation in indigenous communities include meeting venues, traditional courts and judgement centres, new yam and other plant-centred festivals, sacrifice, prayer venues, gravesites, wedding centres, etc. These systems for plant conservation evolved through symbiotic coexistence, interactions, bonds, metaphysical connections and reciprocal responses between the resource and human systems (Negi 2005; Bisht and Sharma 2005).

Plant domestication. Plant domestication is the starting point of plant conservation as it provides indigenous people with the opportunity to shape their settlements, and promote and utilize their rich heritage, e.g. Egyptian wheat (*Triticum aestivum*), teff from the horn of Africa (*Eragrostis abyssinica*) and African rice (*Oryza glaberrima*). It is characterized by the bringing home of plant resources that are most needed for human cultural, social and economic sustenance and likely began over 14,000 years ago. Nikolai Vavilov and Alphonse de Candolle recognized the importance of crop wild relatives to breed improved varieties and plant conservation. Domestication is considered a conservation priority, especially for crop wild relatives of native plant species like cowpea and sweet potato. It is mostly carried out in rural and suburban areas through systematic gathering to encourage growth, and conservation of genetic diversity through for use (Vodouhè and Dansi 2012). The genetic modification in plants that results from domestication probably makes them less competitive in the wild and more suited under human control. This activity has been described as essential to plant conservation, evolution, proliferation and modernization by contributing to diversity at the intraspecific level and results in the formation of mosaic systems of cultivated areas, pastures and forest fragments (Clement et al. 2021). This activity is different from one agroecological zone to another as well as within ethnic groups in terms of their preference for what category of the plant to domesticate and conserve (Vodouhè and Dansi 2012). Nonetheless, it has led to the traditional management and increase in the diversity of plant genetic resources. As pointed out in Vodouhè and Dansi 2012), it produces a dynamic system linking the development of plant genetic diversity with use and conservation. The contribution of local knowledge and domestication to seed crops, hybrid seed crops and genetically modified seeds crops are reported in Ayu et al. (2015) to include resilience and adaptability of the systems, which is essential to plant conservation and breeding programmes and on broad-scale agriculture. Cultural development influences domestication and the related processes such as crop use, evolution and conservation (Gepts 2004).

The sacredness of certain plant species and/or their parts (sacred species). Some plant species, for example, *Chamaecyparis lawsoniana, Cryptomeria japonica, Abies religiosa, Taxus baccata, Ginkgo biloba, Phoenix dactylifera* and many other species found in different parts of the world are considered sacred in some of those places because of their cultural and religious roles (Pungetti and MacIvor 2007). Their consideration as being sacred has led to their maintenance and conservation in the environment with associated knowledge and practices transferred from generation to generation. Their traditional value is what is governing their protection.

17.4 Challenges and Threats to Traditional Methods of Plant Conservation and Utilization

The potential of cultural practices to successfully conserve plant species and ecosystem continue to be reiterated in many research works such as those cited earlier. However, increased pressures on resources and changing social norms and belief systems are undermining many sacred sites that have survived for hundreds of years. Specifically, the increasing loss, modification and fragmentation of traditional lands contribute to global climate change and affect the conservation of biodiversity held therein (Sharrock 2020). Genetic resources of essential plant species maintained in traditional lands or ex situ collections and use in agriculture, horticulture and forestry serve are invaluable sources of material for research, education, conservation and production activities for sustainable development (Sharrock 2020). But there is a gross lack of information on species maintained in traditional methods of conservation that are threatened, endangered and/or require urgent conservation efforts. The focus on extraction, exploration, exploitation and utilization of plant genetic resources maintained within traditional systems of plant conservation is not sustainable in the long term.

In South India, 59% of lands within sacred groves have been lost since the 1990s, and others may have been reduced to below their ecologically viable size especially in Garhwal Himalaya (Anthwal et al. 2006; Chandrakant et al. 2006). A similar pattern of loss to sacred sites and other traditional plant conservation sites is emerging in Africa, recorded in, for instance, Kenya (Bagine 1998) but unrecorded for the most part. The appreciation of traditional knowledge because of the potential benefit is challenging native plant resources. For instance, harvesting plant resources for use as medicine and pharmaceuticals, as well as other industrial products increases the pressure on the resources and might erode the knowledge systems and practices associated with these plant resources. In addition, the practice of

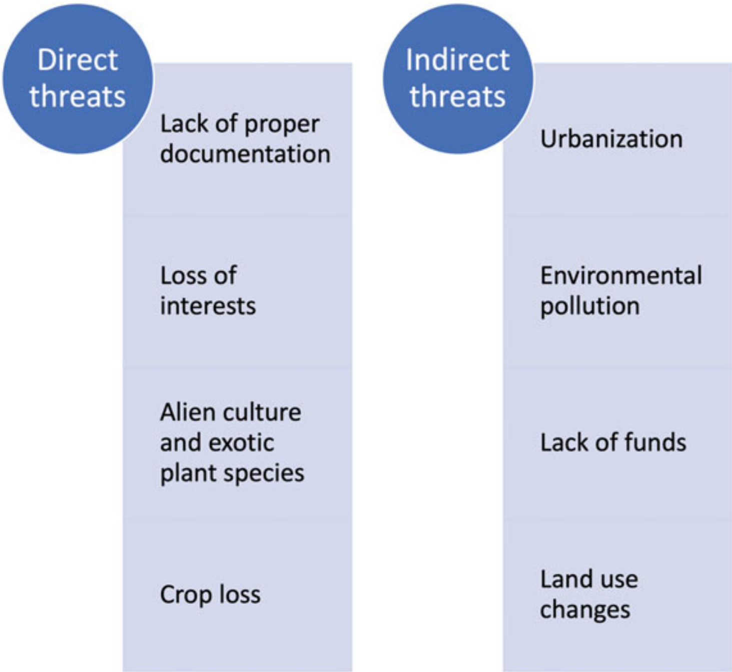

Fig. 17.2 Direct and indirect threats to traditional methods of plant conservation

transferring collected germplasm of native flora to a foreign gene bank instead of building the infrastructure locally for use by the natives is a persistent challenge. Many western gene banks are filled with flora collected from Africa and other parts of the Global South. Trade, tourism and deforestation are some of the factors threatening traditional plant conservation and utilization. For instance, Msuya and Kideghesho (2009) highlighted how trade, tourism and deforestation affect the availability, utilization and conservation of the following medicinal plant species: *Dioscorea dumetorum, Cadaba farinosa, Milicia excelsa, Acalypha fruticosa, Harrisonia abyssinica, Steganotaenia araliacea, Acacia melifera, Ehretia amoena* and *Wedelia mossambicensis.* These traditional practices, which are mostly based on cultural norms and religious beliefs, are the basis for sustainable use and conservation of biodiversity but most of these practices have long been neglected by official conservation policies, they have proved effective, as acknowledged in literature (Berkes et al. 2000; Moller et al. 2004; Saj et al. 2006). The focus of traditional plant conservation practices might not be entirely on the conservation of indigenous plant genetic resources but to retain them for their cultural values and used as food, in cultural ceremonies and feasts, and income generation. Nonetheless, they have huge implications for the preservation and sustainable utilization of this flora and have a positive ecological impact (Msuya and Kideghesho 2009). Direct and indirect threats to traditional methods of plant conservation include the following (Fig. 17.2):

- Urbanization.
- Lack of proper documentation.
- Loss of interest.
- Lack of funds and other resources.
- Environmental pollution.
- Land use changes.
- Alien culture and adoption of exotic species.
- Crop loss (loss of plant genetic resources).

17.5 Benefits of Complementary Approach to Plant Conservation

Conservation is most effective when a complementary approach is adopted at different scales and approaches including all in situ and ex situ strategies. Considering the importance of the preservation, protection and promotion of local plant species and traditional knowledge, innovations and practices, one cannot remove the custodians from sustainable conservation of these plant resources. This is because of the link to their culture and religious identity, health and well-being, food and income security, and environment, despite their numerous shortfalls. The adoption of a complementary approach will be a form of appreciation of traditional knowledge and systems as well as the custodians and provide a sustainable means for adopting an innovative approach for plant conservation. Little is known about native plant species especially in the Global South and a complementary approach provides an avenue for documenting and advancing knowledge about their native flora. Research has shown the effectiveness of traditional ecological knowledge and practices in the protection and maintenance of natural resources (Moller et al. 2004; Saj et al. 2006). However, a key concern for conservation planners and practitioners is understanding the traditional links between indigenous cultures and the natural world especially as it pertains to the responsibility for and ownership of plants and other bio- and natural resources. Indigenous and deeply entwined traditional systems of resource tenure are extremely variable, complex mixtures of individual and community rights, enforced by the local culture with informal systems. Nonetheless, these systems are flexible, rarely documented with formal systems and constantly evolving, often in response to changing environmental conditions, western influence and cultural norms and may provide an avenue for external contribution. Therefore, their survival and efficiency may be contingent upon maintenance as a whole than the mere exploitation or destruction of parts (Rappaport 1972). In this case, traditional users and maintainers of plant genetic resources can be encouraged to increase the size of their living collections and adopt sustainable modern practices.

Sharrock (2020) opined that several plant species do not produce seeds that withstand natural storage conditions nor produce sufficient seeds and will require an integrated complementary conservation method, including both in situ and ex situ approaches such as tissue culture and cryopreservation. No doubt, integrating traditional beliefs and myths with modern-day conservation strategies can help improve plant conservation and our environment (Basnet and Dendup 2020). The complementary approach to plant conservation that draws on indigenous knowledge and practice focused on conservation, sustainable cultivation, harvested and utilization practices as well as on the larger socio-economic and scientific research-based approach of modern practices are more robust for the protection of plant genetic resources. This approach will have the built-in capacity not only to enhance the profitability of vulnerable plant germplasm but also to contribute towards the improvement of the livelihoods of indigenous and non-native collectors, vendors and passionate practitioners.

The product of a contemporary complementary approach may be the establishment of thriving community plant nurseries. An example of this is presented in Sharrock (2020) in an indigenous community in Morocco for medicinal and aromatic plants conserved through a complementary approach that led to greater income distribution within the community and the external distribution of plant genetic resources, thereby fostering opportunities beyond the community. An intrinsic benefit of a complementary approach to plant conservation is building capacity within local communities and the equitable sharing of plant genetic resources that are conserved through this approach. Such capacity is necessary to address current and potential future societal challenges, including climate change mitigation, food security, land management and ecosystem and habitat restoration (Sharrock 2020). In the opinion of Basnet and Dendup (2020), reviving traditional beliefs and myths should be considered pertinent in developing modern-day conservation needs including the development of suitable institutional and policy frameworks:

- Market development.
- Seed production and distribution networks.
- Research priorities.
- Community conservation (socio-economic growth).
- Farmers' rights laws.
- Government policies.
- Ecological benefits.

The adoption of a complementary approach often leads to the inclusion of traditional protected lands into international, regional and regional protected area networks. Also, it expands the ownership and management of traditional plant conservation sites beyond Aboriginal clans for sustainable practices and partnerships. Such as teaching managers of traditional plant conservation sites best practices on how to record, process and bank collections using basic seed banking equipment that can be used anywhere in the country and these managers in turn share their traditional knowledge and are better equipped to participate in plant conservation efforts and to contribute to the mix of traditional and scientific methods that can be used to protect plant species and ensure their future use (Sharrock 2020).

17.6 Recommendations

Food crops including legumes, cereals, root and tubers, herbs, fruits, trees, vegetables and non-timber forest products play important roles in most rural centres and there is often a relationship with the plant genetic resources that exist beyond the rural centres and the physical benefits they produce. With the increasing effects of climate change, new genetic engineering and agroecology technologies are becoming more available and can shift international markets and local interests and perceptions. Without a doubt, Africa (and the Global South at large) is richly endowed with diverse plant species. These vital resources are presently threatened by overuse, lack of sustenance and intensified human development activities. It is therefore essential that we work towards the conservation of these valuable plant resources not just with the thought of preserving nature's bounty but for the well-being and livelihoods of indigenous local communities and the society at large that depends on these resources. Though conservation bodies exist, they are too focused on modern systems and more efforts are required to take environmental policies and conservation strategies to local communities. There is a need for stakeholders to adapt to these changes through robust, ongoing and transitionary planning in conjunction with other efforts aimed at developing environmental accounting systems that incorporate local knowledge systems and practices, and research that are initiated to find the most effective indicators and monitoring systems (Ahmad et al. 1989). The gathering of high-value plants does not end with societal development as it also continues in developed countries for cultural and economic reasons (De Groot et al. 2002). Traditional conservation practices have a direct connection with human health since most of the plant species have medicinal value, which a majority of rural people rely on, hence, it is pertinent that traditional management practices should be encouraged since they serve a dual purpose as an important conservation strategy (Msuya and Kideghesho 2009). The following recommendations to develop a formal system for traditional plant and natural resources conservation are adapted and put forth:

1. Need to integrate traditional knowledge systems and practices into formal environmental education structure.
2. Identify and promote the involvement of indigenous people in development plans as well as the effective and efficient management of traditional conservation systems.
3. Educate local communities about the values of plant and environmental resources.
4. Develop an ongoing publicity approach to sustain social, cultural, religious and other practices that foster the preservation and proliferation of traditional conservation practices.
5. Engage indigenous people in the survey and map traditional lands that hold plant resources through native practices and collaborate with them to collect and document existing resources within those lands.

6. Promote the touristic value of traditional plant conservation sites, knowledge systems and practices.

17.7 Conclusion

Promoting the sustainable utilization and conservation of plant diversity through local practices is important because contemporary approaches alone will not sufficiently protect local biodiversity neither can it sustain the production of plant-based products required to meet human needs and ecosystem resilience. To enhance local utilization and conservation of plant genetic resources, Fischer et al. (2006) suggested that traditional landscape should be made to include patches of native vegetation to maintain species diversity within and across different ecological functional groups and keystone species, and to control invasive species and provide a scientifically defendable starting point for the integration of conservation and production, which is urgently required from both an ecological and a long-term economic perspective.

Msuya and Kideghesho (2009) opined that traditional plant management practices should be considered as one of the international, regional and national priority areas for research and should be supported with relevant policies and laws. Traditional management systems should not be construed as a panacea for mitigating the existing conservation problems. Rather, it should be transformed to complement instead of substituting existing conservation strategies. Traditional plant management practices should be encouraged since they serve a dual purpose as an important conservation strategy and as an essential component of culture. Local plant conservation practices must be preserved alongside plant genetic and associated resources. Moreover, with relevant economic, environmental and conservation policies, local practices associated with plant conservation can serve as a source of revenue and contribute to sustainable development.

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Chapter 18
The Challenges and Conservation Strategies of Biodiversity: The Role of Government and Non-Governmental Organization for Action and Results on the Ground

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Abstract Biodiversity loss is among the most urgent environmental concerns of our day, since it is a crucial element of the Earth's backup systems, with direct impacts on human civilization. We examined the problems and conservation strategies, the role of governmental and nongovernmental stakeholders, as well as scientific data on the degree of biodiversity loss and the factors influencing it. The major direct cause of the continual mass extinction of populations and species of other creatures is the land conversion for agricultural purposes. Biodiversity loss is typically measured in terms of the degree of loss of species variety for practical reasons. Species populations, on the other hand, which are decreasing at an alarming rate than species, provide humanity with the benefits of biodiversity. Demographic heterogeneity has an impact on human health. Different populations of the same species may create different kinds or amounts of defensive chemicals (possible medicinal or pesticide substances). Thus, man's well-being and the sustenance of his livelihood remain inextricably linked to biodiversity. As a result, there is a worldwide concern for biodiversity preservation and conservation in order for man to continue to preserve his livelihood. Industrial development is a component of man's overall development activities. As beneficial as industries are, their expansion has negative effects. This study reviewed the threatened biodiversity caused by man's varied activities and urged all levels of government and non-governmental organizations in Nigeria to prioritize biodiversity protection. This suggests that industrialization, urbanization, biodiversity loss, increasing desertification, greenhouse warming, water and air pollution, as well as hazardous waste buildup have had a deleterious impact on the ecosystem. Conserving natural resources is thought to give social, economic, visual, and aesthetic advantages that will maintain the citizens' sound and qualitative health. This can be accomplished primarily through recognizing, comprehending, appreciating, and/or integrating endogenous and exogenous technologies.

Keywords Conservation strategy · Environmental challenges · Endogenous and exogenous technologies · Biodiversity protection · Industrial growth · Non-governmental organization · Nigeria

18.1 Introduction

Communication between humans and biodiversity is a defining phenomenon of human life (Olalekan et al. 2021). The interactions might be beneficial or harmful. Investors are increasingly concerned about biodiversity. Some analysts predict that biodiversity is around the same developmental phase as climate change was indeed years back (Olalekan et al. 2019a). Climate and biodiversity are inextricably linked (Olalekan et al. 2019a). Not all climate change mitigation strategies remain beneficial to the environment but those that promote biodiversity are more likely to be climate-friendly (Morufu et al. 2021a). At the COP26 summit in Glasgow, delegates from 141 nations adopted a declaration committing to collaborate together to limit and restore forest loss along with land deterioration come 2030. While biodiversity is defined as the total of all animals, plants, fungi, as well as microbes on Earth, their genetic and phenotypic diversity, as well as the communities and ecosystems in which they thrive, are currently richer and more diverse than they have ever been (Olalekan et al. 2019a). However, it is in danger of extinction, which some experts have dubbed the sixth catastrophic extinction of the Phanerozoic Era (Olalekan et al. 2019a). Despite the fact that there is no agreement on the size of Earth's biodiversity, it has obviously attained contrasting color as a result of more than 3.5 billion years of organic development. Simultaneously, human influence over the Earth is so widespread (Olalekan et al. 2019a; Raimi et al. 2019a; Raimi et al. 2019b; Suleiman et al. 2019; Okoyen et al. 2020; Raimi et al. 2022a; Raimi et al. 2022b). Most "scientists agree that extinction is occurring now, however, a few critics differ, stating that this is a doomsday fiction or that extinction predictions remain strident, inconsistent, and data-free" (Dirzo and Raven 2003). We will look at the aspects, difficulties, and conservation methods of biodiversity, the involvement of government and nongovernmental entities, and scientific data about the pace of biodiversity loss as well as the causes that go on driving this damage in this article. This review is significant for the reasons that (a) biodiversity remains a critical part of the planet's backup systems and therefore is explicitly related to human communities; (b) any initiative to safeguard a social purpose, like biodiversity, must be based on best available facts; and (c) biodiversity loss is really the only genuinely irreparable worldwide ecological transition that the Earth currently faces. Living nature encompasses ecosystems, species, as well as genetic resources spanning the ocean, land, lakes, along with rivers, which includes all animals, plants, as well as microbes that dwell within those systems. In simple terms, biodiversity refers to the diversity of nature in all of its aspects (Olalekan et al. 2019a). Consider a big palm oil plantation, for example, which has a lot of nature but little biodiversity. Soil, water, and air are all examples of nonliving nature. Within ecosystems, these nonliving nature parts connect together living aspects of nature toward creating a range of ecosystem services, such as water filtering as well as flood protection (Odubo and Raimi 2019).

Minerals were included in the proposed scope of the Nature-related Financial Disclosures (NTFD) in circumstances where mineral depletion has an impact on ecological sustainability, such as an Amazon rainforest mining operation or oil production in Nigeria's Niger Delta. Because biodiversity is quickly becoming a catchphrase in sustainable finance, it is considered to be synonymous with nature. This erroneous simplification highlights the difficulty that the banking industry will have in extending its sustainability goals to the natural world. Biodiversity issues are currently on the central bank's radar, and their interest in such topic might remain as revolutionary as climate change. While biodiversity is still an essential component of nature, the term "nature" encompasses a far larger concept. The financial markets today face the difficulty of translating nature's intrinsic complexity into accessible and practical terminology, data, and measures while maintaining science and its accuracy. Despite the increased interest, there are few investment prospects. Although the number of funds being launched is rising, it remains a small market. As a result, the aim of this review is to present the challenges and conservation strategies of biodiversity through the role of government and non-governmental organization.

18.2 Review of Literature on Biodiversity Crisis

There cannot be a more fitting place to practice “sustainability” than in rural areas, where the people, most of whom are poor, depend on natural resources for their livelihoods, health, and productivity. Rural development has been the stepchild of growth and investment policies in too many nations and international institutions for too long. From “the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992,” to Habitat II, the welfare of human beings related to environmental sustainability, human rights, social development, the empowerment of women, and human settlements has been the prime consideration of national, international, and non-governmental organizations. In September 2015, the 17 ambitious implementations of the “sustainable development goals (SDGs)” as well as 169 objectives remained adopted with the intention of improving global society. The year 2022 will mark seven years after the SDGs were adopted, and it will be the last decade in which the world will assess its success. A decent society is one which is devoid of hunger (SDG 2), uses clean as well as sustainable energy (SDG 7), along with allowing society to pursue its entrepreneurial socioeconomic goals. Regarding civilization’s interdependence with the milieu, there is a requirement toward preserving robust biodiversity (SDG 15) while sustaining a functioning society via a range of ecological processes, such as the ocean economy (SDG 14). Anthropogenic changing climate, on the other hand, remains one of the most serious challenges to modern civilization and societal objectives (Raimi et al. 2018a; Morufu et al. 2021a). Although environmental worries persist, with suspicions that perhaps the biophysical environment is on the verge of collapsing, despite the fact that the globe has been besieged by a plethora of environmental difficulties connected to global environmental change which has intensified over the previous decade (Raimi 2019; Suleiman et al. 2019; Ajayi et al. 2020; Olalekan et al. 2021). There are concerns that such issues may sabotage global society’s growth efforts and cause societal upheaval. Part of the blame can be attributed to the rise in world population, which has resulted in greater demand for pesticide use and consumption (Isah et al. 2020a; Isah et al. 2020b; Olalekan et al. 2020a; Raimi et al. 2020a; Morufu 2021; Hussain et al. 2021a; Hussain et al. 2021b; Morufu et al. 2021e). The increased demand for resources like industrial, agricultural, along with residential land, as well as other key resources like water as well as electricity, has resulted in environmental deterioration and pollution as a result of their extraction and exploitation (Raimi and Sabinus 2017a; Raimi and Sabinus 2017b; Morufu and Clinton 2017; Olalekan et al. 2018a; Premoboere and Raimi 2018; Suleiman et al. 2019; Olalekan et al. 2019b; Raimi et al. 2019a; Raimi et al. 2019b; Raimi et al. 2019c; Ebuete et al. 2019; Ajayi et al. 2020; Okoyen et al. 2020; Isah et al. 2020a; Isah et al. 2020b; Olalekan et al. 2020a; Gift et al. 2020; Olalekan et al. 2020b; Gift and Olalekan 2020; Raimi et al. 2020a; Afolabi and Raimi 2021; Morufu 2021; Raimi et al. 2021a; Hussain et al. 2021a; Hussain et al. 2021b; Morufu et al. 2021b; Morufu et al. 2021c; Morufu et al. 2021d; Morufu et al. 2021e; Deinkuro et al. 2021; Morufu et al. 2022; Raimi et al. 2022c). The increase in world population has been accompanied by a nearly equivalent decline in environmental quality. The looming threat and the need to ensure long-term viability compelled world leaders to establish the 17 demanding Sustainable Development Goals (SDGs) designed at addressing the globe's socioeconomic, environmental, and political concerns (Suleiman et al. 2019). The alteration of the biophysical environment caused by land pollution that has been a significant subject of concern (Odipe et al. 2018; Sawyerr et al. 2018; Henry et al. 2019a; Raimi 2019; Omotoso et al. 2021; Deinkuro et al. 2021), water pollution (Raimi et al. 2017; Henry et al. 2019b; Olalekan et al. 2018a; Olalekan et al. 2018b; Olalekan et al. 2019b; Raimi et al. 2019c; Raimi et al. 2019d; Olalekan et al. 2020b; Afolabi and Raimi 2021; Raimi et al. 2021a; Morufu et al. 2021b; Morufu et al. 2021c; Morufu et al. 2021d; Morufu et al. 2022; Raimi et al. 22c) both in land and ocean, and air pollution (Raimi et al. 2018b; Adeolu et al. 2018; Raimi et al. 2020b; Raimi et al. 2021c) has put human civilization as we know it in jeopardy. The biosphere degradation endangers natural biodiversity as well as agricultural productivity, both of which also have serious societal consequences. The impacts of rising anthropogenic air pollution, predominantly greenhouse gases (GHG) which contribute to worldwide warming, have been a major topic of concern around the world (Raimi et al. 2018a; Morufu et al. 2021a). According to Morufu et al. (2021a), the energy, agricultural, industrial, and transportation sectors are the most major contributors to world GHG emissions. The rate of global species extinction is tens to hundreds of times higher than the ten-million-year average. At "least 680 vertebrate species have now been pushed to extinction during the sixteenth century, including over 40% of amphibian species and 33% of reef-forming corals (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2019)." Even for species that are not endangered, the abundance, or number of individuals in a species, has decreased in many regions. Mammalian, bird, fish, reptile, and amphibian populations have declined by roughly 70% on average during the last half century (World Wildlife Fund International 2020). An estimated one million species are currently threatened. This will be the first time that a human-caused biodiversity loss has occurred. The world still supports roughly 8.7 million species, with over a quarter of them living in water. However, because humans have a hard time grasping numbers this large, it can be difficult to appreciate (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2019; Olalekan et al. 2019a; Ceballos et al. 2020; Okoyen et al. 2020). Human activities have begun to get a significant influence on the Earth's climate as well as ecosystems. These changes have led to enormous global changes such as climate change, biodiversity loss, poverty, and food insecurity (Suleiman et al. 2019; Oluwaseun et al. 2019). Surprisingly, man has evolved into a formidable force. He wields a vast amount of power. His acts have had a worldwide influence, affecting natural flora and animals throughout a huge region of the globe (Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a; Okoyen et al. 2020; Ajayi et al. 2020). Civilizations and agriculture are rapidly spreading, posing a threat to natural systems. To make room for human settlements and agriculture, hilltops are levelled, meadows are invaded, marshes are drained, or even submerged is being reclaimed. The Earth is stripped bare, natural ecosystems are destroyed, and flora and animals are wiped out (Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a; Okoyen et al. 2020).

While, climate change, intensive farming, and population increase have all had major consequences on marine and terrestrial biodiversity. Urbanization as well as the need intended for such a built-up milieu remained identified as one of the biggest dangers to biodiversity. Terrestrial forests remain vital because they house around 80% of species (Buckland et al. 2005; Fischlin et al. 2007; Olalekan et al. 2019a; Okoyen et al. 2020). The Global Natural Stock Death Bell was rung by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2019. Forests are regarded to be among the globe's most diverse and abundant environments. The world is beginning to lose numerous species related to enhanced human influence, changing climate, desertification, or over in some settings (Groombridge and Jenkins 2002; Duraiappah et al. 2005; Hassan et al. 2005; Carpenter et al. 2009; Addison et al. 2018a; b). Conversely, there is concern over forests loss throughout the globe, which results in biodiversity losses (Díaz et al. 2006; Olalekan et al. 2019a; Raimi et al. 2019a; Raimi et al. 2019b). Togo has the greatest rate of forest loss in the world, with a yearly loss rate of 8.11%. Forest loss is principally troublesome in arid as well as semiarid locations. The extinction of forests contributes to and mitigates the carbon gases release that causes climate change (Morufu et al. 2021a). The majority of forest losses in South as well as Central America, Asia, and Africa are extractive. As a result, member nations may see little value in terms of social as well as economic gains. Increased poverty and inequality might result from such a scenario. The world's forests are under threat from climate change (Raimi et al. 2019a; Raimi et al. 2019b; Raimi et al. 2022a; Raimi et al. 2022b). Peru's development is dependent on its enormous natural wealth for economic growth, prosperity, and human well-being. The loss of biodiversity has been seen as a hazard to society. There have been demands to safeguard both terrestrial and marine (SDG 15 and 14) ecosystems. Addison et al. (2020) propose that a model is needed to ensure that companies may generate biodiversity indicators for diverse business activities in order to improve biodiversity conservation. The United Nations makes a strong case for biodiversity conservation in a number of SDG objectives in the 2030 Agenda aimed at Sustainable Development. This includes: SDG 14.7a—Increase "scientific knowledge, support the research capacity, as well as transmit marine technology in conformance with the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology to improve ocean health as well as the commitment of marine biodiversity toward the development of developing countries, especially small island developing states as well as nations"; SDG 15—Safeguard, "rehabilitate, as well as encourage sustainable utilization of terrestrial ecosystems, sustainably manage forests, prevent desertification, halt and reverse land degradation, as well as stop biodiversity loss"; SDG 15.4—In the year 2030, "ensure that mountain ecosystems, including their biodiversity, remain maintained in effort to expand their potential to deliver benefits that remain critical for lengthy development"; SDG 15.5—Reduce habitat destruction, stop biodiversity loss, as well as protect and avert the extermination of vulnerable species by 2020; SDG 15.9—Ecosystems including biodiversity benefits will indeed be taken into consideration in national and local planning, development, and poverty reduction strategies as well as accounts through 2020; and SDG 15.9a—To protect and use sustainably biodiversity as well as ecosystems, mobilize and greatly expand financial resources from all sources. The Natura 2000 network is the world's prime network of protected areas (PAs), which currently covers 18.5% of European land area and 10% of total EU marine area. These legal structures, legislation, and monetary support have informed a worldwide concerted and coordinated effort (EC 2011; Evans 2012; EEA 2020). The "EU's biodiversity conservation efforts remain limited toward regional policy; the EU has also influenced the development as well as signed international treaties as well as conventions, like the United Nations Sustainable Development Goals (UN 2015) and indeed the Convention on Biological Diversity (CBD 2010), that are in charge of worldwide initiatives to slow or stop biodiversity loss." However, this significant effort has been inadequate to reverse ecological damage on a continental level (EC 2020a). Even through the Biodiversity Strategy's goal of enhancing "the conservation status of 100% of habitats with 50% of species by 2020 (EC 2011), approximately 15% of habitats as well as 27% of species are listed in the Habitats Directive as well as 47% of species listed in the Birds Directive are all at the risk of extinction" in the near future (EC 2020a). The EU's inability to meet biodiversity conservation objectives is not the only environmental front it's fighting, as the effects of global change on civilization, biodiversity, especially ecological services intensify (IPBES 2019). The "EU has enacted the European Green Deal" in response to these environmental and socioeconomic issues, with the goal of producing a sustainable as well as by 2050, the economy will be carbon-neutral (EC 2019). In accordance with the United Nations Decade of Restoration (UN 2019), the European Green Deal demonstrates the European Commission's firm commitment to legally valid restoring degraded habitats, the support they offer, as well as the biodiversity they maintain, and offers monetary assistance for ecological restoration within the next couple of years (EC 2019). In its Green Deal, the European Commission recognizes the significant nature contribution including biodiversity contribution toward our health or economy, as well as the necessity aimed at conservation efforts. As a result, the "Green Deal might remain the first step toward a radical shift in the EU, putting nature conservation at the vanguard of continental priorities as well as encouraging the long-overdue need for improved biodiversity conservation connectivity into other sectoral policies." The newly established Biodiversity Strategy for 2030 reinforces the prospects for biodiversity protection and restoration (EC 2020b). This approach intends to "bring nature back into our life" (EC 2020b), harmonizing through the Green Deal's goals while offering additional policy context, including specific targets and financing sources. The 2030 Biodiversity Strategy is built on three pillars:

(i) safeguarding as well as preserving nature in the EU through strengthening a systematic as well as consistent network through the restoration of habitats that have been damaged;

(ii) facilitating a new public management structure to guarantee co-responsibility as well as co-ownership among all interested parties in achieving biodiversity agreements, plus the establishment of novel financial benefits; and,
(iii) implementing a worldwide biodiversity initiative to deepen the EU's commitment to prevent worldwide biodiversity loss as well as reduce the negative externalities of EU resources usage and consumption in other biodiversity-rich areas of the planet (EC 2020b).

However, lessons from the past show that ambitious goals need to be accompanied by appropriate planning, enforcement, plus governance in order to be effective (Yates et al. 2019). We examine the triumphs and pitfalls of EU biodiversity policy and practice in order to propose recommendations that will help the Biodiversity Strategy for 2030 accomplish its objectives. We concentrate on the following critical areas for efficient government policy: (i) cooperation between or among EU Member States, (ii) biodiversity conservation incorporation into other domains, (iii) budget sustainability as well as sufficiency, and (iv) administration and stakeholder involvement. In order to achieve successful conservation in the future decade, it will be necessary to evaluate and act on these factors. Humanity has the capability of wiping out itself as well as all traces of life from the faces of the planet. Many species already have vanished from the globe, either as a result of overexploitation or of forest degradation (Dhameja 2007; Olalekan et al. 2019a). Each country should maximize the benefits from resource exploitation while minimizing the adverse externalities caused by heavy mineral extraction, such as damage to the environment and pollution, as well as ecological degradation (Augustine 2014; Olalekan et al. 2019a). The instruments of human culture and civilization devastate the natural equilibrium over which our entire survival is predicated, resulting in an absurd predicament in which society's drive for a brighter future sows the seeds of its own demise. Anthropogenic activities have undoubtedly had a harmful influence on the Nigerian milieu (Olalekan et al. 2019a; Okoyen et al. 2020). African continent is losing over ten million acres of forest per year. Earth may eliminate well over 20% of all biodiversity by 2035. Biodiversity changes are causing an alarming pace of extinction of plant and animal species. All of this might have disastrous ramifications for the human species' existence (Khitoliya 2004; Raimi 2008; Raimi et al. 2018a; Olalekan et al. 2019a; Morufu et al. 2021a). Nigeria's rate of deforestation is at 3.5% per year. The nation's forest now covers 923,767 km^2, accounting for 10% of the country's forest area. This is far less than the Food and Agricultural Organization's (FAO) suggested minimum standard of 25% (Raimi 2008; Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a; Ajayi et al. 2020; Raimi et al. 2022a; Raimi et al. 2022b). Currently, 80% of the forests that once encircled the globe in excess have been removed, fractured, or deteriorated. Such forests offer housing for local people and culture, maintain biodiversity, promote economic growth, safeguard water supplies, as well as provide recreational opportunities. Man has lost his ability to predict and prevent events (Awake 2011; Olalekan et al. 2019a). Over 20,000 plant species remain fragile or threatened with extinction, out of a total of roughly 0.3 million creatures on Earth (Olalekan et al. 2019a). About 1000 animal species are thought to be imperiled on a worldwide scale. Overpopulation, coupled with air pollution, has become a major worry (Raimi et al. 2018b; Suleiman et al. 2019; Ajayi et al. 2020; Raimi et al. 2020b; Raimi et al. 2021c). Nature's vital life activities, such as climate stability and water purification, procreation of nurseries and breeding grounds are even more critical. Biodiversity is important for sustainable development because wild species including genetic variations among them contribute significantly to agriculture, medicine, and industry (Ayuba and Dami 2011; Neema et al. 2009; Olalekan et al. 2019a; Morufu et al. 2021a). Biodiversity loss is a severe environmental issue and a country's biodiversity is critical to its socio-economic growth. The continuing extinction of species of plants is especially concerning. Using native plants not just maintains a country's natural history but may also lessen fertilizer, pesticide, and irrigation needs (Margaret and Fubara 1998; Ayuba and Dami 2011; Olalekan et al. 2019a; Isah et al. 2020a; Isah et al. 2020b; Okoyen et al. 2020; Olalekan et al. 2020a; Morufu 2021; Hussain et al. 2021a; Hussain et al. 2021b; Morufu et al. 2021e). Nigerians are being forced to place extra strain on natural capitals, strain that repeatedly exceeds the system's capacity to sustain. Effective resource management has gained popularity across the world. If one component of the system is changed for the sake of gaining an advantage, the influence on the remaining components must be considered (Siddiqui and Akbar 2008; Olalekan et al. 2019a).

18.3 Biodiversity Inventory

The term "environment" refers to a system in which living beings interact with physical factors. The ecosystem is another name for this system. Under this view, human interacts with the creatures within the surroundings as a component of the living organisms (Jimoh 2000; Olalekan et al. 2019a; Olalekan et al. 2021). The natural as well as cultural environments are two large categories that encompass the overall environment (Morufu et al. 2021a). According to Olorunfemi et al. (Olorunfemi and Jimoh 2000), the former includes the atmosphere (gases like nitrogen, oxygen, including carbon dioxide), hydrosphere (bodies of water together with rivers, lakes, seas, and oceans, along with subterranean water), lithosphere (minerals as well as rocks), and biosphere (animals, plants, and beings). The latter is the man spatial unit, which is the cultural context (Raheem 2000). Are there a lot of interactions that drive various forms of human-related activities inside these environmental spheres? As a consequence, interactions readily transcend into a variety of environmental issues, which have a detrimental impact on humans (Jeje and Adesina 1996). It is reasonable to believe that humanity is unaware of the implications of his acts and, as a result, needs to be educated, regardless of perspective or culture. It is vital to discover strategies to control the issue of misuse of environmental resources in order to ensure sustainable growth (Awake 2011; Olalekan et al. 2019a).

18.4 Loss of Biodiversity in Nigeria

Since 1970, the usage of natural resources has over quadrupled, with progressively detrimental consequences for the environment. All these activities account for around half of the world's greenhouse gas emissions. For example, originally, the Guineo-Congonean kind of forest comprised approximately 20% of Nigeria. Forestry operations, both legal as well as illicit, and agricultural activities, have conspired to decrease the nation's forest cover toward less than 10% of the original degree. Nigeria's yearly deforestation rate is about 3.5%. On this basis, it is anticipated that the nation would lose all of its woods by 2035. According to research, Nigeria's wood usage may increase to 122 million m^3 by the year 2000. Natural forests indeed remained substituted by monocultures of exotic trees in some places (for instance, "the Olokemeji as well as Nimbia Forest Reserves in Ogun and Kaduna States," correspondingly). Besides logging roads opening up woods to poaching as well as other criminal activities, however, nothing is known about the entire impact of forestry operations on Nigerian biodiversity. As a result, scientific investigations such as this will help demystify these consequences and should be included in a forest conservation implementation plan.

18.5 What Is the Definition of Conservation?

Conservation, according to Allaby (1988), is both planning as well as resource management in ensuring their judicious usage supply, and potentially raising their standards, value, and variety. As a result, contemporary conservation is the control of human use of the situation in order to provide the most long-term value to the current generation (Lexicon Encyclopaedia 1985). The topic of conservation is fluid as well as encompasses a wide variety of ideas. From a broad viewpoint, conservation might refer to the careful use of landscape approaches (Omisore 2002). Conservation involves using every resource to necessitate and evaluate its environmental consequences. It goes beyond conservation and preservation of sensible resource use in order to preserve long-term viability. Regardless of how high the conservation value is, biodiversity production must be efficient. For every additional euro expended, the maximum quantity of biodiversity must be achieved (Chauhan 2011; Olalekan et al. 2019a). Furthermore, for two important reasons, corporate equity biodiversity creation is budget constrained. First, the price difference between "plus-sustainable forest products" determines the compensation for biodiversity, which is based on the market's willingness to pay for biodiversity. Second, while considering whether or not to provide property for biodiversity management, a landowner must consider an opportunity cost. For instance, a landowner may just have to weigh lost money from wood production plus wind power rent while assigning a parcel of land to biodiversity conservation with little opportunity for future profits from both timber as well as wind. The area preserved is perhaps the most extensively used biodiversity indicator. The size of a single conservation area is a relevant quality concern. Bigger sanctuaries often suggest more variety as well as higher individuals' numbers in each species. None of these concerns can be addressed without considering the entire landscape. Water quantity as well as quality concerns in one section of the landscape might, for example, have an influence on ecological growth or agriculture in other countries. The concept of landscape revolves around comprehensively assessing and evaluating the entire terrain throughout a variety of variables in order to drive financing to solve critical sustainability challenges and achieve significant progress.

18.6 Biodiversity Conservation and Poverty Alleviation

In Europe, biodiversity is created through millions of forest and landowners, most of whom are small-scale landowners with less than 50 hectares of land. Biodiversity preservation is now challenged to interact with more critical UN Sustainable Development Goal, eradicating extreme poverty and hunger. Like the development community has become more centered on this goal, financing for biodiversity has become more frequently as well as specifically linked to eradicating poverty (Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a). Given "the mixed performance of poverty eradication program advocated well over previous half century through agencies as well as groups entirely committed to this job, conservationists confront enormous difficulties in joining this sector." Albeit with enormous population expansion, the pace of poverty reduction was the most fast and widespread in recent times between 1970 and 1990, demonstrating that progress in reducing poverty is achievable. The bulk of places impacted within these two decades of greater poverty reduction were rural, as per "the UN's International Fund for Agricultural Development's Rural Poverty Report from 2001" (Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a; Raimi et al. 2022a; Raimi et al. 2022b). The research does observe, however, that the degree of relief has dropped significantly since 1990, given that international funding supporting agricultural as well as rural goals has, in several cases, hit an all-time deficit. Despite the fact that the whole society is becoming increasingly urban, poverty persists in entrenched rural regions, which are home to 50% of the world's poorest people, with 75% of the population classified as "very poor" (Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a; Raimi et al. 2022a; Raimi et al. 2022b). Notwithstanding the expected improvements in poverty reduction, by 2035, over 60% of the planet's ultimate poor would be living in rural regions (Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a; Raimi et al. 2022a; Raimi et al. 2022b). Natural catastrophes, wars, and economic disruption may drastically alter the amount of impoverished people, as demonstrated through the latest Asian tsunami. The impoverished with assets (little farmers owning housing plus wells, for example) can quickly become destitute without nothing (e.g., refugees). Poverty in rural areas might well remain greatest in areas with the most biodiversity, resulting in the "Rich

Forests, Poor People syndrome." There is also an indication that poverty, disparity, and biodiversity could have regional overlaps. However, the development community must have consistently pushed poverty eradication aims into preservation financing since the 1990s. "Conservation programmes are only valid and sustainable when they have the dual objective of protecting and improving local livelihoods and ecological conditions" (Olalekan et al. 2019a; Olalekan et al. 2021). The impact of rising wealth on biodiversity is affected through complicated sociopolitical as well as ecological circumstances. Increased wealth encouraged certain households to reduce forest product exploitation, while others purchased chain saws and destroyed forests faster. Because many parks now have better types of genetic resources than surrounding regions, some notable development organizations have called for these places to make a significant contribution to rural poverty reduction. Conservationists argue that parks should be seen as part of a larger landscape that can provide essential ecosystem services and contribute to a healthy environment. As the protected area grows, these justifications become more compelling. Other environmentalists are concerned that this may lead to exploitation of park resources. The poor are often dependent on natural as well as wild resources. Sanctuaries have so far only recently been shown to provide substantial economic advantages. Unless the ecological foundation on which the rural poor rely deteriorates, their livelihoods seem likely to suffer as well. The financial rate of return of Madagascar's protected area system was 54% (Worm et al. 2006). Ecotourism was the primary advantage of conservation, but also provided economic benefits to neighboring communities. In this case, 265,000 impoverished rice-farming households and 25,000 urban homes obtain potable water profited. 50,000 changing agriculturalists (also known as "slash-and-burn" farmers) lost their land.

The Working for Water Program in South Africa is working to improve water security with ecological integrity via eradicating invasive species, recovering damaged areas, and encouraging the sustainable use of natural resources (Olalekan et al. 2019a; Ajayi et al. 2020). In less than four years, it has hired nearly 42,000 workers. The landless movement in Brazil's Atlantic Forest has ceased invading reserves including remaining forest areas, realizing their low value for agricultural and environmental deterioration; many formerly landless people are now supporting restoration efforts (Olalekan et al. 2019a; Ajayi et al. 2020). The conservation community is asked by the development community to help reduce poverty. Individuals can be lifted out of poverty through sustainable use of biological resources. Sustainable biological resource management, like non-timber forest products, fish, wildlife, and other resources, can help maintain rural lifestyles (Olalekan et al. 2019a; Ajayi et al. 2020). Broader investments and reforms are needed (Pereira et al. 2010a; Hoffmann et al. 2010). Community projects mostly around nature reserves will not be able to alleviate poverty for a large number of people if they are impoverished as a result of a larger economic system that limits their capacity to obtain commodities. Increasing the safety of rural poor people could necessitate changes in government policies that benefit wealthy organizations (Henrique et al. 2012; Raimi et al. 2019a; Raimi et al. 2019b; Olalekan et al. 2019a; Tuebi et al. 2021; Raimi et al. 2022a; Raimi et al. 2022b). Thus, while conservation cannot eliminate poverty, it may considerably aid in its prevention and reduction via preserving ecological services as well as strengthening livelihoods. More profoundly, there is a need to examine the substantial collection of issues that almost all tropical nations' rural sectors face. The focus on conservation often diverted attention farther from actors as well as policies, which frequently results in biodiversity loss with increased poverty. (Olalekan et al. 2019a; Raimi et al. 2019a; Raimi et al. 2019b; Ajayi et al. 2020). "Without reshaping poverty alleviation strategies, biodiversity will pay the price for development yet again." (Pereira and Daily 2006). For such reasons, the present tendency of conservation policies and initiatives being framed as well as supported exclusively through the prism of poverty should be overturned. Conversely, the development community needs make considerable and focused expenditures outside of protected areas to improve environmental sustainability (Pereira and Cooper 2006; Baillie et al. 2008). More clarity on the objective of parks is required, as well as associated management assistance. Many protected areas will likely continue to be harmed by local, national, and international economic forces (Butchart et al. 2004; Pereira et al. 2010a). Scientists must emphasize low-cost interventions with many good and long-term impacts above short-term promises in order to achieve the SDG objective of reducing poverty while restoring nature.

18.7 Understanding Biodiversity Direct Pressures

The five key kinds of global biodiversity change pressures are investigated. There are worldwide models of the consequences of three of these factors: habitat, pollution, and climate change (Raimi et al. 2017; Henry et al. 2019b; Olalekan et al. 2018a; Olalekan et al. 2018b; Olalekan et al. 2019b; Raimi et al. 2019c; Raimi et al. 2019d; Olalekan et al. 2020b; Afolabi and Raimi 2021; Raimi et al. 2021a; Morufu et al. 2021b; Morufu et al. 2021c; Morufu et al. 2021d; Morufu et al. 2022; Raimi et al. 2022c). Land-use change, on the other hand, has far bigger present biodiversity consequences than the other two causes.

18.7.1 Degradation and Habitat Change

Biodiversity shift is now being driven by habitat modification as well as degradation. Land-use change dynamics in terrestrial systems may be divided into three types. Some species could thrive as forests are transformed to agricultural land, while others, notably habitat specialists, could decrease or become extinct locally. The majority of natural to human-dominated habitat conversion takes place in tropical forests (Pereira et al. 2010a); agricultural intensification began in developed regions and is expanding rapidly to the rest of the globe (Pereira et al. 2010a); the majority of natural as well as forest vegetation restoration takes place in temperate regions in Europe and North America (Pereira et al. 2010a; Dirzo and Raven 2003). An "overall forest loss of roughly 42,000 km^2 per year in tropical regions is largely offset through an 8700 km^2 net forest increase in Europe (Baillie et al. 2008). Moreover, new forest plantations, typically with alien species, account for a portion of the net forest gain, and these plantations always seem to have lesser biodiversity than wild forests. Across many locations, fire plays a critical role in both the transformation of forest to farmland as well as the preservation of open landscapes. In Madagascar, some regions of Global South, Brazil's Atlantic Forest, the Middle East, and Southeast Asia, there is an agreement on the geographical distribution of areas of natural habitat becoming transformed toward agriculture (Olalekan et al. 2019a; Okoyen et al. 2020; Olalekan et al. 2021). There are around 45,000 major dams in the world today. Dams include upstream and downstream effects, such as changing time, amplitude, and water flow temperature. They also contribute to the river systems fragmentation by impeding or even blocking organism dispersion as well as migration (Hassan et al. 2005; Henrique et al. 2012). Other significant habitat modifications in aquatic habitats also include loss of wetlands due to drainage for agriculture or urban sprawl, excessive groundwater extraction (Okoyen et al. 2020; Morufu et al. 2021b; Morufu et al. 2021c; Morufu et al. 2021d), as well as river sand excavation (Okoyen et al. 2020); human activities, predominantly destructive fishing tactics like trawling as well as dynamiting (Butchart et al. 2004; Fischlin et al. 2007; Addison et al. 2018a; b); and urban and aquaculture development, plus coastal engineering projects have all had an impact on coastal ecosystems including wetlands" (Carpenter et al. 2009; Okoyen et al. 2020; Olalekan et al. 2021).

18.7.2 Overexploitation

Ocean biodiversity loss is mostly caused by overfishing. Many fully exploited or grossly misused fisheries were found in the Northern Hemisphere's coastal zones by the mid-1960s. Fishing operations had an influence on locations farthest away from the coast by the 1980s, in the center of the northern and southern Atlantic Oceans. After a century, the fisheries' geographical growth had covered most of the world's seas, with just a few regions of the Indian Ocean, Pacific Ocean, as well as Antarctic Ocean being not yet achieved their highest historical catches. Hunting is a big problem in tropical savannahs and woodlands on the ground (Olalekan et al. 2019a). Large birds as well as mammals get hunted for their meal, while charismatic species are hunted for their decoration as well as purported therapeutic properties. The "wild-meat harvest in the Brazilian Amazon is projected to be 67–164 thousand tons, with 1–3.4 million tons in Central Africa." In Southeast Asia and Central Africa, the effects remain extremely severe. In West Africa, a link has indeed been demonstrated concerning decreased fish supply per capita plus increased bush animal hunting pressure (Olalekan et al. 2019a). Hunting as well as other factors, like land use, have multiplicative relationships.

18.7.3 Pollution

Nitrogen burdens via point sources, like home as well as commercial sewage, plus nonpoint sources, including agricultural production, grew from 1970 to 1995. In Europe and Northern Asia, nitrogen burdens are starting to fall or are anticipated to decrease until 2030. Lakes are especially prone to eutrophication-induced regime changes (Okoyen et al. 2020). Terrestrial ecosystems, notably temperate grasslands, could be harmed by nitrogen deposition in the atmosphere from intensive agriculture plus fossil-fuel burning. Increased nitrogen availability alters competitive dynamics in plant as well as lichen communities, encouraging the growth of nitrophilous species while decreasing the number of nitrogen-sensitive species. According to one study, "there is a direct correlation with both nitrogen deposition rates as well as species richness losses in temperate grasslands, and the thresholds of nitrogen deposition noted across much of central Europe (17 kg/ha/year) are predicted to advance in a 23% drop in species diversity. Regrettably, other high-diversity places (e.g., Southeast Asia and Brazil's Atlantic Forest) are indeed experiencing similar amounts of nitrogen deposition, although more study is necessary to determine the effects. A visual examination of the geographical overlap across global patterns of nitrogen deposition as well as the distribution of pollution-affected animals reveals satisfactory agreement in Europe but divergence in other regions of the world," like Central Africa.

18.7.4 Exotic Species Introduced and Invasions

The rising homogeneity of flora and fauna variety as a result of biotic interaction is one of the primary patterns in global biodiversity variation. Exotic species can sometimes expand further than the areas in which they were introduced, invading the landscape as well as displacing local species. Invasive species have had a notably negative impact on islands (Duraiappah et al. 2005; Fischlin et al. 2007; Olalekan et al. 2021). Epidemic illness is a seriously deadly sort of invasion. Chytridiomycosis, for instance, has decimated frogs in several parts of the globe as well as being a major contributor to worldwide amphibian decrease (Pereira et al. 2010a). Invasive species also have wreaked havoc on freshwater ecosystems, in which their prevalence is linked to human economic activity, as well as marine and estuary habitats, where ballast water or hull fouling delivered by ships has caused significant damage (Olalekan et al. 2019b; Raimi et al. 2019c). Nonetheless, countless invasive species seem to have more modest consequences on the environment (Duraiappah et al. 2005; Díaz et al. 2006) and some ecologists had also repeatedly termed a more comprehensive and integrated attitude against exotic species, contending "that alien species must not remain recognized as a negative in any ecosystem, but rather must remain screened for eligibility for their consequences. Others "have advocated for active relocation or aided species migration," threatened by changing climate (Fischlin et al. 2007), a strategy that appears risky given our history of human introductions of foreign species, sometimes together with right intentions.

18.7.5 Climate Change

Between 1906 and 2005, the global mean surface temperature climbed by 0.74 °C, and has been anticipated to rise by 1.8 °C to 4 °C over the twenty-first century. Warming has been most significant in terrestrial systems as well as at higher latitudes (Morufu et al. 2021a). Remarkably, a high occurrence of species badly impacted by climate change has indeed been found in the Cape region of South Africa as well as southeastern Australia, despite the fact that these areas are still not experiencing significant warming. One explanation might be that many species in those areas are especially sensitive to climate change. Species exhibiting increased susceptibility have confined climatic niches, are unable to migrate their ranges, or cannot modify their phenology, change their physiology, or behaviorally adjust to new environments (Fischlin et al. 2007; Morufu et al. 2021a). For example, mountaintop species' have restricted capacity to move elevation, and has indeed been recognized as a key climate vulnerability. In the "Northern Andes, portions of the Amazon, Central America, Southern and Southeastern Europe, sub-Saharan tropical Africa, including Southeast Asia," significant future climatic consequences on amphibians have been predicted. This contradicts current regional patterns of increasing extinction risk as a result of changing climate.

18.8 Protected Areas System and Conservation Infrastructure

Better attention to environmental governance is a consistent pattern in protected area policy discourse. Conservationists have been debating who should be in charge of managing specific nature reserves, in addition to determining what sort of nature reserve is best for a certain location. Local communities are becoming the "predefined center point of most tropical preservation activity," according to Barrett et al. (2001), attributable in portion to identified failures with highly centralized organizations' "fences as well as fines" strategy to management and conservation, along with stress to incorporate community engagement as well as poverty alleviation with protection and conservation (Barrett et al. 2001). The management arrangement as a whole refuses to acknowledge the complicated web of connections that interact with other groups of the protected landscape as well as mineral wealth. The problem is that the community has assumed the majority of the monetary responsibility with management responsibilities, while other organizations and stakeholders either have vanished or play minor roles. These dimensions include those of the local communities that rely on them for their livelihoods and the regional and national constituents. The link also stretches to international organizations as well as those aimed at minimizing the impacts of global warming. Weaker state institutions or local communities would tend to endure the majority of the fiscal cost of preserving these locations if international institutions including donors refuse to help (Olalekan et al. 2019a). Conservationists should avoid imposing standard conservation practices across the emerging globe. Instead, they should acknowledge the significant as well as profound distinctions in institutional responsibilities with power that exist across Latin America, Africa, and Asia. Most protected places will certainly continue to be harmed by local, national, especially worldwide economic forces (Addison et al. 2018a; b), more clarity on the objective of parks is required, as well as associated management assistance, so that they may successfully achieve their designated mission. Nature reserves have the potential to sustain biological variety while also laying the groundwork for improved environmental management in neighboring regions, which is essential if long-term poverty reduction is to be realized.

18.9 The Biodiversity Nature and the Issues it Causes

Nature loss has a significant influence on all businesses, affecting operations and supply networks, including markets, as well as putting whole economies at risk. Lack of response to resource conservation has resulted in resource abuses and difficulties in the past. Nigeria, as any developing nation, is undergoing fast urbanization (due to rural–urban migration). This has resulted in a variety of environmental issues, including biodiversity loss with increased desertification, greenhouse warming, salinization of agricultural land, air and water pollution, rainstorms, bushfires, erosion, and hazardous waste accumulation (Raimi and Sabinus 2017a; Raimi and Sabinus 2017b; Morufu and Clinton 2017; Olalekan et al. 2018a; Premoboere and Raimi 2018; Suleiman et al. 2019; Olalekan et al. 2019b; Raimi et al. 2019a; Raimi et al. 2019b; Raimi et al. 2019c; Ebuete et al. 2019; Ajayi et al. 2020; Okoyen et al. 2020; Isah et al. 2020a; Isah et al. 2020b; Olalekan et al. 2020a; Gift et al. 2020; Olalekan et al. 2020b; Gift and Olalekan 2020; Raimi et al. 2020a; Afolabi and Raimi 2021; Morufu 2021; Raimi et al. 2021a; Hussain et al. 2021a; Hussain et al. 2021b; Morufu et al. 2021b; Morufu et al. 2021c; Morufu et al. 2021d; Morufu et al. 2021e; Deinkuro et al. 2021; Morufu et al. 2022; Raimi et al. 2022c). Any nation's environment as well as development are inextricably linked (Faniran and Adeboyejo 1999). The necessity for conservation arises as a result of the latter's harmful impact on the former. Man has received infinite capabilities to exploit the environment rather than safeguarding it for future advantages (Chauhan 2011). Consequently, fictitious necessities such as brewery products, cosmetics, unneeded drugs, luxury as well as fancy items, insecticides, detergents, and so on have infiltrated the market economy, seducing customers using false advertising and glamour (Olalekan et al. 2018c; Isah et al. 2020a; Isah et al. 2020b; Hussain et al. 2021a; Hussain et al. 2021b; Lateefat et al. 2022a; Lateefat et al. 2022b). Resources that might be used to address humanity's true needs are being squandered. Energy usage in the production of unneeded expensive items and pollutants emitted by these firms have contributed to society's abuses (Morufu et al. 2022; Raimi et al. 2022c). The dominance of natural resources owned by private persons, organizations, and state governments precludes optimal resource exploitation in the public interest. Instead of producing more necessary but less profitable crops, land is exploited to grow commercial or worthless products such as tobacco. Waste of resources is also caused by insufficient planning and maintenance. Using good planning, oil spills, gas leaks, spoiling during storage, illegal use of lower utility, plus inefficient transportation may all be reduced (Premoboere and Raimi 2018; Deinkuro et al. 2021; Raimi et al. 2022c). Furthermore, because of inadequate planning with ineffective leadership, intrinsic resources such as intellect, entrepreneurship, enthusiasm, plus expertise are not harnessed to increase production (Ayuba and Dami 2011).

18.10 The Role of Government at all Levels in Biodiversity Conservation

18.10.1 At the National/Federal Government Level

A federation is an organization of states in which governmental authorities remain shared among the state as well as federal governments, which conduct their tasks in a coordinated (independent) and superior manner, while state functions remain termed as "residual functions" (Jiriko 1999). Several of the responsibilities that the national government may undertake in the policy formulation tools to ensure greater environmental protection in Nigeria include:

(i) Through the use of the media, the national government can persuade the overall public to refrain from behaviors that may have a harmful impact on the environment.
(ii) Direct controls, like air pollution legislation limiting allowed amounts of emissions and defining how these controls must be carried out successfully.
(iii) The federal government may rely on market mechanisms to collect taxes on environmental harm. The charges might be assessed in terms of societal harm and what is required to meet current environmental quality requirements. Furthermore, companies might get subsidies per unit of reduced waste emissions, similar to those provided by the government to offset the cost of damage control equipment.
(iv) The Federal Government should invest in damage prevention facilities, regenerative activities (e.g., forestation and slum clearance), information dissemination, and research, according to a report by the World Resources Institute

(WRI). The report also recommends that universities and research institutes should focus on environmental conservation and education.

(v) Administrative mechanisms for environmental preservation at the federal, state, and local levels. This might come from people who caused the environmental harm, and payments from those who gain from environmental improvements and general income. Using an investigative tool, such as a regulatory agency or the police, to prosecute persons who break environmental rules.

(vi) Focusing more on science as well as technology development in order to conserve the milieu while applying local expertise and enhancing decentralization and local participation.

(vii) Establishing effective sanctuaries as well as enabling democratic governance and administration. Also, indigenous peoples' and local communities' rights must be respected.

(viii) Encouraging repair as well as conservation efforts; taking part in international initiatives including treaties; and enacting and implementing biodiversity protection legislation.

(ix) Developing concession agreements to ensure that enterprises function sustainably; bringing natural capital accounting into the mainstream; embedding social plus environmental analyses into national as well as local development plans; guaranteeing accountability and openness; and reinvesting exploitative rents at the local as much as national levels.

18.10.2 At the State Government Level

Regardless of the level of resources under her control, the "state is required to play duties comparable to those of the federal government to some extent. Furthermore, the states' roles in environmental protection and sanitation agencies need to be improved." The majority of the responsibilities for the multiplicity of tasks of agencies controlling environmental concerns is attributed to several policies, particularly legal legislation and national constitutions (Jiriko 1999; Olalekan et al. 2019a). Most environmental issues have national ramifications. As a result, federal and state policies and programs must be developed in light of general national policy issues. A monitoring system comprising officials from the federal as well as state governments would be established for interaction as needed for the policy objectives to be implemented through:

(i) State institutions including legislation must be strengthened.

(ii) Improving state national resource accountancy and place emphasis on State resource conservation training and orientation program.

(iii) Raising citizen knowledge as well as consciousness about the environment.

(iv) Promoting acceptable environmentally friendly technology in the state.

(v) Collaborative environmental partnerships with networks with women in the protection and repair of the environment.

18.10.3 At the Local Government Level

Local councils are the third layer of government in Nigeria, as well as it is closer to the people. Local residents are often more aware of the many tasks of local government than of the state, much alone the federal government. The 1976 Local Councils Reform in Nigeria burdened the local government with a slew of obligations. The planning plus management of development under its authority is one of the fundamental tasks of local government (Federal Republic of Nigeria 1976: 3). As a result, they have more opportunities aimed at bottom-up, people-centered collaborative environmental protection. Some of the functions that local government may play in environmental protection are as follows:

(i) On environmental concerns, forming environmental partnerships as well as networks with other government agencies including civil society groups, such as bilateral and multilateral funders, ecologically specialized NGOs, African universities, the commercial sector, as well as the media.
(ii) Utilizing local council information devices with traditional rulers to communicate relevant content to the local population, improving environmental education as well as awareness programs within its area of control.
(iii) Organizing environmental conferences for all employees on the importance of environmental protection via the use of environmental impact assessments to create a bigger variety of projects and sectoral strategies, including adjustment processes in order to choose the best option in terms of sustainable development.
(iv) Investment in environmental training, especially for personnel who are not engaged in environmental work, to incorporate the environmental protection idea into all of the day-to-day tasks of local government agencies.
(v) Developing environmental information systems as well as expanding them comprehensively to the total environmental portfolio along with sector loans including environmental components of an environmental protection campaigner issues.
(vi) Establishment of a Local Council environmental conservation board in each local government across the country, comprising all heads of departmental as well as units, supervisory councilors, private sector delegates, as well as delegates from each of the units, with the advisory council secretary being the local government secretary.
(vii) Assigning sufficient funds for environmental conservation programs or activities, along with other things.
(viii) Getting the whole societal structure, as well as the private sector, to work together to solve the environmental issues that are hurting them.
(ix) Again, for conservation of both the physical and cultural milieu, the formulation of applicable bylaws accompanied by police force is required.
(x) Polluter fees should be implemented as a policy to safeguard water, air, as well as land quality.

(xi) Coordinating development efforts with appropriate federal and state government agencies, along with non-governmental organizations (NGOs) on programs that could have an unfavorable impact on the Local Government area on a routine basis.
(xii) Promoting cost-effectiveness through tackling land degradation in three stages: avoidance, reduction, and reversal. Attempts to prevent or reduce land degradation are less expensive than efforts to reverse prior deterioration.
(xiii) Investing in land remediation to mitigate the effects of climate change.
(xiv) Guaranteeing that land rehabilitation expenditures take an interconnected landscape strategy, particularly in settings with fluctuating land potential.
(xv) Engaging in quantitative and qualitative modeling, notably scenario building, at the local and global levels to direct future investments as well as assisting to traverse the complexities of elements that influence the co-benefits of land reclamation.

18.10.4 The Non-Governmental Organization

In the implementation of programs and projects, NGOs have a huge amount of potential to become more practical and reliable than government organizations. They likewise show significantly more professional expertise when it comes to questioning as well as projecting alternatives to government development programs. Environmental protection has received minimal support from NGOs as well as the commercial sector in Nigeria. Nevertheless, by advocating environmental protection, they may play a crucial part in sustaining a healthy environment.

(i) Non-governmental organizations (NGOs) might support diverse environmental education and awareness programs in the mainstream press to enlighten the general public about the need of maintaining environmental integrity, which would improve overall health.
(ii) At the basic and secondary levels, non-governmental organizations (NGOs) can provide evidenced materials to kids, educating them about the fragile status of the environment.
(iii) At the higher institutional levels, scholarships might well be provided to the brightest students to inspire students to pursue environmental-related studies.
(iv) On a community scale, NGOs might provide environment protection lectures as well as deliver seedlings to farmers in order to encourage regeneration.
(v) Establishing as well as supporting local extension organizations that will examine local people's environmental actions and serve as an advisory council to them on environmental matters.
(vi) Non-governmental organizations (NGOs) can provide training to anybody interested in environmental issues. The effectiveness of environmental conservation programs, concepts, and methodologies hinges on the development of human resources.

(vii) The managerial competence of non-governmental organizations (NGOs) must be improved. Training programs for NGOs must be coordinated on a state-by-state basis. At every district office, a rural NGO advisory cell must be established.

(viii) Non-governmental organizations, social organizations, including village-level institutions such as forests must be given locus standi plus assistance in order to mobilize popular opinion through involvement in development efforts.

(ix) Advances in telecommunications will offer Africa with a variety of possibilities plus problems, notably in terms of environmental management, during the next century. As a result, taking use of developments in digital networking and telecommunications, as well as gathering environmental data, is critical. NGOs ought to be active in the maintenance and distribution of environmental data at the provincial level.

(x) The conservation approach could not be implemented alone without people's active participation. This would necessitate a network of non-governmental organizations (NGOs) and a public–private partnership. NGOs must likewise have a significant investment in research on the environment, human resources, and a sound policy framework.

(xi) Building biodiversity objectives into policy dialogue with borrowers and incorporating biodiversity considerations into country assistance strategies and economic and sector work.

None of these methods can achieve the desired outcome without a mix of them, even though it is important to note that NGOs could indeed not ensure environmental conservation on their own; they should collaborate with the federal, state, including local governments. As a result, environmental conservation would be strengthened. Emerging environmental assistance programs will help African countries construct demand-driven, cost-effective environmental conservation information systems, which must include geographic information system technology since environment protection concerns remain location-specific.

18.11 Constraints and Prospects for Biodiversity Conservation

From an economic and social standpoint, the Global South relies on its natural resource base more than any other area on the planet. This resource base, nonetheless, is in jeopardy due to a slew of interconnected concerns. Mainstreaming environmental conservation remains an important challenge for Africa. The following are some of them:

(i) Inconsistent political unpredictability and fragmentation.

(ii) Environmental protection is hampered by a lack of strong regional collaboration structures.

(iii) Playing about with the contract between the parties involved (agencies) on natural resource conservation.
(iv) Dishonesty as well as non-charlatan sentiments among the general population.
(v) Mainstream segment noninvolvement, e.g., communities.
(vi) Inadequate budget allocation.
(vii) Partisan politics includes politicization of environmental concerns, such as land use legislation.
(viii) Poor or nonexistent public awareness of natural resource issues.
(ix) Base maps and other planning processes toward environmental conservation are unavailable.
(x) Appraisal of natural resources plus strategic plan.
(xi) There is a lack of consensus within stakeholders when it comes to conservation choices.
(xii) Inadequate ethical as well as coordinating capability on the local level.
(xiii) A lack of trust in the capital allocated to natural resource protection and the manner in which it is managed.
(xiv) Among other things, there is a lack of monitoring of natural resource protection projects.

Natural resource preservation, on the other hand, is one of the areas in which viable solutions to today's environmental issues seem to be in high demand (Kolk 2000; Olalekan et al. 2019a). A well-preserved natural resource provides social, economic, visual, as well as artistic benefits, and it ensures the residents' well-being. It draws a large number of scholars who are deeply invested in natural resource challenges. If it were not for the numerous good aspects that are developing, the work ahead of us is overwhelming. Africa is now a part of a global community blessed with vast natural resources that are, surprisingly, getting overexploited. Rapid urbanization, in combination with increasingly rapid industrial growth, has created issues with environmental assets. All of these required the need to protect our precious natural resources.

18.12 Future Directions

From poorly inhabited rain forests to highly populated savannas including drylands, as well as from flat coastal areas to plateaus as well as mountains, as the Global South features a great biodiversity. This variability necessitates the development of unique methods as well as initiatives. NGOs and different levels of government now have a plethora of untapped resources (material, human, including financial) that might be directed into natural resource conservation in Nigeria. Whereas a number of restrictions were found throughout the course of the study that may stymie all initiatives in Nigeria to conserve natural resources, they might be overcome if everyone works together to rally around sound, clean, as well as viable natural resources. As the scientific research on local plus indigenous knowledge as well as practices has progressed, the focus has shifted from utilitarian perspectives to improved consideration of values. Viewpoints include ideologies toward nature, political upheaval plus violence, research ethics, environmental change drivers linked to economic development pressures, and changing climate. Indigenous peoples, as well as community groups, can add value to conservation of biodiversity, sustainable use, and environmental governance. Partnerships between academics and indigenous researchers can inspire knowledge collaborative projects for configuration that will lead to a fairer and more sustainable society. The success of COP15 hinges in part on governments and market players repaying nature's VIP treatment in Glasgow. Bridging these linkages has significant market and policy benefits. Nature is entirely responsible for every product, currency, as well as employment in the globalized trade. Nature's value in the international economy is obvious, but its monetization is now in its infancy. To make sustainable conservation a reality, channeling funds from the markets toward nature conservation must present investors with a long-term investment option based on Natural Capital's appealing earnings profile. Also, carbon credits and rewards can encourage people to participate in initiatives that decrease emissions and improve carbon sequestration. As a result, we possess built-in demand stemming from the fact that governments have objectives under the Paris Agreement. Policies that safeguard forest carbon as well as aid in the improvement and protection of biodiversity do have socioeconomic advantages.

Lastly, recent papers have shown that little is learned regarding national and regional institutional landscapes, while more study is needed before conservation managers could build an efficient management "menu" that allocates responsibilities to a variety of stakeholder groups at various levels (Olalekan et al. 2019a). Professionals should also avoid imposing standard conservation practices throughout the developing globe. They must instead acknowledge the significant and intricate inequalities in institutional positions as well as power. Help spur communities to embrace new rights-based participatory processes that encourage and enhance community-led conservation, as well as traditional sustainable uses as well as relationships with environment (Olalekan et al. 2019a; Raimi et al. 2019a; Raimi et al. 2019b). A global campaign to conserve, manage, and regenerate biodiversity will reap immediate and broad dividends. If we promote inclusive as well as gendered equitable land governance, we could build an army of land stewards. We require innovative strategies, like carbon pricing, which are soil degradation neutral plus gross nature positive, precisely as we need legislative changes. Debt swaps for the environment and climate may motivate people to take action. Individuals will be more empowered to govern land sustainably with new financial tools and policy portfolios which extend financial inclusion and social protection, with adaptable safety nets. While, the lack of action-oriented maps in land-based policy is alarming since without geographical analysis as well as spatial planning, neither biodiversity nor even the climate catastrophe could be handled. Governments require geographical data to determine whose land regions have the most capability to generate complementarity among biodiversity conservation and the benefits of nature to humanity.

18.13 Conclusion

In conclusion, biodiversity is our existence, and its worth is unfathomable, but it is evident across every breath we breathe, single morsel of food we eat, as well as every time we spend admiring the beauty as well as wealth of nature. If biodiversity disappears, all Earth life struggles. Today or for coming generations, people may all profit by rebuilding a healthy, productive, and diversified home. However, the clock is ticking. Every extinction event results in permanent loss. Pollution as well as changing climate have been wreaking havoc on the environment, with long-term consequences. The probability of ecological collapse increases as human actions toss ecosystems farther out of equilibrium. There's a lot on the line. The actions we take today are significant. Humans should act, and therefore we must respond now, to stop the devastation, reconstruct what we can, as well as reap the advantages of conservation. As a result, the International Resource Panel (IRP) has recommended that humanity need to comprehend how to divorce economic growth from environmental deterioration while improving human well-being. As a result, the intensity of the COVID-19 outbreak has offered us a heightened appreciation for the interdependence of society with ecosystems. To rebuild better, smarter use of natural resources is essential. We should change to a new approach of resource use that is socially fair, economically robust, and ecologically healthy, starting with how we produce wealth and ending with how we live, move, as well as eat. This study demonstrates that it is doable and suggests viable courses to take. "We need to act immediately."

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Chapter 19
"Let Them Eat Their Declarations": Interrogating Natural Resource-Rich States' Inertia Towards Biodiversity Conservation Treaties in Sub-Saharan Africa

Olawari D. J. Egbe

Abstract Biodiversity is critically threatened in sub-Saharan Africa (hereafter SSA). Concerns in the form of declarations, conventions, treaties and communiques have been issued and held severally in SSA. Whereas these efforts are commendable, what is responsible for the inertia on biodiversity conservation by state authorities in SSA, especially resource-rich states? How many such conferences were to be held and declarations issued in the future to spur states of SSA into assertive action? Is it greening the environment unending? Worried by the foregoing questions, this chapter interrogates the sterility of assertive actions on biodiversity conservation by state authorities in SSA. This chapter relies on the Rentier State Theory (RST) as its theoretical handle and argues that to the extent that resource-rich states such as Nigeria, Angola, Gabon, Ghana, South Sudan, Equatorial Guinea and others are rentier states whose economic well-being and sustainability depend on economic rents/royalties which make them to have an asymmetry between economic development and biodiversity conservation, biodiversity protection remains rhetoric. The chapter is entirely qualitative. It concludes that while countless declarations, conventions, treaties and even communiques have been ratified and deposited by resource-rich states of SSA, these efforts remain ephemeral—as rentier states are ever reluctant to engage in sustainable resource extraction strategies in so far as economic rents accrue to their coffers. Therefore, this chapter recommends that resource-rich states of SSA should negotiate their economies away from the present knee-deep dependence on non-renewable resource exploitation to renewable resource extraction for the sake of biodiversity conservation; moreover, it is the international best practice.

Keywords Biodiversity · Conservation · SSA · Declarations · Environment · Rentier states

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19.1 Introduction

Globally, biodiversity[1] is extinction-imperiled (Wilson 1989; Chivian 2002; SIDA 2002; Craigie et al. 2010; IUCN 2012; World Bank 2021). Africa, though, is set apart as a continent home to extinct prone wildlife and a conserver of forests and game reserves (IUCN 2015). Interestingly, Africa's wildlife, which comprises a quarter of global biodiversity, supports the earth's assemblages of mammals that roam freely in several countries (Koudenoukpo and de Souza Dias 2016). Singularly, Africa amongst others, hosts the Maasai Mara National Reserve, Kenya; the Serengeti National Park, Tanzania; Kruger National Park, South Africa; Chobe National Park, Botswana; Etosha National Park, Namibia; South Luangwa National Park, Zambia; Volcanoes National Park, Rwanda; Nouabalé-Ndoki National Park, DRC; Salonga National Park, DRC and Chad Basin National Park, Nigeria (Hastings 2020; Cannon 2021).

Little wonder, these game reserves are accorded pristine conservation for foreign exchange, especially from international tourism, research and scientific knowledge advancement, occupation and job creation, recreation, traditional medicine, arts and crafts, cultural heritage and aestheticism (Morton and Hill 2014). These accruing benefits have since compelled demands for biodiversity conservation in Africa (Gandhi 1991; Kaunda 1991; Mugabe 1991). Thus, for the interest of biodiversity conservation, there is an urgent need for the regulation of biodiversity exploitation by all governments to reverse the disturbing disappearance of minerals, forests, wildlife and other non-renewable assets (Perman et al. 2003; UN 2005).

Thus, heeding this clarion call, several African states have engaged in concerted intervention efforts to preserve this rare heritage through declarations, communiques, conventions, protocols, treaties, charters, statements of commitment, etc. Efforts in this direction include the "African Ministerial Declaration on Biodiversity (2018)", the "Lusaka Agreement on Cooperative Enforcement Operation Directed at Illegal Trade in Wild Fauna and Flora (1994)" and the "Abidjan Convention for Cooperation in the Protection and Development of the Marine and Coastal Environment of the West and central African Region".

Whereas the foregoing is apposite for Africa, it is noticed that mineral-rich states, though playing host to game reserves, are Janus-faced towards biodiversity conservation. Ordinarily, biodiversity conservation is dependent on a synergy between environmental conservation and economic goals (Ola and Benjamin 2019). However, among rentier states, economic development of the state takes precedence over biodiversity conservation (Anwadike 2020). This ensuing asymmetry between state

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[1] Gaston and Spicer (2004) define biodiversity as "most straightforwardly, biological diversity or biodiversity is 'the variety of life', and refers collectively to variation at all levels of biological organisation".

For DeLong (1996), biodiversity is "a state or attribute of a site or area and specifically refers to the variety within and among living organisms, assemblages of living organisms, biotic communities, and biotic processes, whether naturally occurring or modified by humans".

economic survival and biodiversity conservation has constrained resource-rich states to play rhetoric to the avalanche of declarations, conventions, charters, treaties, communiques, etc. they have hitherto consummated.

Nigeria is a peculiar case in reference. Whereas, the International Union for Conservation of Nature's red list of threatened species indicated that 26 mammals, 19 birds, 8 reptiles, 13 amphibians, 60 fishes, 1 mollusc, 14 other invertebrates and 168 plants totalling 309 species are threatened in Nigeria (IUCN 2013); however, out of the 82 subsisting global environmental conventions, Nigeria has only ratified 30, leaving out 52 unratified (Atsegbua et al. 2003).

It could be inferred from the foregoing that mineral-rich states' unrestrained economic interest has constrained them from implementing biodiversity conservation agreements. Thus, this chapter is compelled to ask the following question: Why do natural resource-rich states in sub-Saharan Africa play rhetoric to biodiversity conservation? Following this introduction, the balance of the chapter is organised as follows: Sect. 19.2 explains the theoretical framework of the chapter. Section 19.3 identifies the multiplicity of declarations/conventions/treaties on biodiversity that states of SSA have consummated. Section 19.4 adduces the reasons for the futility of resource-rich states' unenthusiasm towards biodiversity conservation. Section 19.5 concludes the chapter.

19.2 The Rentier State Theory

The theoretical framework of this chapter is dependent on the Rentier State Theory (hereafter RST) popularised by North African and Middle East scholars like Mahdavy (1970), Skocpol (1982), Beblawi (1987), Yates (1996), Owen and Pamuk (1999), Gary (2011), etc. Rentier State Theory is a political economy theory that explains state–society relationship in states that generate income from economic rents. It further held that so far as the state receives external income and distributes same to society, it is relieved of imposing taxation and not to offer concessions to society such as democratic dividends and even development (Mahdavy 1970; Gary 2011).

From the foregoing, rentier states abstain from the imposition of taxation on their population, and rather generate income from non-tax sources such as rents and royalties (i.e. unearned income) from natural resources (oil, gas, mining, etc.). Yates (1996) identifies rentier states as those entangled in several defects such as (a) a parasitic enterprise that violates hard work as a liberal ethos, (b) a rentier mentality (a scenario where one never works but must eat), (c) the preponderance of the service sector to the disadvantage of agriculture, (c) the tendency of consumption almost always exceeding production—a consumption pattern financed by economic rents and (d) the proliferation of autocratic tendencies—as it is so commonplace in Nigeria where military measures are deployed against pro-environmental demonstrations as the Ogoni did in the 1990s (Kew and Lewis 2016).

This chapter takes its point of departure from items (a) and (b) above; because rentier states are natural resource-rich states almost solely reliant on rents[2] paid to them by extractive industries. This condition makes them to eschew hard work and instead sit back to await economic rents and royalties (Issavi 1982; Mazawi 1999).

Characteristically, mineral-rich states are active negotiators of biodiversity agreements but they are the worst culprits in defaulting such agreements because they suffer from most of the aforementioned rentier effects. It is this peculiar entanglement that constrains Africa's resource-rich states from genuinely implementing declarations on biodiversity conservation. In order words, they are rentier states that give primacy to state economic survival over biodiversity considerations.

19.3 Declarations on Biodiversity and Their Accountability Gaps in SSA

Biodiversity has the luxury of multiple scholarly definitions (Spellerberg and Hardes 1992; Wilson 1992; Noss and Cooperrider 1994; DeLong 1996; Maclaurin and Sterelny 2008). Article II of the "Convention on Biological Diversity" defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". Instead of an overview of definitions, Oguamanam (2013) was interested in what biodiversity is not; which amongst others include first, biodiversity is not a synonym for natural resources and second, biodiversity is essentially an intangible concept that is better appreciated as an abstract conception.

It is in this context that the International Union for Conservation of Nature and Natural Resources (IUCN) observes that rather than seeing biodiversity as biological resources, it should be seen as an attribute or way of life (Oguamanam 2013). These discourses indicate the value of biodiversity to humanity (Basu 2020; Wackernagel and Rees 1996); however, it has been a victim of intense anthropogenic disturbance from fires, diseases and resource extraction activities (Dornelas 2010; Wilson 2016). Dornelas (2010) identifies three major varieties of disturbance on biodiversity: "D disturbance (shifts in mortality rate), B disturbance (shifts in reproductive rates) and K disturbance (shifts in carrying capacity) are easily identified as being caused by humans".

These disturbance regimes have compelled state parties and Intergovernmental Organisations (IGOs) to consummate treaties, protocols, etc., to achieve biodiversity conservation. Whereas this section identifies select declarations (in Table 19.1) entered into by African states, two brief caveats are necessary here: first, it is that the declarations mentioned below are only those among African states and did not

[2] Rents are "rentals paid by foreign individuals, concerns or governments to individuals, concerns or governments of a given country" (Mahdavy 1970).

Table 19.1 Selected declarations on biodiversity by sub-Saharan African states

Title	Description	Signature	Ratification	Depository
Convention concerning the Conservation of nature and natural resources, Algiers	Article II says that the parties shall ensure conservation, utilisation and development of the soil, water, flora and fauna resources in the best interests of the people	15/09/1968	07/06/1974	The OAU (AU), Addis Abba
Bamako Convention on the ban on the import and transboundary movement and Management of Hazardous Wastes within Africa	Against the dumping of toxic, radioactive and pharmaceutical wastes and residues on African territories	19,991	30/01/1999	The OAU (AU), Addis Abba
The Basel Convention on the control of transboundary movement of hazardous wastes and their disposal	To combat dumping of hazardous wastes	22/03/1989	13/03/1991	
The Convention to combat desertification	To combat the threat of desertification in Africa	17/06/1994	08/07/1997	
Convention for cooperation in the protection and coastal Environment of the west and central African region, Abidjan		23/05/1984	06/06/1984	Cote d'Ivoire
Convention and statutes relating to the development of the Chad Basin, fort Lamy, Chad		22/10/1964	Unknown	
Lagos Plan on the Environment, 1980–2000	To address Africa's environmental concerns on air and marine pollution, deforestation, drought, desertification and soil degradation			
African ministerial conferences on the Environment (AMCEN)	To promote sustainable development and environmental protection through regional action plans, policies, etc.	1997		Olive Convention Centre, Durban, SA
Phyto-sanitary Convention for Africa	To eliminate plant diseases in Africa, prevent the introduction of strange diseases to plant communities and undertake quarantine measures on organisms, soils, plants, etc.	13/09/1967		

(continued)

Table 19.1 (continued)

Title	Description	Signature	Ratification	Depository
The Convergence Plan for the Sustainable Management and Use of Forest Ecosystems in West Africa, Accra, Ghana, 2012		12/09/2013		FAO regional office, Accra, Ghana

Source: Compiled by the Author

include declarations that African states have entered into at the global stage; and, second, in analysing the accountability gaps of African state parties towards biodiversity declarations, Kiss and Shelton's (2000) seven characteristics of environmental treaties, as stated below, serve as the threshold to determine states' level of commitment towards biodiversity conservation:

(a) an emphasis on national implementing measures being taken by the states' parties;
(b) the creation of international supervisory mechanisms to review compliance by states' parties;
(c) simplified procedures to enable rapid modification of the treaties;
(d) the use of action plans for further measures;
(e) the creation of new institutions or the utilisation of already existing ones to promote continuous cooperation;
(f) the use of framework agreements and,
(g) interrelated or cross-referenced provisions from other environmental instruments.

An interrogation of the implementation of the various declarations, conventions and treaties on biodiversity yielded mixed results (UNEP-WCMC 2016). First, from an optimistic perspective, the Africa Ministerial Conference has made giant efforts in presenting unified African fronts on global environmental issues such as climate change, biodiversity, etc. at global fora. Second, on a sad note, African states have never fared well compelling the UNEP-WCMC (2016) report to emphatically state that biodiversity among African states is steadily on the decline; especially in habitats, species and forests and chiefly attributed to anthropogenic causes.

Thus, a huge accountability gap exists in almost all of the declarations mentioned in Table 19.1—thereby faltering most of Kiss and Shelton's (2000) benchmarks on the characteristics of environmental treaties in the process. What is so commonplace among state parties in Africa is the holding of intermittent conferences on biodiversity and of course their trademark issuance of communiques to mark the end of their respective jamborees on biodiversity conservation.

Implementation of biodiversity conservation treaties, especially, among the resource-rich states who are knee-deep on economic rents for their sustenance are the worst performers. Nigeria and its fellow oil producers like Angola, Algeria, Equatorial Guinea, Gabon, Libya, Sudan and South Sudan are state parties to the

Phyto-Sanitary Convention for Africa; however, none of these oil-rich states has neither ratified nor deposited this treaty. More specifically, the antecedents of the government of President Muhammadu Buhari since assuming office in 2015 have demonstrated environmental blindness in diverse ways. For example, President Buhari's administration through the state-owned Nigerian National Petroleum Corporation (NNPC) has engaged in intensive oil exploration in the Lake Chad region (Punch Editorial Board 2016; Egbejule 2019); a mirage project that has cost the administration about ₦149.4million (Oladipo 2021).

Arising from the huge accountability gaps from all of the foregoing declarations, the African Youth Declaration on Nature was issued by African youths on 22–24 May 2019 at Nairobi, Kenya, which amongst others demanded as follows:

> We**,** the youth representatives from various African countries assembled at the #IAm4Nature Youth Conference in Nairobi from 22nd to 24th May 2019 to (a) Advocate for informed youth participation and inclusion at all levels of decision-making regarding biodiversity conservation and climate change and (b) Protect and conserve our biodiversity to ensure sustainable socio-economic development of Africa...for us to achieve our commitments we call on our Governments to: (a) prioritise and mainstream biodiversity protection in development by committing financial resources to tackle biodiversity loss...(b) urgently enforce regulations and legal instruments that improve biodiversity management and protect genetic resources in order to improve bioprospecting and reduce trafficking and/or biopiracy; (c) impose and enforce strict regulations to reduce pollution in the environment.

As a follow-up, the African Youth Biodiversity Forum Declaration in Tshipise, South Africa, 7 February 2020, called on the African Union to:

> Actively account for present and future short-term and long-term impacts on biodiversity, and take actions to avoid or minimise potential negative impacts in response to the common but differentiated responsibility of all generations in ensuring a fair and sustainable planet for the generations that follow, with full and effective participation of children and youth, ensuring our capacity-building and access to environmental information that concerns us...Be alarmed by the lack of data on valuation of biodiversity in most African countries and promote long term scientific research and monitoring on biodiversity.

The worries so expressed by youths affirm the fear of H. L. Mencken (in Wolfgang Kasper 2007) who asserts that any attempt to save humanity is always a ruse but a desire to rule it. The wide accountability gaps in various declarations have compelled ecologists to conclude that the pledges of state parties to the World Summit on Sustainable Development in Johannesburg in 2002 to employ measures to reduce biodiversity loss after all are myopic, ephemeral, ruse and all Janus-faced approaches and attempts to subdue and rule the environment (SIDA 2002).

19.4 Explaining the Ruse in Biodiversity Conservation in Sub-Saharan Africa (SSA)

As noted earlier, sub-Saharan Africa (hereafter SSA) is home to enormous renewable and non-renewable natural resources. Resource richness in SSA has contributed significantly to the economic well-being and external relations of most of these states. However, this accruing wealth is culpable in making these states to demonstrate a disturbing blindness towards biodiversity conservation.

Little wonder, from the oil-rich Cabinda region in Angola to the Niger Delta region in Nigeria, biodiversity is treated with levity. For example, despite the several environment-related laws and regulations, Nigeria's national parks are still dependent on a military decree—the National Parks Decree—which was consummated under the military and is still in effect. A point worthy of note is that the following factors explaining SSA state's lukewarmness towards biodiversity conservation agreements have external underpinnings.

19.4.1 The Rentier Character of Africa's Mineral-Rich States and Fate of Biodiversity

Mineral-rich states are debacle by a dilemma called environmental dialectic—a scenario where mineral extraction exacerbates biodiversity loss, but mineral extraction enables mineral-rich states with foreign exchange to cope with environmental challenges including biodiversity loss (Ferguson and Mansbach 2012). The foregoing notwithstanding, profit extraction from nature is fundamentally harmful to biodiversity in several ways:

First, it is the most unfriendly industry to biodiversity conservation because it triggers climate change and its associated vagaries in sea rise, flooding, drought, desertification, deforestation, etc. (Schimel 2013). Second, as a corollary, the induced climate change adversely impacts on ecosystem distribution of species (Peters and Lovejoy 1992; Field et al. 2008). Climate change threat is so real that it places demand on concerted efforts at biodiversity conservation (Wilson 2019; Felicani-Robles and Woolnough 2019). Third, resource extraction is the ultimate demonstration of the rentier character of resource-rich states. Simply put, rentierism is unearned profits from economic rents/royalties remitted by oil and mining corporations to resource-rich states. Thus, a rentier character subsists when states with cap in hand await economic rents from TNCs without commensurate work.

A major manifestation of rentier states is the Janus-faced rentier character that they inadvertently engage in double speaks and playing rhetoric towards biodiversity conservation agreements. Whereas Nigeria exhibits a worrisome avidity towards economic rents from the oil industry, successive Nigerian governments have pledged their unalloyed commitments to protect the environment (Al-Amin 2013). For example, in the 78th Session of the United Nations General Assembly, President Muhammadu Buhari (2021) said,

> The impact of climate change is already with us in Nigeria, manifesting in various ways. . .in the circumstances, we intend to build a climate-resilient economy that effectively aligns with the SDGs and that has great potentials to unlocking the full opportunities in different sectors of the economy, while protecting the resources for present and future generations. . .Nigeria believes that protecting our planet and its biodiversity and climate are important to our collective survival. That is why, we are working on a transition to low carbon economy, consistent with achieving the Paris Climate Agreement and the Sustainable Development Goals (Buhari 2021).

This statement by the president on the floor of the UN General Assembly by a government dependent on economic rents is indeed worrisome for biodiversity conservation; knowing that the reality on ground is the direct opposite in all resource extraction sites in Nigeria. And more worrisomely, resource-rich states are lukewarm towards biodiversity conservation where the invisible forces of demand and supply play out thus: where there are ready buyers (external interests), there are ready sellers (resource-rich states). The prevailing unrelenting external interests in crude oil compel resource-rich states to engage in unsustainable resource extraction that undermines biodiversity conservation.

19.4.2 Oil Transnational Corporations and Biodiversity Loss

The fossil fuel interest of oil Transnational Corporations (hereafter TNCs) is never hidden; however, it is an interest that adversely impacts the environment. Often, TNCs' avidity for fossil fuel is bolstered by the massive profits realised from resource extraction (Cohen et al. 1979). To ensure an uninterrupted flow of profit, they engage in (a) joint venture agreements with the state authorities in the states where they operate, (b) paying rents and royalties running into trillions of petrodollars to the states and (c) influencing state authorities to deploy whatever means possible, including military measures, to achieve their profit interests. Expectedly, these petrostates in turn work tirelessly by collaborating with TNCs to ensure the continuity of the flow of petrodollars to their state coffers. This, of course, only demonstrates their nature as rentier states.

However, while this unholy friendship strives, biodiversity suffers because states only accord Janus-faced attention. There is an ensuing dilemma that rentier states suffer from: it is that whereas they may be willing to protect the environment, however, the accruable economic fortunes compel them to pay lip service to biodiversity conservation.

The foregoing scenario played out in Okoroba, a community near Nembe in Bayelsa State, Nigeria. Okoroba community is sandwiched by salt and freshwater streams on its reverse sides. This community from time unknown has relied on the fresh water for drinking and cooking purposes while the saltwater stream for seafoods such as periwinkles, sea snails, etc. However, this blessing was disrupted when oil was found in the community in 1991 by the Shell Petroleum Development Company of Nigeria (hereafter SPDCN). In order to transport heavy machinery to begin exploration, SPDCN dredged a two-and-a-half-mile canal to convey its equipment, rather than engaging a more difficult land route. The effects of this man-made canal were monumental: the two naturally opposed fresh and salt ecological waters became mixed and in the process aquatic lives were highly hampered and affected the community's drinking, cooking and seafood sources (Doyle 2002). Cognizance of the fact that ecological factors largely determine species presence and abundance, population, livelihood patterns, dominant values and social organisations of most African societies (Fortes and Evans-Pritchard 1950; Schimel 2013), the Okoroba community experience was unpleasant.

Whereas SPDCN did what it did in Okoroba community, the Nigerian state and its cohort of regulatory agencies looked away from the ecological disaster that impacted the environment. The biodiversity of the two rivers sandwiching Okoroba community was sacrificed at the altar of profit to SPDCN and economic rent to the Nigerian state (Amokaye 2014).

19.4.3 External Interests in Resources and Biodiversity Loss

In collaboration with African governments, foreign interests in Africa's rich natural resource heritage remain a source of Africa's biodiversity loss, genetic erosion,[3] environmental stress and destruction (van de Wouw et al. 2009; Rogers and McGuire 2015). Pullen and Schulmeister-Oldenhove (2021) reported that:

> The EU is the second biggest importer of deforestation after China. In 2017, the EU was responsible for 16% of deforestation associated with international trade, totalling 203,000 hectares and 116 million tonnes of CO_2. The EU was surpassed by China (24%) but outranked India (9%), the United States (7%) and Japan (5%). Between 2005 and 2017, soy, palm oil and beef were the commodities with the largest embedded tropical deforestation imported into the EU, followed by wood products, cocoa and coffee. During this period, the largest EU economies–Germany, Italy, Spain, the UK, the Netherlands, France, Belgium and Poland–were responsible for 80% of the EU's embedded deforestation through their use and consumption of forest-risk commodities, EU demand for these commodities is also driving destruction in non-forest ecosystems, such as grasslands or wetlands.

As an immediate consequence of the foregoing, Virginijus Sinkevičius, the European commissioner for the environment, oceans and fisheries admonished that "we must protect biodiversity and fight climate change not only in the EU, but globally, and our consumption should not contribute to global deforestation, which is a major cause of biodiversity loss and greenhouse gas emissions" (Radwin 2021).

[3] Genetic erosion is "the loss of genetic diversity—often magnified or accelerated by human activities. It can result from habitat loss and fragmentation" (Rogers and McGuire 2015, p. 1). It is also described as "the loss of variation in crops due to the modernisation of agriculture" (van de Wouw et al. 2009).

Indeed, countries of the Global North (Britain, European Union, France, United States, etc.) by their consumption patterns are noted for inflicting diverse stress on biodiversity in Africa even as the following instances suffice:

First, crude oil has received enormous deification from humanity. As a non-renewable resource, crude oil has sustained the lives of people and the economies of both exporting and importing nations alike. Simultaneously, oil enables the industries of the Global North to work and provides the foreign exchange for oil-exporting states to undertake economic development plans. Thus, oil has become the hallmark for progress, a tool for diplomatic efforts and an ingredient for state politics. However, behind this deification of oil, the impact on biodiversity is cavalierly treated.

Second, tropical forests are a major cover that supports biodiversity and also helps in regulating climate change (Watson et al. 2019). However, tropical forest has been converted to cropland and permanent pasture (Bryant et al. 1997; Perman et al. 2003). Agribusiness is the chief culprit. Agribusiness and forest products such as timber, plants, medicinal herbs, etc. are of huge interest in the Northern Hemisphere. Agribusiness involving clearing and burning vast portions of land for industrialised farming is an established cause of deforestation in Africa.

Agribusiness is, supported by selected banks like Barclays, JPMorgan Chase, Goldman Sachs, Morgan Stanley, BlackRock, etc. (Global Witness 2019). However, a major fear arising from the financial endeavours of these banks is that deforestation resulting from agribusiness is an underlying contributor in "disrupting nature's balance and increasing the risk and exposure of people to zoonotic diseases such as Covid-19" (Dongyu and Andersen 2020). Also, the demand for palm oil, soya and industrial-produced meat instigates biodiversity loss. This is because the demand for palm oil as a key ingredient in products (shampoos, soaps, creams and snack foods) found on the shelves of supermarkets worldwide comes from oil palm trees—the cultivation of which involves massive forest clearing (Greenpeace n.d.-a, b).

Trade in timber, especially covert commercial logging, is a flourishing business for both exporters and importers alike in Africa and beyond (Greenpeace 2014; Hoare 2015); however, it remains a major deforester (Fleshman 2008). It is widely reported that the avalanche of exotic wood products in the international market is undertaken in an illegal trade; where timber is cut in the Global South (Cameroun, Indonesia and Papua New Guinea), shipped to and made in China but largely sold in the Global North (especially, the US) (Greenpeace n.d.-a, b; Kleinschmit et al. 2016; Global Witness 2017; WWF 2021). Greenpeace (2004) particularly noted that:

> The global trade in illegal and destructively logged timber is now out of control. Unlawful access to forest resources, environmental damage and forest destruction, human rights abuses and social dislocation of forest-dwelling peoples in some of the poorest areas of the world, are being fuelled by those who buy timber and timber products from these illegal sources.

The consequences of these programmes vary from land grabs, forced evictions and displacement impacting African countries (Allan et al. 2013). For example, in Ethiopia's Gambella region, agribusiness in the name of villagisation programme

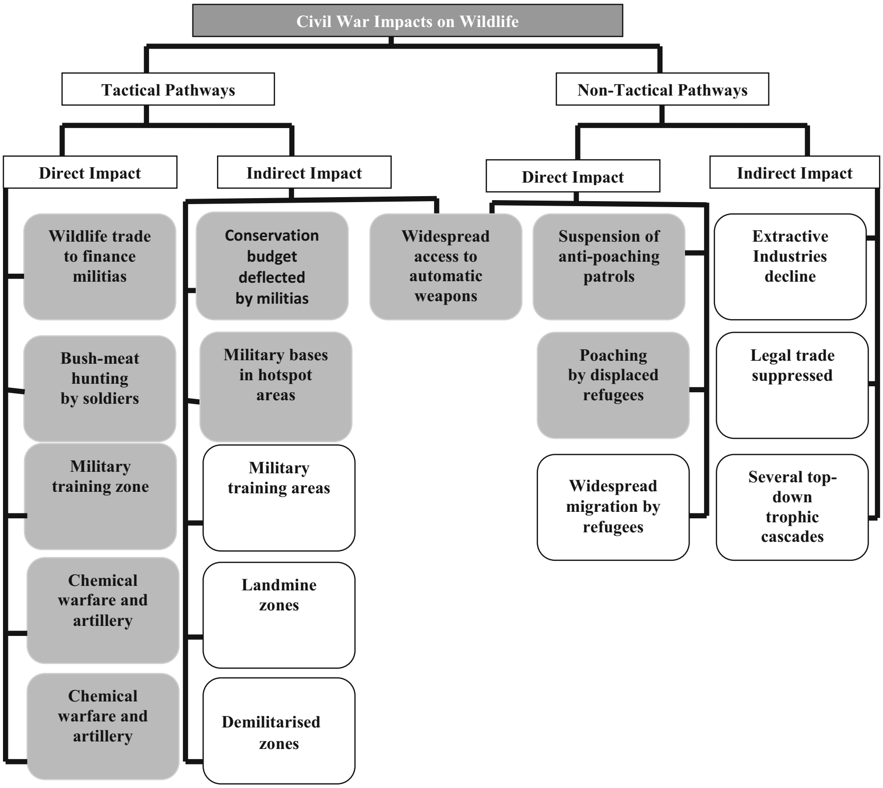

Fig. 19.1 Impact of civil war on wildlife. (Source: Braga-Pereira, F., Peres, C. A., Campos-Silva, J. V., Santos, C. V. D., Alves, R. R. N. (2020) Warfare-induced mammal population declines in Southwestern Africa are mediated by species life history, habitat type and hunter preferences. Scientific Reports, 10: 15428. Rights and Permissions: The work available here: https://www.nature.com/articles/s41598-020-71501-0#rightslink is licensed under the Creative Commons Attribution 4.0 International License. No modifications were made to the chart)

(land grabbing) has caused the invasion of indigenous peoples' lands and evicted indigenous communities from their ancestral lands (HRW 2012a, b). Similarly, indigenous peoples in Kenya and Zambia have suffered similar fate of being displaced without resettlement schemes (Couldrey and Morris 2002; Soroos 2014).

19.4.4 Armed Conflicts, Peacetime and Biodiversity Loss

Biodiversity is at a crossroad in conservation. As it is indicated in Fig. 19.1 (where the white and dark boxes indicate positive and negative effects of armed conflict on wildlife), scholarship is divided in arguing that wartime and peacetime are either good or bad to it (Reeve and Ellis 1995; Austin and Brunch 2000; Dudley et al. 2002;

Jachmann 2008; Beyers et al. 2011; Daskin et al. 2015; Lindenmayer et al. 2016; De Merode et al. 2007; Braga-Pereira et al. 2020a). Myers (in McNeely 2002) argues that war is good for biodiversity because "combatant armies effectively designate war zones as 'off limits' to casual wanderers, thus quarantining large areas of Africa from hunters and poachers". McNeely (2002), however, quickly countered that "any benefits of war to biodiversity are incidental, inadvertent and accidental rather than a planned side-effect of conflict". Thus, biodiversity conservation is worse in peacetimes because it ensures forest exploitation with impunity (McNeely 2002).

In recognition of wartime effects on biodiversity, deliberate efforts at conservation are commonplace. Among several other conventions, the Convention on the Prohibition of Military or any Hostile Use of Environmental Modification Techniques, or Environmental Modification Convention (the ENMOD Convention (1978), Protocol I of the 1977 Geneva Conventions, the 1994 Red Cross Guidelines for Military Manuals and Instructions, etc. merit mention.

In this regard, the African Convention on the Conservation of Nature and Natural Resources (2003) implore African state parties to:

> (a) take every practical measure during periods of armed conflict to the environment against harm; (b) reframe from employing or threatening to employ methods or means of combat which are intended or may be expected to cause widespread, long term, or severe harm to the environment and ensure that such means and methods of warfare are not developed, produced, tested or transferred, (c) refrain from using the destruction or modification of the environment as a means of combat or reprisal; (d) undertake to restore and rehabilitate areas damaged in the course of armed conflicts. The Parties shall cooperate to establish and further develop and implement rules and measures to protect the environment during armed conflicts.

In defiance to the foregoing, armed conflicts in Africa, sometimes with the support of international forces, have negatively impacted on all levels of biodiversity—starting from genes to ecosystems (McNeely 2002; Braga-Pereira et al. 2020b). In fact, warfare is commonplace in areas of resource hotspots where conscious attempts at biodiversity destruction writ large (Hanson et al. 2009; Chase and Griffin 2011; Gaynor et al. 2016; Daskin and Pringle 2018). The following cases make typical examples: First, the Liberian civil war compelled indigenous peoples to hunt forest elephants, duikers, chimpanzees, etc. for food. Second, in Burundi, the Kibira and Ruvudu National Parks were occupied by rebel forces fighting the government (McNeely 2002). Third, of the various brutal Nigerian state counter-insurgency responses—with diverse code names like Operation Python Dance, Operation Crocodile Smile, etc. (Egbas 2017)—against insurgent groups in the Niger Delta, the environment was a secondary factor in consideration. Winning the battle over the insurgents was most important because a military victory guarantees unhindered access to economic rents from oil Transnational Corporations (TNCs) operating in the region.

Finally, a characteristic trend in most of these armed conflicts is the hand of corporate and external interests. In the context of corporate interest, SPDCN was implicated in supplying flotilla pontoon boats to the Nigerian army deployed to quell the 12-Day Revolution declared by the Isaac Jasper Adaka Boro-led Niger Delta

Force (Cummins and Beasant 2005). Internationally, in the various resource conflicts, authorities in the U.S. denied complicity, but the following statements credited to senior U.S. officials point to the contrary:

> The Iraq war has nothing to do with oil, literally nothing to do with oil (Donald Rumsfeld, Secretary of Defense, 2002). The most important difference between North Korea and Iraq is that economically we just had no choice in Iraq. The country swims on a sea of oil (Paul Wolfowitz, Deputy Defense Secretary, 2003). Oil has literally made foreign and security policy for decades (Bill Richardson, Secretary of Energy, 1999). (Kaldor et al. 2007).

Singularly or collection of the afore-discussed explanations are definitely responsible for the Janus-faced attitude of mineral-rich states towards biodiversity conservation and preservation in sub-Saharan Africa. Indeed, it is in such contexts that Edward Osborne Wilson, American biologist, naturalist and writer admonished that as part of humanity "we study and save it (biodiversity) to our great benefit. We ignore and degrade it to our great peril" (NASEM 2022). Martha Gellhorn (in Good 2002) was rather blunt: "Never believe governments, not any of them, not a word they say; keep an untrusting eye on all they do".

This section succinctly identified the factors that have hindered state authorities in SSA from engaging in genuine efforts at biodiversity conservation. The section, especially, noted that biodiversity conservation efforts are mostly undermined among states that are rich in non-renewable natural resources such as oil and gas and mineral deposits.

19.5 Conclusion

Africa is indeed blessed with huge biodiversity, but it is easily sacrificed at the altar of economic rents. Africa's mineral-rich states are much more bothered by their economic sustainability vis-à-vis the environment, biodiversity, ecosystems, etc., which are collectively considered nature's providence meant to be dominated. This attitude of mineral-rich states of sub-Saharan Africa is overtly or covertly encouraged by external interests such as corporate interests and interests from states of the Global North.

Under these prevailing circumstances, occasions of meetings of African states leading to declarations, conventions, treaties, and communiques on biodiversity amount to mere jamborees, talk shops, making large commitments yet limited progress, overpromises and yet under-deliveries; all of which explains the huge accountability gap for all the multiple treaties, declarations and conventions on biodiversity protection and conservation. Going by the lack of genuine commitment towards biodiversity conservation, it is no surprise that resource-rich SSA states are unable to meet the 20 Aichi Biodiversity targets.

It is against the foregoing that this chapter makes the following recommendations:

(a) Regional approaches should be adopted in tackling deforestation in West Africa. The West African Governments' initiatives of the "Global Transformation of Forests for People and Climate: A Focus on West Africa" and the "2025 Vision of ECOWAS Heads of State" are good innovations to turn West Africa into an area without borders with citizens benefiting from the enormous resources of the region,
(b) National policy on knowledge in environmental education is most needed to provide employability education to students and teachers at secondary and tertiary levels of education on the valorisation and conservation of nature and as a measure to cushion the impact of the prevailing unemployment scenario in most African states. A good venture in this context is the policy of beekeepers and honey production education.
(c) Natural resource-rich states in SSA should engage in biodiversity offsets in order to mitigate the impacts of mining and exploration on biodiversity. Biodiversity offset is the creation of benefits elsewhere to mitigate the impact of mining and exploration. This is achievable by the acquisition of comparable land for biodiversity conservation, a process otherwise referred to as biobanking.

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Chapter 20
Sacred Groves in the Global South: A Panacea for Sustainable Biodiversity Conservation

O. Imarhiagbe and M. C. Ogwu

Abstract Sacred groves retain pristine or secondary forest tracts with rich biodiversity protected for centuries due to their sociocultural and religious values as well as indigenous belief systems. In the Global South, deities and related practices are often associated with sacred groves. The populace believe deities reside within them and perform their holy function of protection from within the confines of the groves like the Tenoboase sacred grove, Ghana. Moreover, these sacred groves have legends, folklore, taboos, rituals, feasts and festivals and myths, which are integral to maintaining them. Diverse cultures and traditions recognize sacred groves differently and have different rules for their protection and, in turn, the safety of the vast biodiversity they hold. Therefore, these groves serve as informal centres for in situ conservation of biodiversity. In some cases, rare, endangered or threatened plants and animals have been documented in sacred groves within the Global South. The sacredness, spiritual, religious beliefs and taboos contribute significantly to the preservation and management of biodiversity found within these sacred groves. However, globalization and shifts in sociocultural and traditional outlooks are driving a drop in the number, size, management regimes and composition of sacred groves in the Global South. This chapter seeks to highlight the roles of sacred groves in biodiversity conservation and how they can be effectively managed.

Keywords Sacred groves · Global South · Biodiversity conservation · Globalization · Sustainable traditional practices

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20.1 Introduction

For centuries, protected areas have existed in different forms, shapes and ownership regimes. Sacred groves represent one of the earliest means of biodiversity conservation. According to the works of Brussard et al. (2010) and Ervin et al. (2010), protected areas continue to evolve with societal needs, views and perceptions. Based on these, they may be categorized into classic (before mid-1800), modern (mid-1800–2010) and emerging (post-2010) models, with each model reflecting the connectedness with human and natural systems, roles, management structure and development (including the focus) that characterize protected area of that era. In classical models like sacred groves, spiritual, religious, and traditional beliefs, and cultural mores are considered invaluable in environment as well as biodiversity conservation as it requires an active physical cum metaphysical participation from the local populace (Singh et al. 2017). Sacred groves are delimited and set aside segments of human societies, especially within indigenous communities that are relatively undisturbed or pristine, to express important human-divine–nature relationships (Hughes and Chandran 1997). Singh et al. (2017) opined that these may be relic forests or areas surrounding temples maintained for the sake of social, culture or religion and recently economy. These groves may be spatially restricted as their origins are enveloped in folklores and relevance to livelihood is considered invaluable and inextricably linked to a group or groups of indigenous people. They are unevenly distributed globally (Jaryan et al. 2010) with the Global South (Africa, Asia and south-central America) having more sacred groves compared to the Global North. Some of the places where they are found have been reported as biodiversity hotspots and contain endemic species.

Sacred groves contribute to preserving ecosystem integrity, function, systems and processes like ensuring clean air, soil and water, and protection of agriculture and food systems, flora and fauna using traditional knowledge and practices that differ from one place to another (Ogwu 2019b; Ogwu et al. 2018). Therefore, sacred groves may be patches of trees on forest lands within communities protected for ages by sociocultural and religious connotations (Kandari et al. 2014). Anthwal et al. (2010) noted that the relationship between humans and sacred groves may be expressed differently but has core indigenous cultural and religious values. Wherever they are found, the sacred groves act as a connector in the intricate symbiotic relationship between religion, sociocultural practices and biodiversity conservation; this relationship is vital for sustainable human and societal development. The importance of this relationship is reflected in IUCN's protected area categorization and objectives by including considerations pertaining to cultural approaches, social dimensions and belief systems (IUCN 2007). Although sacred groves are not primarily established for managing and protecting biodiversity and environment, their complex social-spiritual and religious connections with native deities and ancestral spirits continue to implicate them in the protection of biodiversity and ecosystems. Specifically, as they are less-degraded land patches, curtail species loss and effective instrumental in protecting habitats, biodiversity and landscapes

(Bharuch 1999; UNU-IAS and IR3S/UTIAS 2016). These sacred groves can be built monuments within a protected landscape, monuments with incidental ecological value or landscape/seascape with an enduring feature on a natural or semi-natural site for biodiversity and ecosystem conservation on varying location-specific scales (Dudley et al. 2005). Therefore, they are unique complex institutions that combine cultural and religious values into management ideas and practices for the conservation and use of natural resources (Vasan and Kumar 2006).

The chapter seeks to highlight the intrinsic values of sacred groves to biodiversity and nature conservation in the Global South. It will present the origin and historical perspective of sacred groves in the Global South and some traditional knowledge and practices like myths, beliefs and taboos associated with sacred groves and how these practices can be made sustainable to halt the disappearance of sacred groves. The chapter will suggest integrating sacred groves into modern and emerging protected areas for biodiversity and nature conservation.

20.2 Origin and Historical Perspectives of Sacred Groves in the Global South

Sacred groves also called natural museums, relict climax communities, treasure houses, dispensaries of medicinal plants, pristine refuges, temple groves, burial or cremation groves, sanctuaries, regulators of watersheds, recreation centres, church forests, fetish forests, veritable or pious gardens, gene banks, a paradise of nature lovers and living/nature laboratories (Basu 2000; Bhagwat 2009; Jaryan et al. 2010; Manikandan et al. 2011). The origin of sacred groves may be linked to domestication and the commencement of agriculture (around 12,000–14,000 BC), which might have led to the designation of certain traditional lands as sacred and set apart for special functions and to curb over-exploitation, which in turn led to the preservation of flora and fauna they hold. In some cases, the existence of sacred groves has led to the creation of villages as well as the simultaneous creation of human settlements and sacred groves like the Malshegu village in Ghana. Regardless of their origin, sacred groves continue to be invaluable but primitive avenues for biodiversity and nature conservation. Over time, these set apart land patches became residences for deities and grew to become identities of the community and its indigenes. They are sustained by conscious effort of the local people through folklores, taboos, rituals, reenactment ceremonies, feasts, festivals, myths, secrecy, belief, etc. such as those of the MIzhi festival of the Sani people in China, Kpalna festival in honour of Kpalevorgu (fertility deity) in Malshegu village, Ghana, fertility ritual in Osun State, Nigeria, initiation ceremonies of Dossi tribe in Burkina Faso and Mali, and secret practices of the Temne people, Sierra Leone, etc. (Guidoni 1987; Parmentier 1987; Carneiro 1998; Dorm-Adzobu et al. 2012; Bender 2001; Swain 2001; Anthony 2007; Nyamweru 2010).

Indigenous people and tribes in the Global South consider natural resources and life forms like plants, animals, water bodies, landscapes, as well as inanimate objects where ancestors, spirits, gods, goddesses and sometimes their appointed and anointed human representatives dwell and from where they serve the roles of protection and providence for the community like the Tenoboase sacred grove, Ghana. Therefore, they are revered, conscious efforts to protect these resources and objects. In parts of India, for instance, nature worship dates are believed to date as far back as before the Vedic Age (ca. 5000 BC) (Singh et al. 2017). Sacred groves are considered as a refuge for rare and endangered flora and fauna species (Falconer 1992). In Tanzania, the Miombosacred woodlands are central to the culture as well as religious and spiritual needs of the native people, with specific tree species and huge woodlands conserved mainly for cultural and ritual grounds, specifically as burial sites for local chiefs (Shepherd 1992; Sørensen 1993; Morris 1995; Rodgers 1996). In Nigeria, there are the sacred grove of Oshogbo—a forest patch by the Osun river banks, TafiAtome Monkey Sanctuary in Ghana—housing the Patas and Mona monkeys, Aiyana shrine sacred grove, India and Got Ramogi sacred forest hill (Kaya forests), Luo Kenya. These groves are associated with taboos and other religious-cultural practices as well as protection of biodiversity (Dudley et al. 2005; Nganso et al. 2012).

Sacred groves have been tried, tested and proven to conserve nature and natural resources for thousands of years. Globally, there may be over a million sacred groves, with many of them undocumented by science, government and other instituted bodies charged with protecting nature and biodiversity but reserved by native people's traditional ecological knowledge and practices. Malhotra et al. (2007) reported the existence of ca. 150,000 sacred groves mainly distributed around Himachal Pradesh, Kerala and Chhattisgarh. Several groves of Mugumu trees can be found in East Africa, Ginkgo groves are common in China, while Monkey forest groves are found in Indonesia (Hughes and Chandran 1997; Wei et al. 2008). Although these sacred groves wherever they are found in the Global South may be more or less than 1 hectare and 0.01% in size and representative cover, respectively, of a country's geographic area, their number and distribution make invaluable tools for biodiversity conservation (Bhagwat et al. 2005). Together, there are more than one million hectares of sacred groves within the Global South (Borrini-Feyerabend 1997; Pathak 2002). They can be found in different habitats, including coastal, cultivated, hills, rocks, beaches, volcanoes, islands, forests, gardens, lakes and rivers, mixed landscapes, semi-deserts, montanes, riparians, savannas, woodlots, etc. However, many sacred groves are disappearing unprecedentedly (Sunitha and Rao 1999). For example, the last half century has witnessed a 90% loss of sacred forests in Xishuangbanna Dai Autonomous Prefecture (Yunnan Province, China) (Shengji 2010). The challenges faced by many sacred groves are diverse and include a breakdown in cultural values, increasing pressure on land, natural and biological resources from local people and other forms of development-linked issues, and external pressure like legal and illegal logging, mining and pollution (Osawaru et al. 2013a, b; Ogwu and Oladeji 2014; Ogwu 2019b; CBD 2003). There is a need to produce a comprehensive document containing the total number of sacred groves in the Global South.

20.3 Some Challenges Facing Sacred Groves: Disappearance of Sacred Groves in the Global South

Humans as custodians of biodiversity and nature have a socio-ethical responsibility to maintain the religion–sociocultural practices–biodiversity conservation connection and sacred groves provide the ideal platform. Therefore, even though holy groves are treated piously and protected from indiscriminate access (Kandari et al. 2014), they are disappearing due to different reasons that are similar to challenges facing other forms and types of protected areas globally. Manikandan et al. (2011) opined that the main threat to sacred groves is the unsustainable management approaches to the status of each biodiversity taxa and the richness of groups within the sites. Also, Singh et al. (2017) provided evidence that changing attitude of indigenous people and mistrust of traditional beliefs, especially among the younger generations is contributing to the disappearance and degradation of sacred groves in parts of the Global South. Sacred groves are traditionally managed with little to no input from the government using a community-based conservation approach like taboos and restrictions (Manikandan et al. 2011). The informal management of these groves through traditional management system is now being threatened by several economic and sociocultural issues, which renders them less effective and calls for a formal external intervention capable of taking the local people into confidence as well as their inclusion in National Protected Area Networks and Global Conservation Initiatives (Bhagwat and Rutte 2006; Khan et al. 2008). With threats from socio-economy via a shift towards a market-oriented economy and environmental challenges from global warming, the strong beliefs of pilgrims to these sacred sites, some local people and priests may be considered a ray of hope for the maintenance of sacred groves (Jaryan et al. 2010; Ogwu et al. 2016a, b). Also, research into the ecology and underlying sociocultural and economic mechanisms of sacred sites is necessary to fully reveal their potential for biodiversity conservation (Bhagwat and Rutte 2006). This is necessary as they comprise small patches of forests, often with a higher floral diversity and richness when compared to managed forests (Bharuch 1999).

Unsuitable practices like greed and custodians' migration have weakened and decreased the size, structure, sociocultural conditions, biological and ecological integrity and value of sacred groves. Many anthropogenic activities continue to alter the structure and function of different natural resources and systems within sacred groves through ecosystem perturbation (Malik et al. 2014, 2016). Others include the disappearance of indicator species due to different anthropogenic disturbances like alteration of natural habitats, excessive utilization, pollution, global climate change, proliferation of non-native species, etc. (Khan et al. 2008; Ogwu et al. 2014; Osawaru et al. 2013c, d; Osawaru and Ogwu 2014a, b; Ogwu 2019a). Kushalapa et al. (2001) documented the changing of sacred groves to coffee plantations and residential areas for humans in Karnataka, India, which compounds the threat to biodiversity. Also, Anthwal et al. (2010) noted that enforcement of the sacred status of sacred groves is becoming increasingly difficult to enforce and has resulted in conflicts between local people and sacred grove managers due mainly to restrictions enforced versus traditional rights of people. However, this enforcement of sacred status is a valuable tool for sacred groves to act as biodiversity and nature conservation sites. Most of the existing rules protecting sacred groves are not supported by proper legislation, which must be addressed moving forward.

According to Singh et al. (2017), the encroachments of sacred groves by different government agencies, sections of the community, and elders for development and meeting needs coupled with the emigration and migration of people are contributory factors in the extinction of sacred groves in the Global South. Sacred groves should be protected and effectively and efficiently managed if their role as a protected area for biodiversity and nature is to be preserved. The protection and strengthening of sacred groves is a collective effort that can be achieved through education and active participation of everyone because of the shared derivable benefits such as improved standard of living, preservation of culture, communal faith and belief systems, and conservation of biodiversity and protection of nature. Therefore, the existence and management of sacred groves disagrees with the concept of conservation without compensation. Nonetheless, it is worth mentioning that the practice of biodiversity and ecosystem conservation is deeply rooted in natural science, social science, economics and technology along with spiritual, cultural and religious values (Anthwal et al. 2010; Ogwu 2020; Osawaru and Ogwu 2020). Therefore, a holistic view is required to halt the disappearance of sacred groves in the Global South.

20.4 Traditional Practices that Protect the Sacredness of Sacred Groves

Sacred groves are represented mainly by patches of forest set aside as sacred for spiritual and cultural purposes (Cincotta et al. 2000). They exist in various forms, including cemetery sites (Wadley and Colfer 2004), ancestral monuments and deities (Ramakrishnan 2002). Notwithstanding the variations, each sacred grove is recognized by its myths, legends and lore, which form an essential part of the sacred grove (Mgumia and Oba 2003). Sacred groves are particularly useful in places where traditions are upheld and, by this, significant in protecting the biodiversity that lies within them. These traditional beliefs or practices that aid the sacredness of sacred groves vary across different locations. But, generally, they are linked to the history and cultural peculiarity of the people. The local people establish rules that protect the grove, and such rules vary from one grove to another; these often prohibit encroachment into the site; forbid the felling of trees and the killing of animals, but in some cases, it could permit the collection of plant parts for medicine, fuelwood and fodder by local people (Chandran and Hughes 1997). With these restrictions in place, sacred areas are preserved for generations and increase their functions as biodiversity reservoirs and informal conservation sites.

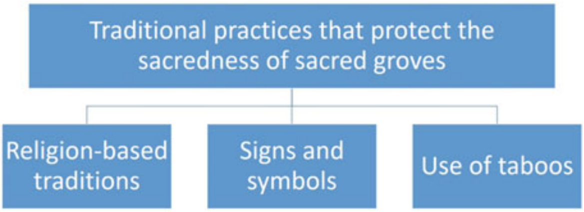

Fig. 20.1 Traditional practices that contribute to protecting the sacredness of sacred groves

Among other means of biodiversity conservation, for example, creating formal conservation sites like national parks and forest reserves, sacred groves appear to be more sustainable in their approach (Cincotta et al. 2000). To a large extent, these formally protected sites can effectively protect biodiversity but cannot prevent human encroachment and degradation of these sites (Brandon et al. 1998). Countries in the Global South are likely to sustain biodiversity conservation successfully if the traditional approach of sacred groves is adopted. Firstly, sacred groves are located in lands with other uses besides protecting forest species (Bhagwat et al. 2005). In other words, aside from preserving biodiversity, the grove is revered by nature for its sacredness. Secondly, formally protected areas exclude the interference of the local people despite huge sums of money and workforce investment (Brown et al. 2006). Lastly, according to North (1990), there is a clear difference between development planning and conservation management strategies of sacred groves and formal protected areas especially in their enforcement and sanctioning mechanisms. This form of protection depends on legal frameworks and many officers to enforce the laws, while community members mainly implement informal nature conservation. The former system is also more expensive, while the latter is carried out voluntarily and costs little to nothing.

Some of the traditional practices that protect the sacredness of sacred groves include the following (Fig. 20.1):

Religion-based traditions: Religion is a powerful tool for influencing people's beliefs. It is beneficial in convincing people through various traditional activities. Many societies have attained their desired objectives via the instrument of religion-based traditions. Religion forms the central belief system that contributes significantly to protecting the forest ecosystem. It aids in disseminating customary norms, practices and beliefs that ultimately install caution on prospective trespassers. Some examples of a religion-based approach that supports biodiversity conservation include sacred groves, sacred species and sacred landscapes. The conservation of biodiversity by sacred groves is hinged on religious practices, strong beliefs and customs. Religious-based traditions prevent removing any material from the grove (Gadgil and Vartak 1975). And as such, the vegetation in the sacred groves is kept preserved in its original form. Sacred groves mainly comprise essential trees that are relevant to religious activities. There are several cited cases where religion-based traditions have aided biodiversity protection. The existence of religious aura protects several sacred groves in West Africa.

Knowing the repercussion of trespassing such sites, local people would cease and prevent others by informing them, especially visitors who might not be aware. In India**,** based on the religion-based practice among the locals living in the Koraput district (Orissa state), the forest has enjoyed protection from a shrine within it, thereby preventing human interference. (Thusu and Jha 1969). In southern India, precisely near Madurai (Tamil Nadu state), part of the people's religious belief is the recognition of specific patterns of tree arrangement as sacred. Wherever that pattern is found, such a site is restricted and assumed to be a holy area. Due to this practice, several forested grove sites have sprung up, providing habitats for birds to roost. The Indian flying fox (*Pteropus giganteus*) is endemic to these sacred groves and has found a protective habitat that prevents hunting for medicine (Marimuthu 1988).

Signs and symbols: Signs and symbols confer sacredness on groves. The emblem awakens people's consciousness on the need to avoid trespassing in the forest. However, the sign and symbols must be linked to a religion to be effective since they are critical identities in the realms of worship. The sacredness is adapted to human beings' perceptual and conceptual faculties in its material manifestation (MacKenzie 1926). The use of signs and symbols to protect the sacred grove has been very effective, especially in places where fetish and diabolic practices are religious. Therefore, signs and symbols associated with such methods could be used as a deterrent factor. Based on the effectiveness of the signs and symbol approach, various stakeholders in the conservation sector have adopted this system to conserve biodiversity. In the Udaipur district, north-western India, the local people have a standard and symbolic practice: sprinkling saffron water around a piece of land. The people assume the approach as sacred and hence avoid trespassing such land. According to Gandhi (1997), following unsuccessful attempts by the local forest department to protect the forest against persistent transgressions by local people, the forest officers decided to sprinkle saffron water around the site. Subsequently, the local people began to respect the conservation area's boundaries. Also, in southern Nigeria, the tying of red and white clothes on land, tree or animals signals that such items are not to be touched or tampered with. The local people believe that such signs indicate a property owned by a deity (Onyekwelu and Olusola 2014).

Use of social taboos: Social taboos are religious customs prohibiting or restricting a particular practice. These rules are used to protect the sacred nature of groves. Most cultures, particularly in Africa, recognize social taboos. These taboos are informal practices that determine the people's behaviour rather than laws (Colding and Folke 2001). According to Barre et al. (2009), the Tallensi-Nabdam district sacred grove and other sacred groves in Ghana are protected by taboos. The adherence to taboo and fear of repercussions, which in most cases are characterized by barrenness and even death, plays a role in preserving the sacred groves. People who do not believe or adhere to the social taboo practice also avoid sacred groves to avoid dealing with traditional authorities (Barre et al. 2009). These restrictions may not be designed for biodiversity conservation; instead, the setting of taboos is primarily aimed at promoting the traditional practices and beliefs of the deity, and this culture is passed through generations (Samakov and Berkes 2017). In Osun-Osogbo groves, south-west Nigeria, tree felling is considered an abomination. However, the Osun goddess offers sacrifices in gifts following any tree felling activities. Thus, the fear of the Osun goddess refrains the people from felling trees within the grove (Onyekwelu and Olusola 2014). In Tanzania and Sierra Leone, sacred groves are protected against over-exploitation by sanctions and taboos associated with some deities. Hence, only certain persons are allowed access (Rajendraprasad et al. 1998) (Table 20.1).

20.5 Ecological Relevance of Sacred Groves

The importance of sacred groves in marinating the forest ecosystem integrity has been reported (Rodgers 1994; Khumbongmayum et al. 2004). Sacred groves provide immeasurable ecological services to various ecosystems by directly sustaining and protecting the diverse biological wealth, balancing the ecosystem, reducing habitat destruction, conserving the viable population of pollinators and predators, protecting the indigenous plants and animals, preserving traditional knowledge and promoting species coexistence. Sacred groves serve as a repository for medicinal plants, crops, wild relatives and many essential species. Because these revered patches of forest that constitute the sacred groves are protected, it creates a natural habitat for species to strive by excluding the impact of anthropogenic factors. Sacred groves promote the ecological integrity of the habitat. It stimulates the sustainable utilization of bioresources that lies therein via the religious and cultural attributes of species present in the grove (Singh et al. 1998). Some of the ecological relevances of sacred groves include the following (Fig. 20.2):

Sacred groves as reservoir for threatened species: Biological species have so far witnessed unprecedented survival threats from several facets, which include the exploitative and unsustainable utilization of bioresources, the climate change impact, anthropogenically induced pollution increase and encroachment of wild habitats by invasive species (Brondizio et al. 2019). The people revere sacred groves due to belief, taboo or religion (Malhotra et al. 2001); these restrictions help preserve the biodiversity integrity of the forest over many generations (Barre et al. 2009). Sacred groves vary in size, and in most cases, their small sizes may limit the potential to accommodate a wide range of different ecosystems. Notwithstanding, sacred groves are renowned for having effectively preserved the biocultural practices of the people (Samakov and Berkes 2017); forest species, notably different species of bird conservation (Brandt et al. 2013); and other rare, threatened and endangered species (Khan et al. 2008). Sacred groves' role in protecting and harbouring a vast diversity of threatened species has been highlighted (Brandt et al. 2013; Samakov and Berkes 2017). They are now recognized as a more practical approach than most conventional protected sites like the national parks and forest reserves. For example, Bhagwat et al. (2005) reported the role of the Kodagu district sacred groves, Karnataka state, India, to protect relict populations of trees such as *Actinodaph nelawsonii, Hopeaponga, Madhuca neriifoli* and *Syzygium zeylanicum*. These tree

Table 20.1 Biodiversity status of selected sacred groves in the Global South

Continental region	Location of sacred groves	Number of sites	Biodiversity status description	References
Africa	*Central Tanzania*: Sacred groves, Wanyamwezi	5	Species richness index of the sacred grove: 25 Species richness index of the adjacent natural forest: 15	Mgumia and Oba (2003)
	Cameroon: Mandara Mountains	1	Species richness: 182	Kemeuze et al. (2015)
	Nigeria:Osun-Osogbo sacred grove, Osun state	1	Number of tree species: 40 Margalef index: 19.20 Shannon-Weiner index: 2.30 Percentage of endangered species: 32.6%	Oladeji et al. (2021) Onyekwelu and Olusola (2014)
	Ghana: Accra Plains	1	Possess higher small mammals biomass (insectivores, bats and rodents) than surrounding areas	Ormsby (2007)
	Ghana: Akwapim North District, eastern region of Ghana	1	Status of bird biodiversity in the groove, number of individuals: 411 Number of representative families: 22 Species number: 66 Status of bird biodiversity in the cultivated forested boundries: 211 individuals of 41 species Status of bird biodiversity in pristine forest: 111 individuals of 36 species Status of bird biodiversity in secondary forest: 89 individuals of 40 species	Kangah-Kesse et al. (2007)
	Ghana: Nkodurom and pinkwae sacred grove	1	Habours significant number of molluscs (*Tympanoto nusfuscatus*) and three unique turtles—Green, dive ridley, and leatherback than areas where the species are not protected	Ntiamoa-Baidu (2008)
	Ghana:Tafi Atome sacred grove	1	The Mona monkey *Cercopithecus* monamona is endemic to the sacred grove	Nganso et al. (2012)
	Ghana:Jaagbo sacred grove in	1	Status of plant species in the grove: Approximately	Nganso et al. (2012)

(continued)

Table 20.1 (continued)

Continental region	Location of sacred groves	Number of sites	Biodiversity status description	References
	northern Tolon-kumbungu		220 Status of plant species in outlying areas: 60	
Asia	*India*: The sacred groves of Purulia district of the state West Bengal in India	87 Sq m 40,200 Sq m [1]	Status of biodiversity: 73 species of insects, 35 birds species and 47 species of plants from 36 sacred groves	Das et al. 2015
	Himalayas: Kumaon	1	Species richness: 64	Singh et al. (2012)
	China: Xishuangbanna hills	28	Species richness: 268	Liu et al. (2002)
	India: Cuddalore, Pudukkottai and Villupuram districts	75	Species richness: 312	Udayakumar and Parthasarathy (2010)
	India: TDEF, Tamil Nadu, Sivaganga district	4	Species richness: 106	Sundarapandian and Subbiah (2015)
	India: Jaintia hills, Meghalaya	3	Species richness: 315	Jamir and Pandey (2003)
	India: Midnapore district of West Bengal in India	1	The sacred grove houses about 277 plant species, distributed in 238 genera	Sen and Bhakat (2019)
	India: Sacred groves in south-western districts of West Bengal	1	Number of tree species (diversity) = 50	Malhotra et al. (2001)
	India: Sacred groves of Kodagu district of Karnataka	1	The grove shelters a huge diversity of fungi species, particularly the macro types of 163 species of macrofunga that are found in the grove, 49 species are endemic to the grove	Brown et al. (2006)
	Northeastern India: Meghalaya	3	The grove houses a total of 395 plant species, of which, 14% are endemic to the grove	Jamir and Pandey (2003)

species are classed as threatened species and were not found in the formally protected areas. In addition, the Kodagu district's sacred groves are home to a high diversity of macrofungi species. It is estimated that of the 163 species recognized, 49 are present in the grove (Brown et al. 2006). Sacred groves have also been reported to harbour more woody species richness and taxonomic diversity in sacred sites than the state-managed forest reserves (Mgumia and Oba 2003). In central Tanzania, Mgumia and Oba (2003) found that sacred groves harbour a significantly

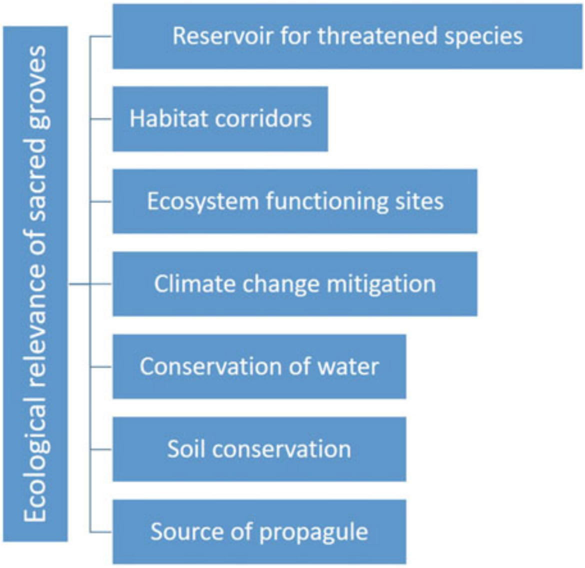

Fig. 20.2 The ecological relevance of sacred groves

greater woody plant species richness than in a state-managed forest reserve. Also, in Nigeria, the OsunOsogbo grove was located to have the highest species richness and harboured a higher count of endangered species compared to both degraded and primary forests in south-west Nigeria (Onyekwelu and Olusola 2014). The sacred riparian groves of the coastal regions of Karnataka state, south-west India, are renowned for harbouring unique members of the nutmeg family, rarely found in officially protected areas, mostly *Myristica fatua* and *Gymnacrantheracanarica* trees (Chandran and Mesta 2001).

Sacred groves as habitat corridors: One of the consequences of habitat fragmentation is that it creates disintegration of habitat areas resulting in plants and animals losing their natural habitat and the ability to access and use all of the resources they need to survive (Samakov and Berkes 2017). Habitat corridor connects wildlife populations separated by anthropogenic activities such as roads, settlement sites and logging. Sacred groves are tracts of virgin forests that provide a respite for habitats faced with anthropogenic disturbance. The conservation success of the sacred grove is attributed to the local people's perception of the site, the fear and respect of god (s) and the fear of negative consequences for violation of rules/taboos (Onyekwelu 2021). Sacred groves can also provide habitat corridors for the free movement of organisms between two disturbed forest habitats (Decher 1997). Hence, sacred groves may potentially moderate biodiversity loss, particularly habitat fragmentation (Wadley and Colfer 2004).

Ecosystem functioning site: Sacred groves create a near-pristine ecosystem habitat that promotes biodiversity conservation through their protective mechanisms. These groves are essential reserves of floral and faunal diversities and the other microorganisms that interact with the abiotic factors to preserve the unit's integrity.

An ecosystem is an autonomous unit. Consequently, every part of it, whether biotic or abiotic, plays a role in the overall well-being of the system. Increased deforestation rates and depletion of forested ecosystems have led to the loss of valuable species of plants and animals and created vacuums for productivity that could have helped maintain the healthy, balanced nature of the ecosystem (Singh et al. 2012). Research has shown that the soil nutrient level of a forest remains relatively constant over seasons as long as the vegetative composition and structure of the forest remain constant. However, when the vegetation is upset by way of forest depletion, as in the case of the conversion of forests to farmlands, there is usually a drop in the nutrient level following seasonal cultivation of the land. Each species plays its role in the forest ecosystem, maintaining soil fertility. Therefore, the transformation of a forest with abundant species to monotypic plantation results in loss of species, for example, detritus species, pollinating species, microorganisms, and many more, which, singly and together, play vital ecological roles in the ecosystem.

Climate change mitigation potentials: Sacred grove also offers an avenue for indirect ecosystem services by acting as a climate change mitigating agent, for example, the possession of carbon sinks (Kandari et al. 2014). However, more research needs to be carried out to estimate the carbon sequestration potential of the sacred groves and how the components of the forest contribute to the ultimate prospects of climate change mitigation. A few reports have attempted to address the carbon sequestration potential of selected tree species; for instance, Hangarge et al. (2012) reported the possibility of *Terminalia bellirica India glauca* and *Ficus amplissima* to sequester carbon. Since sacred groves possess thick vegetation comprising trees that have stayed relatively long enough, there is a strong possibility for these plants to have a high carbon sequestration potential, thereby contributing to reduced concentration of CO_2 in the atmosphere (Hangarge et al. 2012).

Conservation of water resources: Sacred groves can help protect the integrity of watershed resources like springs, lakes, rivers and ecosystem processes such as nutrient cycling. Most sacred forests are often associated with ponds, streams or springs, which help meet the water requirements of the local people (Chandran and Hughes 1997). The vegetative cover of the sacred grove helps recharge these aquifers (Parthasarathy and Babu 2019) and increases the nutrient recycling potentials of the microclimates associated with these ecosystems. For example, in the Nakuleshwar sacred grove of Pithoragarh district, Uttarakhand, the dense forest forms plenty of land around the perennial water stream. It provides the essential water requirement to the villagers and other people living in the vicinity of the sacred sites. In the Western Ghats, most sacred groves are linked with perennial streams that are essential water resources for surrounding communities throughout the year (Chandran and Hughes 1997).

Sacred groves promote soil conservation: Sacred groves create vegetation that helps preserve the fertility and properties of the soil. The soil components like soil organisms are likely to be protected. By so doing, the soil component of sacred groves has the original strain characteristics of the living system of the soil and therefore can be used as a source of forest soil restoration.

The sacred grove is a source of propagule: The capacity of the sacred groves to harbour rare, threatened and endemic species have been extensively reported (Parthasarathy and Babu 2019). Like other sacred places in nature, often sacred groves stand out as vegetation-rich ecosystems compared to their surroundings. Therefore, sacred groves can also serve as a seed source for the ecological restoration of degraded landscapes.

20.6 Roles of Sacred Groves in Biodiversity Conservation

The need for biodiversity conservation has been emphasized among concerned authorities, from local, national and even regional. Although several strategies have been tested, it has now been observed that biodiversity conservation requires more than just formulating policies but a more people-inclusive approach for proper management. Though a rather ancient technique, scattered groves seem to be most effective in protecting the natural dwelling habitats of species. Irrespective of size, the continuous existence of the sacred grove enables it to act as an ideal centre for biodiversity conservation. Because various rules limit bioresource extraction from the forests.

Sacred grove plays a vital role in protecting components of biodiversity, some of which are threatened. These holy groves have a rich repository of plant species, and the species diversity is much higher than in the adjoining forest areas and in most cases results in the development of relict patches of climax forest (Anthwal et al. 2010).

Several studies have emphasized that many sacred groves are repositories of rare species. Haridasan and Rao (1985) found 50 endangered and rare species in the sacred groves of Meghalaya. Other arguments support the significant roles of sacred groves in conserving rare and highly vulnerable species. According to Mukhopadhyay and Roy (2015), the sacred grove provides microclimatic conditions for the luxuriant growth of those plant species not present in the surrounding areas at the same altitude.

Studies have shown that sacred groves are primarily not intended for biodiversity conservation or a science-based natural resource management strategy (Vipat and Bharucha 2014). However, biodiversity conservation of groves is thus a by-product of a traditional belief of locals in the supernatural power of the forest deity. Several threatened plants and animals in the forest are still well conserved in some sacred groves (Khan et al. 2008). The support and cooperation from the local people in maintaining the sacred grove status are reasons for its perpetual existence and success. As a result, the sacred grove can protect the local biodiversity in areas where it would be impossible to preserve the forest using other conventional means. Hence, several habitat types such as coastal, cultivated, forest, garden, lakes, montane, riparian, savanna and woodlots have been protected. These habitats harbour wild relatives of domesticated and cultivated plants whose usefulness goes beyond the immediate. In a study by Kühnert et al. (2019), to assess the potential of sacred groves to conserve distinct bird assemblages within the Afrotropical savanna, sacred groves were valuable in protecting different avifauna, and their conservation may therefore be crucial for forest specialist species and the re-establishment of bird assemblages in fallow riparian areas. The Western Ghats' sacred groves are characteristically small patches of forest that support a rich source of fruit-bearing trees and act as a habitat for several birds and reptiles (Chandran et al. 1992).

The importance of sacred groves in conserving biodiversity is even more efficient than conventional protected sites, according to Chape et al. (2005). Areas used as protected sites exclude certain critical species because they are often located on land with no other use. Brandon et al. (1998) opined that the management of protected areas is often ineffective in preventing human encroachment. These shortcomings, amongst others, give credible support to the sacred grove, which is the hallmark of the traditional concept of biodiversity conservation. Sacred groves serve as a repository for rare and endemic species; for instance, the climbing legumes *Kunsteria keralensis* and *Belpharisterm mamembranifolia*, *Buchanania lanceolata* and *Syzygium travancoricum* have only been reported from a sacred grove in southern Kerala (Nair and Mohanan 1981). The Kumta taluk, Karnataka, despite its location in a highly populated village, is rich in endemics like wild nutmegs (*Myristica malabarica*), *Cinnamom ummalabathrum*, Garciniagummi-gutta and wild pepper. *Petiveria alliacea*, an endangered medicinal plant, has been reported from the sacred grove of Kanyakumari as reported by Sukumaran and Raj (2007).

20.7 Contemporary Approach to Biodiversity Conservation in the Global South that Integrates the Efforts and Systems of Sacred Groves

Indigenous communities where most sacred groves are located are characterized by the close interconnection with nature and natural resources with positive emergent properties and feedback. In contrast, their ecosystems and biodiversity sustain themselves through a dynamic balance of non-linear cycles and fluctuations (Anthwal et al. 2010). The importance of sacred groves as a tool for in situ biodiversity conservation as well as sites for ecosystem preservation relies on their distribution and their potential roles as reservoirs of local biodiversity, especially of rare, endangered and threatened species (Laird 1999). Indigenous people's traditional ecological knowledge and perceptions define their values, worldview and environmental ethics. Adopting and incorporating these views into modern and emerging protected area establishment rationale and planning, as well as in the purpose, management systems and actors, financing strategies, connections, and biodiversity and nature assets valuation can provide a contemporary holistic approach for biodiversity management in the Global South that includes sacred groves. This system also emphasizes the ecological services of sacred groves and informs stakeholders, including local people, about the conservation relevance of groves, which is crucial for their sustenance (Khan et al. 2008). This view is also supported by Bhagwat et al. (2005), wherein they suggested a landscape approach to biodiversity and ecosystem conservation within sacred groves. The study noted that the landscape surrounding the sacred groves influenced their biodiversity and recommended that native tree cover and associated practices be retained. Moreover, to build on this contemporary approach, there is a need to undertake the following within sacred groves in the Global South:

Documentation: Documenting the state of sacred groves in light of the modern and emerging protected area models. Books and literature should be written and popularized about these sacred groves in the Global South.

Socio-scientific survey: Socio-scientific survey and explorations should be undertaken to record the biodiversity and natural systems protected by the sacred groves. This approach will strengthen the role of sacred groves to act as protected areas.

Integrate traditional knowledge and practice into modern biodiversity conservation systems: Incorporating current views into traditional knowledge and practices that have sustained these sacred groves for thousands of years to make them more appealing to the younger generation. Most of these unwritten and orally transmitted mores regulate human behaviours and discourage the participation of particular groups of people within and from outside the community. For instance, restricting women and girls' access entirely during a specific time of the month should not be encouraged. After all, religious beliefs, tradition, and culture are the products of logical internalization of human experiences and lessons (Singh et al. 2017).

Economic benefits: Increase the financial benefit of sacred groves. Encourage and efficiently manage the use of specific resources within the sacred groves. However, rare and threatened biodiversity should be protected at all costs so that sacred groves can keep acting as a genetic reservoir. An example is the practice of ethnobotany in Africa and Asia. In ethnomedicine, the ability to treat the ailment and bring respite to residents is believed to have been vested in the plants by gods, goddesses and other deities (Osawaru and Ogwu 2014a, b; Ogwu et al. 2017). The preservation of the groves ensures the availability of these natural resources used in ethnomedicine.

Feasts and festival celebrations: Festivals and feasts should be celebrated, and where they have been abandoned should be brought back. These will help reaffirm the commitment of indigenous communities and people's devotion to a deity associated with the sacred grove. Evidence of the benefit of this practice is the celebration in India of Navratri, Shivratri and Holi, which are related to specific biodiversity. The tourism from such feasts and festivals can contribute to socio-economic development.

20.8 Conclusion

To improve the dwindling appreciation of the roles of sacred groves in protecting the unique biodiversity and natural resources of the Global South, there is a need for external support to improve the largely degraded and unkept conditions of these groves. There is proof that sacred groves can contribute to in situ conservation and serve as a refuge for some species. Still, there is a need for inventory of all existing sacred groves in the Global South and for government to declare these groves as biodiversity and ecosystem preservation and protection sites and integrate them into modern conservation systems as an extension of the current community-based conservation of biodiversity (Mgumia and Oba 2003).

There is a need to address the lack of awareness of the long-term challenges of neglecting and or destroying sacred groves in the Global South, especially from international organizations set up to manage and protect sacred groves. Specifically, these international organizations should work with indigenous communities, local, regional and national governments and non-governmental organizations to institute relevant environmental laws to halt the neglect and destruction of sacred groves in the Global South. Together, they can promote sustainable practices, stop the encroachment of these groves and educate the populace about the benefits of sacred groves as repositories of biodiversity genetic resources. In the opinion of Singh et al. (2017), sacred groves are victims of deteriorating faith and belief systems in indigenous communities within the Global South. However, integrating faith with broader aspects of human life and societal needs might contribute to indigenes' and denizens' preservation of this biodiversity haven. This approach might have a significant impact, as documented by Anthwal et al. (2010) when they noted that the increased threats to sacred groves might be linked to a lack of an in-built conservation approach, effort and system, higher demands for non-timber forest products, fuelwood extract, and a decrease in the religious value and spiritual philosophies along with reduced commitment on the part of present generation towards natural sacred places. In addition, the following may be instituted to strengthen the contemporary management approach for sacred groves in the Global South:

1. Establish, train and retrain sacred grove corps with a specific mandate to protect biodiversity.
2. Stakeholders or board of trustees from within and outside the community where the sacred groves are domiciled.
3. Compliment in-situ biodiversity management of resources within the sacred grove with a viable ex-situ facility located near or within the sacred grove.
4. Capacity building within local communities where sacred groves are located and conducting regular awareness programmes.
5. Adoption and regular update of management practices aligned with global rules and standards.

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Chapter 21
Forest Conservation Strategies in Africa: Historical Perspective, Status and Sustainable Avenues for Progress

O. Imarhiagbe, I. I. Onyeukwu, W. O. Egboduku, F. E. Mukah, and M. C. Ogwu

Abstract African forests are endowed with rich forest biodiversity due to their strategic positions on the global map. These forests comprise a variety of ecosystems ranging from tropical rainforests, deciduous woodlands, savannah belts, coastal, montane to desert. However, some challenges in the region, particularly climate change, poverty, invasive species, deforestation, population increase, human encroachment, landuse changes and diseases outbreaks, have significantly led to a continued loss of forested areas in the continent. The forest conservation strategies so far adopted by representative countries have gone through several phases over the years, from precolonial through colonial to the postcolonial era. Efforts to ensure the sustainability of this rich heritage have often been erratic and unsuccessful due to alternating policies installed by traditional rulers and political dispensations. Through all these travails, the forests have always been impacted with short and long term ecological and evolutionary legacies. However, the relative impacts of several forest conservation policies on the sanctity of African forests are yet to be evaluated. By synthesizing information from both published and unpublished materials, the current chapter re-examines issues emanating from the historical account of

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forest conservation in Africa as well as contemporary approaches and proffers optimal conservation strategies for African forests.

Keywords Sustainable policies · African forest resources · Forest biodiversity · Phytogeography · Conservation · Biodiversity management

21.1 Introduction

African forests are endowed with rich biodiversity due to their strategic position on the global map (Gibson et al. 2011; Catarino and Romeiras 2020). These forests comprise a variety of forest ecosystems ranging from tropical rainforests, deciduous woodlands, savannah belts, deserts, etc. The distribution of African forests varies from one subregion to another, with Central Africa having the densest cover whereas the southern and northern subregions possess Namib and Sahara deserts, respectively, with minor forest covers (Gondo 2010). The benefits of African forests range from cultural value to socio-economic development and environmental protection of the continent. The forest serves as raw materials for industries globally, a storehouse for medicine (Dike and Obembe 2012), food, energy and shelter and provides a critical buffer against global climate change (Ogwu et al. 2016, 2019; Katerere et al. 2009; FAO 2016).

In recent times, threats to forest conservation in Africa have increased exponentially and exacerbated by weak management systems. Other threats to the conservation of African forests and their sustainable utilization include climate change, population growth, invasive species, pollution, unsustainable and overharvesting, agriculture, natural disasters, etc. (Ikhajiagbe and Ogwu 2020; Ogwu et al. 2014; Osawaru and Ogwu 2014). However, Ladle et al. (2011) recognized and classified these factors into external, proximate and internal drivers of forest loss in Africa. On the other hand, accelerating urbanization, exponential increase in population growth, agricultural expansion, poverty and increasing demand for forest products for survival and revenue were included in Onuche (2010) and Ogwu (2019) as the contemporary drivers of forest and forest resource loss in Africa. The forest conservation strategies so far adopted have gone through several phases over the years, from precolonial through colonial to the current postcolonial era. Related mechanisms, such as the traditional protective approach for sacred groves and related sites, were used to protect African forests during the precolonial period. These forests were believed to house local deities and evil spirits; hence, only the chief priest and brave warriors could access them (Aigbokhan 2016). However, in the nineteenth century, the colonial administrators initiated wildlife conservation systems that are foreign to the continent (Munro 2021) to mitigate the deforestation of African forests. In an attempt to conserve the African forests, the postcolonial period has witnessed the creation and increase in the number of national parks and other protected areas that are enshrined in laws and protected by policies (Lamprey 1969).

Moreover, efforts to ensure the sustainability of this rich heritage have often been erratic and unsuccessful due to alternating policies installed by traditional and political dispensations. Through all these travails, African forests have always been impacted with ecological and evolutionary legacies. However, the relative impacts of several forest conservation policies on the sanctity of the African forest is yet to be evaluated. There is a need to develop strategies to balance the effects of current forest conservation systems and approaches by incorporating traditional mechanisms to have an optimal conservation system for Africa by Africans. The chapter examines issues emanating from the historical approaches to forest conservation in Africa as well as contemporary practices, status and challenges affecting African forests and forest resources. Finally, the chapter proffers what may be considered optimal conservation strategies for African forests and forest resources to contribute to the sustainable development of the entire region.

21.2 The African Forest: Biodiversity Richness and Diversity

The forests of tropical Africa has many unique features that distinguish it from other tropical landmasses (Catarino and Romeiras 2020). The forests are characterized by high species endemism, which may be attributed to the geographical location, topography and climatic history of the continent (Munro 2021). However, there are contrasting reports on the diversity of the African forests compared to other tropical regions of the world. Brenan (1978) described the African flora as not rich and often more noteworthy for its floristic poverty. In his opinion, the present distribution of flora in the continent could be attributed to spectacular disjunctions in floristic distribution, islands of floristic similarity and close affinities among species now widely separated geographically amongst others. Little wonder, Richards (1973) considers tropical Africa as phytogeographically an 'odd man out' compared to other tropical areas of the world because certain species well represented in other low areas of the world were largely absent in the tropical forests of Africa. For example, plant families like Theaceae, Myrtaceae, Melastomataceae, Lauraceae and Arecaceae were much more poorly represented than they should be (Brenan 1978). However, the climatic history of Africa has produced a more diverse flora that comprises different forest types (White 1993). The geographical analysis of the African flora reveals four major groups, namely the evergreen sclerophyllous forest, which runs along parts of Northern Africa bordering the Mediterranean, the tropical dry forest and woodland, the humid tropical forest and various disjunct areas of montane forests (Linder 2014). The number of higher plant species present in Africa is between 40,000 and 45,000 in 29 million km^2 (Klopper et al. 2007), while approximately 90,000 species are present in 17.84 million km^2 in South America and 50,000 in 3 million km^2 in tropical and subtropical Asia (Davis 2005). Notwithstanding, Africa's forest is botanically more recognized than others (Pottinger and Burley 1992). Linder (2001), using a simple grid-diversity count, quantitatively estimated the location of centres of species richness and endemism in the sub-Saharan African flora, indicated the Mt. Cameroun area as the most diverse in tropical Africa and it is closely followed by the East African coast. Other regions with considerable rich flora include the high countries ranging from Mwinilunga (Zambia) in the west to Songea (southern Tanzania) in the east, the Kivu centre in the eastern Congo, the West African region of Sierra Leone and Liberia (the 'Upper Guinea centre'), the eastern highlands of Zimbabwe, the adjacent escarpment mountains in Mozambique and the Cape Floristic Region.

21.3 Phytogeography of the African Forests

Biogeographers have always been enthusiastic about understanding the evolution of the African flora diversity and phytogeography. The likes of Good (1974), Schnell (1977), White (1965); Chapman and White (1970); and Wickens (1976) gave different postulates, each attempting to define the phytogeography of the African flora. White (1983) extensively characterized the vegetation of Africa based on endemism, or phytochoria. In this regard, the major forested regions in Africa are listed below (Fig. 21.1). Some of these regions are discussed below:

21.3.1 The Guinea-Congo Region

The Guinea-Congo region is considered the richest tropical rainforest in Africa in terms of tree species. It extends southwards to Angola and eastwards to Ruwenzori; the three domains which make up the Guinea-Congo region include Guinea Domain which extends along the northern coast of the Gulf of Guinea from the Gambia to central Nigeria, Congo Domain comprises a rich area in endemism (i.e. the Guinea-Congolian regional centre of endemism) that extends from eastern Nigeria to Angola and Congo, and the Usambara-Zululand Domain which contains scattered relics of rain forests along the east coast of Africa extending from southern Kenya southwards into South Africa. This region includes the Congo rainforest with old-growth forests and enormous diversity.

21.3.2 The Sudan-Zambezian Region

The Sudan-Zambezian region is considered the largest in tropical Africa, corresponding to tropical savanna extending to north and south of the equator but physically continuous only by a narrow comparative isthmus in East Africa. The Sudan-Zambezian domain is further characterized into different domains based on the nature of plant species associated with these domains. The domains include the region comprising the *Sahelian Domain* that stretches from Mauritania and Senegal on the Atlantic to the Red Sea coast of the Sudan Republic, the Sudanian Domain which extends from Senegal to Sudan, the floristically rich Afroriental Domain, the

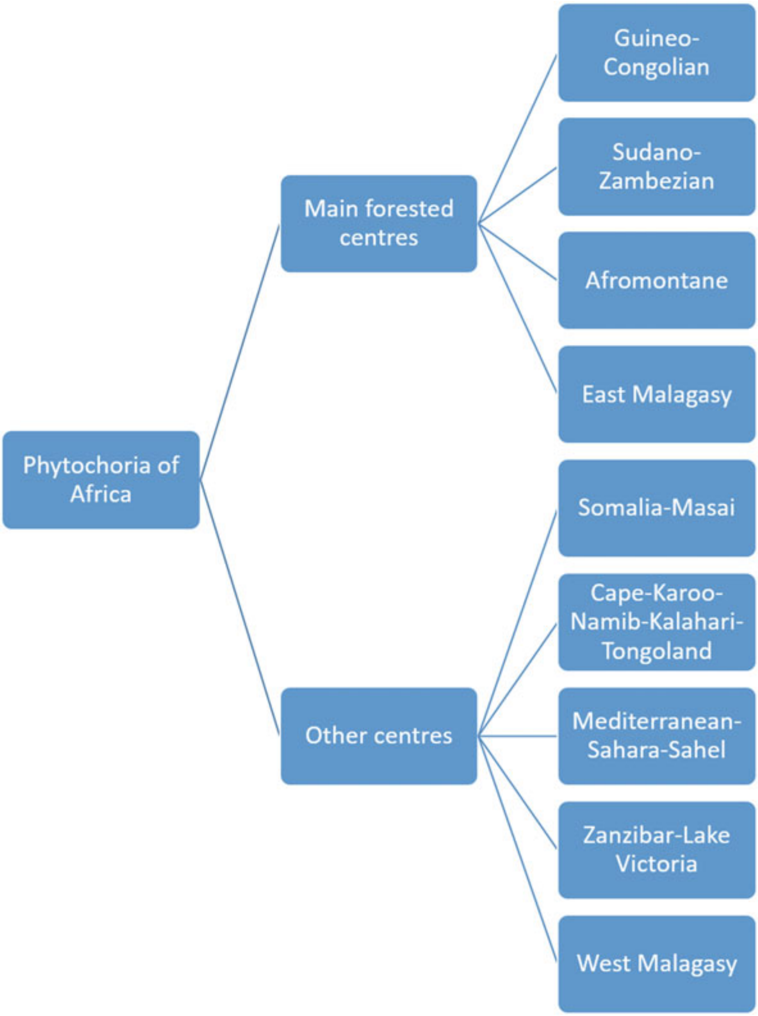

Fig. 21.1 Main phytochoria of Africa

South Arabian Domain that extends the Afroriental Domain, leading into southwestern and southern Arabia, and the Zambezian Domain. The Sudan-Zambezian region is characterized by various vegetation types, from poor thorn scrub to rich deciduous woodland, reflected by a strongly seasonal climate.

21.3.3 The Afromontane Region

The Afromontane region comprises discontinuous areas that are largely separated from each other by lower lying areas. It is similar to the tropical African mountain regions' Montane Forest and Ericaceous belts but further extends southwards to Malawi and westwards to Cameroon and West Africa.

21.3.4 East Malagasy Region

East Malagasy region comprises the humid and evergreen forests of Madagascar. Also called the Madagascan region with unique forests that have island-defined species richness and diversity patterns and endemism. The characteristics (biogeography and evolutionary properties) of this region are not well understood but are likely the outcomes of defining stochastic events from the Oligocene era to date.

21.4 Historical Perspectives of Forest Conservation in Africa

African forests, from time immemorial has witnessed several conservation approaches aimed at ensuring their continuous existence. The conservation of African forests originated from an indigenous system through colonization influence to the present-day status that seeks to implement the most reasonable means of sustaining the forests, following the lessons learned from the previous approaches**.** Before the colonial period, the traditional belief systems in Africa were significant in protecting the African forest (Martin 1991). The people had a strong reverence for their forests even though the people lived and dwelled amid the forest. The traditional belief system varied across the different cultures in Africa and even with the cultural differences, there appears to be a holistic mechanism that effectively conserved the forest. In parts of West Africa, several cultures considered particular forests as evil forests for evil forces inhabited them, and people who mysteriously died were thrown into them. The evil forest that contain notable plant species used for healing and sacred religious rituals are generally preserved and not destroyed (Martin 1991).

Based on the African perception of reality, life is seen as one that is interconnected with man, where all things come from God (Maguire 2000). According to Sindima (1990), the African concept about the Earth is life-centred, and a world in which existence is interconnected. This is further supported by Ehusani (1991) that the perception of Africans about the world is believed to be the one that places humans at the centre along with the universe been controlled by a sacred religious order that should not be disturbed. According to Maguire (2000), African culture is environmentally safe for all; animals, plants and even humans. In the strictest sense, the locals perceived the African forest as the source of life. As put forth by Burnham (2000), the forest is a communal heritage from the ancestors of the African people and was controlled by the town elders and chiefs for the entire community's well-being. In some other cultures, the forest was believed to be the dwelling place of evil spirits. Hence, only chief priest and the brave could access the forest in search of medicinal herbs and for hunting animals (Aigbokhan 2016). The trees or forested areas with special significance to the gods were set aside as sacred groves. The perception of the African indigenous people is that the sacred grove is a site that for local deities with rules and regulations governing every member of the community and non-members. This practice was well adhered to and has enabled the sacred groves refugia for rare and endangered species that may not be found in formally protected areas.

21.5 Current Approaches to Forest Conservation in Africa

Before the adoption of current policies to stem forest destruction, drop in quality and quantity of African forests and aligning it with sustainable global forest management approaches, traditional means like culture and religion played significant roles in protecting forest areas in an approach that may be described as informal community-based management. It was considered a 'taboo' to cut down certain tree species, let alone destroy or encroach forest areas without prior approval from the community or appointed representatives within or from the community. These practices were effectively carried out in some parts of Africa, particularly West Africa (Martin 1991). The arrival of the Europeans to Africa resulted in a change of the original forest protection methods to a policy-controlled approach. The Europeans were mainly interested in the forest resources of Africa as reported by Martin (1991), in contrast to the distance between the rainforest of West Africa and the principal harbours of the major European countries were much closer than the rainforests in Latin America and the forests of Southeast Asia. This consideration influenced the choice to establish trade relations with Africa (Martin 1991). This subsequently led to commercial exploitation, which began with salve trade and later, the extraction of African forest resources, particularly in West Africa where economic native tree species like *Daniella, Funtumia*, and the establishment of plantations in attempts to increase export of agricultural products (Munro 2021). Consequently, it suffices to say that deforestation in the strict sense was introduced to Africa by the colonial masters who at that time were business merchants of African forest resources. According to Martin (1991), 'Europe Casts its Spell upon the Rainforest of West Africa'. In a bid to stem the spate of deforestation of the African Forests, wildlife conservation was initiated by the colonial administrators in the late nineteenth century (Munro 2021). The system led to the creation of protected areas in the form of forest reserves and national parks which were designed to serve the recreational needs and economic interests of expatriate whites, settler communities and foreign tourists (Crush 1980). The postcolonial period has witnessed the growing number of national parks and other protected areas which has provided Africa with a powerful impetus for devoting increased attention and funding to the preservation of natural African habitats and the conservation of indigenous floral and faunal stock (Lamprey 1969).

Among other means of forest protections such as forest reserves, community forest, private forest, plantation forest and the national park model form the cornerstone of biodiversity conservation not just in Africa alone but across the globe (Imarhiagbe et al. 2020). Since the creation of the Virunga National Park, in the Democratic Republic of the Congo around 1925, the oldest national park in Africa, the number of national parks in Africa has continued to increase. On a regional basis, East Africa has the highest number of national parks while Southern Africa has the least (Table 21.1). In terms of the areas of protected space of the national parks, Central Africa has the highest while Southern Africa has the least (Table 21.1). Apart from the numbers and areas of the protected space that vary between countries and regions, the degree of protection and accessibility also vary. In essence, different countries sustain the protected areas by setting policies and regulations in the form of laws to ensure the sustainability of the protected areas. Although the majority of these policies look feasible and effective, there are however challenges in implementation due to several factors such as corruption on the part of government officials, policy alienation, especially towards the locals who feel the forest has been forcefully taken away from them, and sometimes, insincerity on the part of policymakers to incorporate the concerns of all stakeholders, objectively, is also a major factor.

21.6 Actual and Emerging Benefits of the African Forests

Apart from providing export resources to the Western world, African forests also form a veritable base from which a substantial proportion of the populace derive their source of livelihood. The majority of countries in Africa rely on forest resources to build a capital base for economic development. For instance, the forestry sector ranks among the highest revenue and employment generating sectors in West Africa (Onwubuya et al. 2014). The forests serve as raw materials to the industries, providing employment opportunities to thousands of people. Apart from timber resources, the forest is also very rich in various non-timber products that provide food, medicine, energy, shelter and recreational facilities for people in rural and urban centres in West Africa (Ikhajiagbe et al. 2020). The forests and trees also provide a way to express human, cultural and spiritual values. In recent times, the value of the African forest has been further appreciated. It sustains the local economies of countries harbouring it and acts as a storehouse for rare, endemic plant species of the African continent. Some of the actual and emerging benefits of African forests that should motivate sustainable conservation and management strategies include the following (Fig. 21.2).

Table 21.1 Current status of the numbers and estimated areas of protected forests (national parks)

Regions	Representative countries	Total estimated size of protected area (Km^2)	Estimated number of national parks	References
North Africa	Morocco, Algeria, Libya, Egypt, Sudan, Tunisia	176,315.68	48	Djamel et al. (2014); Humphrys (2010); Davies (2009); van Hoven and Mutasim (2004)
West Africa	Mauritania, Cape Verde Benin, Senegal, Guinea Bissau, The Gambia, Guinea, Sierra Leone Liberia, Cote d' Ivoire, Mali, Burkina Faso, Ghana, Togo, Nigeria, Niger	194,832.45	61	Kitchener et al. (2017); Catarino et al. (2017); UNDP/GEF (2005); Madsen et al. (1996); UNEP-WCMC (2020a, b); Sheku and Edward (2009); UICN/PACO (2010); Imarhiagbe et al. (2020); Stuart et al. (1990)
East Africa	Eritrea, Seychelles, Djibouti, Mauritius, Ethiopia, Comoros South Sudan, Somalia, Kenya Uganda, Tanzania, Malawi, Mozambique, Madagascar Zambia, Zimbabwe	290,311.77	143	Mauambeta (2010); Timberlake et al. (2016); Fanshawe (2010); Burgess and Clarke (2000), Critical Ecosystem Partnership Fund (2014); Ferguson-Lees and Christie (2001); Ham and Bainbridge (2010)
Central Africa	Chad, São Tomé and Príncipe, Cameroon, Central African Republic, Democratic Republic of Congo, Republic of Congo, Rwanda, Burundi, Equatorial Guinea, Angola, Gabon	335,910.00	61	Brundu and Camarda (2013); Mesmin et al. (2001); Bouché et al. (2010); UNEP-WCMC (2020a, b); Barakabuye et al. (2007); Üllenberg et al. (2015); Barnett et al. (2018)
Southern Africa	Botswana, South Africa Namibia, Lesotho, Swaziland	135,737.94	35	IUCN Cat Specialist Group (2006); Chris (2008); Helgren (1984); Cooke (1980)

21.6.1 African Forest Is a Source of Revenue

The African forest harbours a substantive amount of bioresource that, if well harvested sustainably, can help reset the fortunes of Africa from the current state comprising mainly of underdeveloped and developing countries to represent the most developed countries of the world. The African forest has always been a source

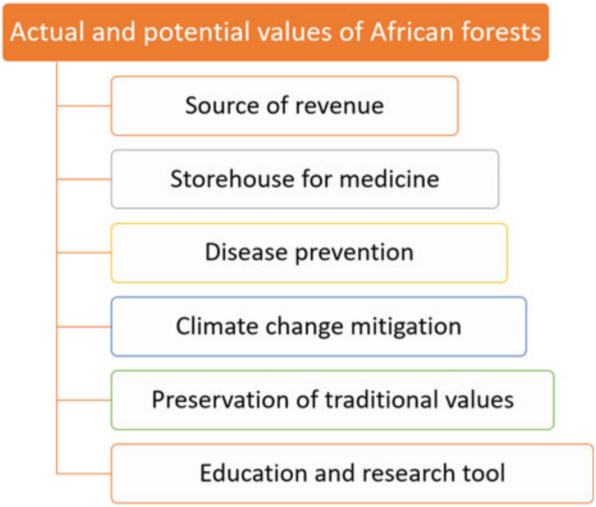

Fig. 21.2 Some actual and potential values of African forests

of raw materials extraction for the Western nations since the colonial era. To date, the value of the African forest has only been appreciated**.** Africa's forests hold tree species and valuable woods to the international market (Ogwu et al. 2016a, b, c; Ikhajiagbe et al. 2020). This has further exacerbated the rate of forest depletion in Africa. Hence, if Africa uses the forest for much economic gain, it must approach the harvest of these resources in a sustainable, environmentally friendly way. For instance, from 2000 to date, the rosewood from Africa has increased over 700% (Treanor 2015). The rosewood is valued as the traditional material for antique future and décor. It was traditionally found in Southeast Asia, but these forests have already been depleted. Other precious African trees valuable to the world market include Moabi—*Baillonella toxisperma* (used in oil and furniture making), Mukula—*Pterocarpus chrysothrix* (an exceptional hardwood native to Zambia), Afrormosia—*Pericopsis elata* (used for construction and furniture making), wenge (used for drum, canes and panelling), Okoume—*Aucoumea klaineana* (used for boats and guitars), Sapele—*Entandrophragma cylindricum* (used for doors and musical instruments), iroko—*Millettia laurentii* (used for boats and furniture) (Treanor 2015). Many of these products are a common sight in traditional markets within the region (Osawaru and Ogwu 2020; Ogwu 2020).

Forestry activities and operations of the forest industries offer many job opportunities. Therefore, African forests considered sources of forest-based employment are many and diverse. Sawmills are the most widespread forest-based industries and one of the largest employers of rural labour. The integrated wood industries that offer employment to rural people include the Plywood and Veneer Mills, particularly mills and furniture factories. Aside from timber, African forest provides non-timber forest products, such as the industrial roundwood and pulpwood extracted from the forest.

21.6.2 *Africa's Forests Are a Storehouse for Medicine*

From time immemorial, the African forest has been renowned for harbouring many plant species that possess medicinal properties. Apart from the tree diversity associated with the rainforest region of Africa, the large expanse of the savanna region is home to numerous medicinal plants. According to Dike and Obembe (2012), the vegetation cover of the African Savannah is recognized to be endowed with various medicinal plants. Consequently, a large number of Africans extract these plants for medicinal purposes because they are reservoirs of curative elements in the treatment of various diseases ranging from malaria, diabetes, mental disorders, cancer and hypertension to HIV and AIDS (Cunningham 1993). At the domestic level, anyone with the knowledge of traditional medicine can venture into the forest to harvest plants with medicinal potentials to cure various ailments. These are mainly the parts of plants that possess healing properties, including root, stem bark, leaves and inflorescence. The reliance on traditional medicine in Africa is alarming. Over two-thirds of Africa's 600 million people rely on forests for their livelihoods (Somorin 2010). Also, an estimated 70–80% of people in Africa consult traditional medical practitioners for healthcare (Cunningham 1993). However, this is not surprising considering the poverty level and the high cost of using the orthodox medical facility. However, on the other hand, the African forest is pressured for plants that possess unique secondary metabolites that could be useful to the big international pharmaceutical companies in manufacturing drugs. This trend has further exacerbated the depletion rate of the African forest, an act that has been on since the colonial era. Hence, the need for sustainable management of African forests.

The diversity of the African forest translates to the huge medicinal properties of the plant that lies within it. In many instances, the African forest has provided herbal concoctions that can potentially remedy several diseases that plague the world. For example, in searching for solutions to the novel Coronavirus, several African plant species were proffered as potential start materials in developing vaccines and suitable cures. According to Attah et al. (2021) and Erinle et al. (2021), some of these indigenous plants used in sub-Saharan Africa as antiviral remedies with potentials for the prevention and management of COVID-19 include *Azadirachta indica, Allium sativa, Mangifera indica, Garcinia kola*, *Artemisia annua, Vernonia amygdalina*, *Nauclea pobeguinii*, *Argemone mexicana, Combretum micranthum*, *Nauclea latifolia* and *Morinda lucida*.

21.6.3 *Prevent Diseases Outbreaks*

The African forest is a diverse entity comprising both the abiotic and biotic components that maintain the unit's integrity. Nearly 2000 Key Biodiversity Areas support the world's most varied and abundant large mammal populations (Wolf and Ripple 2016). Due to the vulnerability of people living around various ecosystem areas, these treasures are currently under threat from forest degradation and unsustainable exploitation of forest resources. African countries are faced with a high level of poverty and mainly do not operate a technologically driven economy like their Western counterparts. Hence, most of its populace resorts to bioresources to drive the local economy's growth. Although this might be necessary for survival, it impacts the structure of the forest, creating other forms of ripple effect that can be harmful in the long run. Deforestation could result in the displacement of wild animals from their natural habitat to seek refuge in places closer to humans. Such proximity can result in interaction resulting in disease outbreaks mainly, zoonotic diseases transmitted between species from animals to humans. For instance, Lassa fever caused by the multimammate rat (*Mastomys natelensis*) is an acute viral illness endemic in parts of West Africa, including Sierra Leone, Liberia, Guinea and Nigeria. *Mastomys natelnsis* is a common rodent that inhabits natural areas in subtropical dry and moist savanna. Following the destruction of their habits through forest depletion, in seeking new habitats, these rats are reasonable to associate closely with humans and, in the process, transmit the virus. Only recently, the pandemic of Coronavirus diseases (COVID-19) caused by SARS-COV-2 was designated as a zoonotic disease. Although the classification is still being investigated, there are indications that several known Coronaviruses are circulating in animals that have not yet infected humans (Haider et al. 2020). Apart from the two cases of cross-species spill-over mentioned, others are yellow fever, dengue, measles and smallpox (WHO 2020). Since the potential of the African forest to harbour, a vast diversity of organisms have been established. Therefore, the conservation of African forest biodiversity should be given utmost consideration to ensure that the chances of vectors of most zoonotic diseases are kept at bay. This can be achieved by maintaining and not compromising the African forest integrity. Forest resources are also harvested for the management and treatment of several disease conditions within the region (Osawaru et al. 2016; Ogwu et al. 2017).

21.6.4 Africa's Forests Are Critical for Mitigating the Impact of Climate Change

Anthropogenic activities such as fossil fuels and deforestation arising from population increase and the subsequent need to modify the environment have exacerbated climate change. One of the dire consequences of climate change is its impact on the planet's habitability, upsetting biological species adaptation and even the existence of humanity. Although it is often reported that Africa contributes minimally to climate change, data, however, suggest that it is most vulnerable (Sudo 2014; Ogwu 2019) to its impact. Climate change is a global issue and therefore calls for necessary interventions regardless of the economic or developmental status of the region. Forest can contribute to climate change mitigation through carbon sequestration, carbon substitution and carbon conservation (Beverly 2018) and subsequently plays a crucial role in climate change adaptation strategies by ensuring ecological processes that sustain the ecosystem are uninterrupted (Xu et al. 2018). African forests are rich in biodiversity and it is one of the richest endemic floras in the world (Catarino and Romeiras 2020). It comprises various forests such as the dry tropical forests and woodlands, tropical rainforests in Western and Central Africa and mangroves in the coastal zones (Oyewole et al. 2019). These diverse forest ecosystems could store massive amounts of carbon and play a part in regulating climate. It is estimated that 20% of the global forest carbon stock is held by Africa's forests (FAO 2016); Western and Central African forests store some of the highest carbon densities globally (FAO 2015). Hence, the diversity of African flora endows it with the potential to deposit carbon in parts of the forest biomass, like roots and leaves, and in the soil.

Among other tropical forests of the world, the role of the African forest in contributing to the global mitigating plans of the climate change impact cannot be overemphasized. The importance of the African forest to global carbon sequestration and climate regulation was initially underestimated and thought to absorb only 89 tonnes of carbon per hectare. However, recent findings by Cuni-Sanchez et al. (2021) suggest that an intact tropical mountain forest in Africa stores about 150 tonnes of carbon per hectare, about 1.5 times more than they were thought to absorb. This means that some African rainforests store more carbon units per hectare than the Amazon rainforest (Cuni-Sanchez et al. 2021). Several initiatives have sprung up to identify with the African forests in climate change mitigation by reducing deforestation and ensuring afforestation and reforestation plans. Some of these initiatives include reducing emissions from deforestation and forest degradation, the role of conservation of forest carbon stocks, sustainable forest management and the enhancement of forest carbon stocks, the Clean Development Mechanism and Nationally Appropriate Mitigation Actions (Gizachew et al. 2017). Other supportive structures like Global Environment Facility, Central African Forest Initiative, Forest Carbon Partnership Facility, etc. including support by institutions such as Japan International Cooperation Agency via collaboration, have ensured that the integrity of the African forest is secured (Ordway et al. 2017). Therefore, it is confirmed that the African forest promises to tackle climate change sustainably. There is a need for more research to identify suitable native plants species in the region with effective carbon sink potential to help increase the capacity of the African forest. These species can then be incorporated in afforestation and reforestation projects.

21.6.5 African Forest Sustains Traditional and Cultural Practices

Aside from the utilization of forest species for economic and medicinal purposes, the African forest, by its potential habitation of diverse species of plants and animals, plays a significant role in preserving the culture and tradition of the indigenous people living within the forest habitat. The forest provides the species symbolic of the cultural practice and festival of most ethnic groups in Africa. Each ethnic group, based on its culture and belief system, has its festivals and ritual practices. During the process, biodiversity resources are deployed and used. However, the utilization of these bioresources had minimal threat impact on the species because the traditional system also regulates and ensures that such plants or animals used for these purposes are protected. In recent times, cultural infiltration appears to have impacted significantly the future of these traditional and cultural practices. For instance, the new yam festival of West Africa was widely celebrated in the past but in recent times, it seems to have experienced a reduction in zest due to the infusion of Western cultures (Coursey and Coursey 1971).

21.6.6 A Resource Tool for Science

Africa's forests are treasures of biodiversity. According to WWF (2015), of the 40,000 plant species on the African mainland, about 12,000 of these plant species are held in a tropical forest. About 7500 species are endemic to the continent, meaning that they cannot be found anywhere else. The richness of the African flora and the diverse fauna in the forest serve as veritable teaching and learning tools. The forest provides wild species of plant and animal experiments for various aspects of scientific research, including pharmaceutical research, horticulture research, plant breeding, plant genetic engineering research, agricultural research, soil microbial research, etc. (Kerfahi et al. 2019). In the form of scientific disciplines such as Forest Science, Silviculture, Environmental Management and Conservation, Plant Science, which studies the forest as a complex ecological unit. The African forest provides a unique pattern of various aggregation of forest types, allowing forest scientists to expand the scope of their research. Forest Science has become a function of a description of forests and forest processes and how those processes are efficiently manipulated to meet human wants and needs.

21.7 Threats to Forest Conservation in Africa

Conservation of forests in Africa is militated against by several interacting factors, operating across various geographic and sociopolitical scales (Ladle et al. 2011). Although endowed with abundant natural and mineral resources, including the forest, Africa has somehow found the sustainable management of these resources challenging. In economic terms, aside from South Africa and countries in North Africa, the others are characterized mainly as underdeveloped (Bhattacharyya 2009). There is a wide disparity between the underdeveloped countries in Africa and the rest of the developed world; this difference only requires that policies regarding forest conservation in these African countries be designed holistically by considering those endemic threats to forest conservation in Africa. The state of these African countries' economies seems to be a significant factor that influences the attitude of the populace to give forest conservation the utmost attention it deserves. The present situation warrants a trade-off, where on the one hand, the people need the forest resources to survive while on the other hand, conservationists keep the forest preservation advocacy on high momentum. To successfully address forest conservation in Africa, these endemic factors must be first considered. Some of these endemic drivers that militate against forest conservation in Africa include the following:

21.7.1 High Rates of Deforestation and Forest Degradation in Africa

In two decades (1990–2010), Africa lost 75 million hectares of its forest area, with an average deforestation rate of 0.5% per year (FAO 2010). Deforestation and forest degradation are the biggest threats to forest conservation in Africa and worldwide. In Africa, deforestation rates vary across various countries. For instance, Nigeria and Ghana have cleared over 75% of their forests, whereas in Kenya and Congo Basin, the deforestation rate is less than average at 0.35% and 0.5% per year, respectively (Brown and Schreckenberg 1999). In Madagascar, deforestation has claimed about 90% of the island's natural forest, leaving fragments that provide a poor template for large-scale species to range shifts (Hannah et al. 2008). Most countries still have a growing economy where the primary emphasis is placed on the forest for resources to drive the economy. Hence, much of the forest loss in Africa can be attributed to pressures from competing land uses, agricultural systems, infrastructural development, fuelwood sources, urbanization, industrialization and high population growth (Onuche 2010).

21.7.2 Lack of Proper Monitoring of Invasive Alien Species

Many African natural forests, plantation forests and even agricultural systems have suffered from invasive alien species. These species could either be plants or animals that accidentally get into a natural environment outside its natural range resulting in serious negative consequences for their new environment (Ehrenfeld 2010). The invasion process by these alien species often involves the establishment of new life forms that may have intrinsic properties that differ from those of native species (Brooks et al. 2002). Because these species can better compete, they can alter the structure of native plant communities through competition with native plants and modification of fire regimes (Brooks et al. 2002). Some deplete soil water faster and at greater soil depths; others utilize increased soil nutrients more quickly than native species and thus reduce their growth rates (Ikhajiagbe et al. 2022; Haubrock et al. 2021). These can significantly reduce native seedling biomass and species richness, affecting forest composition and structure (Brooks et al. 2002). The invasion of the Afromontane habitat by invasive alien species like *Pinus, Eucalyptus, Acacia* and *L. Camara* in the Eastern Highlands of Zimbabwe fuels wildfire. These wildfires kill long-lived *P. Africana* and other native Afromontane plants (Jimu 2011). Aside from the ecological significance, invasive alien species could have momentary severe implications. According to Eschen et al. (2021), Africa loses about US$3.66 trillion annually from the impact of the Invasive Alien Species (IAS) on agriculture and other food sources like the forest. Early detection remains a high priority for properly managing alien invasive species for prompt response to address its impact on the forest structure (Eschen et al. 2021).

21.7.3 Occurrence of Adverse Events Like Fire

The savannah ecosystem comprises almost half of the size of the African continent. Fire is a regular occurrence in the savannah ecosystem. Hence, there has been a reported incidence of wildfires in this zone. In Sudan, Angola, DRC, Lesotho, Zambia and Zimbabwe, the Afromontane woods were vulnerable to fire (Betti 2008). Wildfire mainly interferes with regeneration, as it wipes out seedlings and saplings which cannot withstand the damage (Jimu 2011). In Botswana, it has been reported that the number of fires increased by 67, from 81 in 2006 to 148 in 2008 (FAO 2010). This fire, if unmanaged, could disrupt the ecosystem balance, affect tree growth and survival, soil properties, water quality and yield, biodiversity and so on (Song et al. 2019; Giacomo 2005).

21.7.4 Poor Management Strategy of the Concerned Authority

In most cases, it is sad to believe that protecting the forests in Africa has been unsuccessful due to the negligence and failure of the people in authority who are supposed to give managerial direction to the course. Unfortunately, due to corruption, government officials often compromise in their duty to implement rules and policies that are set up to protect the forest and forest resources.

21.7.5 African Agriculture and Food Production System

The agriculture system practised in Africa is likely to put more pressure on the already threatened forest. Generally, two agricultural systems exist in Africa: shifting cultivation which is native and the plantation system, which the European colonial masters introduced (Benneh 1972). In the shifting cultivation agricultural system, farmers cultivate lands temporally, moving to another plot to enable the former to undergo a post-disturbance fallow period to replenish lost nutrients. There have been controversies about whether the shifting cultivation system results in forest depletion or not. However, the argument is mainly on what should be regarded as a forest. According to Kurien et al. (2019), the definition of 'forest' is too broad and does not distinguish non-forest land uses (mainly agriculture).

Conversely, the practice of shifting cultivation ensures that the forest must be constantly disturbed to cultivate the land. This activity will reduce the areas of the primary forest and lead to forest ecosystem disturbance. About half of tropical deforestation is commonly explained by the expansion of traditional agriculture (shifting cultivation) (Angelsen 1995). On the other hand, the plantation agricultural system is likely to increase the deforestation rates of the African forest due to the demand to expand the area of cultivation for the crop with commercial value. The plantation system will ensure the displacement of native trees in the forest for the monotypic forest such as a plantation. Ordway et al. (2017) explored the risk of deforestation as agriculture increases in Africa. They posited the long-term impact of multinational companies' involvement in African agriculture to expand markets for their commodity in this regard. Currently, international companies have bought up a land area in the heavily forested Congo Basin, Nigeria and Ghana primarily for crops such as oil palm, rubber and so on. Between 2017 and 2018, Ghana lost about 60% of its primary forest to cocoa cultivation according to the Global Forest Watch.

21.7.6 Unemployment and Poverty Index

The increased rate of deforestation in Africa can also be attributed to the problem of high unemployment and poverty index rate. Many countries in Africa have record-high unemployment rates (Blaser et al. 2011). Due to this, people are likely to seek greener pastures using forest resources, not minding if there are restrictions or not. Poverty is one of the most significant indirect reasons causing deforestation in Africa. Due to the high poverty rates in Africa, people have turned to the forest to secure their food security and way to lift themselves out of poverty.

21.7.7 *Over- and Unsustainable Harvesting of Forest Resources*

Forest resources are at the receiving end of the economic woes of most African countries. In contrast to gains made from conserving the forest, over- and unchecked harvesting of forest resources for short term benefits significantly affect the regenerative capacity of forest, which may in-turn impact future generations. Hence, most people would prefer to extract these resources from the forest rather than the long-term benefits of protecting the forest. Logging, in particular, is principally responsible for the increased deforestation rates recorded in Africa (Blaser et al. 2011). In West Africa, logging has been taking place for over 100 years, even during the colonial era. This has evolved into a big market that encourages wood extraction for both local and international transactions. Logging activities have persisted in Africa due to the inability of forest administrators to properly implement policies on logging concessions that can sustain forest conservation. For instance, in Ghana, due to the activities of informal and illegal logging pressures, the official logging concession of 10–40 m^3 per hectare is not usually adhered to (Dupuy et al. 1999). Also, in Nigeria, there have been recent reports about unlawful logging activities in both community forests and protected forests such as the national park. Aside from logging activities, there are increasing pressures on the forest for fuelwood. The economic situation in most African countries where basic amenities are lacking, for instance, shortage of energy and gas supply, leads to the fuelwood option being the principal source of energy for cooking food and keeping warm. The importance of fuelwood to developing countries in Africa cannot be overemphasized. According to Sola et al. (2017), more than 70% of the population in sub-Saharan Africa rely on wood fuel as their primary household energy source.

21.8 Towards an Optimal Conservation Strategy for the African Forests

African forests are renowned for species richness and a high degree of endemism. These features attest to its uniqueness and, consequently, the need for its conservation. To conserve the African forests effectively, two approaches come to mind: the traditional and the contemporary. The former was the mainstay conservation strategy before the influence of the colonial administrators; during this period, the African forests were preserved by techniques backed by customs and religion for which the indigenous people revered, understood and complied. This approach was undoubtedly highly effective in ensuring that plant species were not threatened. The latter represents the colonial conservation strategy where the forest is protected by legislative means. Even though this system has been relatively effective for several decades in preserving the African forests, several issues have been raised about its suitability for the effective conservation of the African forest, mainly as the local people are yet to embarrass the system thoroughly. Therefore, there is a need to re-strategize and modify the current approach of forest conservation in Africa by incorporating the traditional approach to have a proper conservation system for the African forests. The progress achieved so far in protecting forests in Africa will be sustained by integrating the local people to have a sense of belonging during policy designing. In addition, the traditional systems that gave much reverence to the forest in the past must be adopted. With such a design, the local people are likely to accept policies with such elements than something alien to them.

For any conservation strategy to be successful, educating the people is essential for the sustainable use and conservation of the African forest. Hence, the government and policymakers must promote local and indigenous biodiversity knowledge. The local people should be aware of the benefits of forest conservation and the demerits of continued forest degradation. Community education has preserved and conserved forest and forest resources (Adekola and Mbalisi 2015).

21.9 Recommendations

African forests are unique, diverse and essential to the economy of both Africa and the rest of the world. Hence, it is imperative to re-evaluate existing methods of conservation to avoid the danger of losing this very important treasure and heritage. The following recommendations are essential to achieving an optimum conservation strategy for African forest:

1. The views of local people must be incorporated into policymaking and management decisions for forest conservation. In other words, there must be active participation of the host communities where these forests are housed. Their involvement in policymaking and implementing forest management policies is highly recommended.
2. Government policies must now clearly advocate placing values on the forest rather than on a specific commercial tree. The people must be enlightened on the importance of holistic consideration of the forest ecosystem rather than placing priorities on a few economic trees.
3. Tree planting exercises must be conducted from a forest restoration standpoint as against afforestation. Deforested areas must be reforested with native trees and plants that were initially there to maintain the natural integrity of the ecosystem and also avoid the introduction of invasive alien species.
4. The people should be informed about the consequences of unlawful forest resource depletion. At the same time, violators of these forest laws on conservation, maintenance and protection of African forests should be prosecuted.
5. People should be encouraged to find alternatives to forest products to reduce pressure on the forests.
6. Regeneration activities such as afforestation and reforestation of already utilized forest resources should be prioritized and sponsored by governments, communities, individuals, private sectors and NGOs, etc.

21.10 Conclusion

Among other tropical forests of the world, African forests stands out in terms of species richness and diversity. Its phytogeography includes the tree species-rich Guinea-Congo region, the expanse of tropical savannah**,** the Sudan-Zambezian region, the Afromontane regions and the evergreen forest of East Malagasy. The African forest is essential to Africans and indeed the rest of the world because it serves as a source of revenue, a storehouse for medicine, buffer against disease outbreaks, mitigates the impacts of climate change, sustain various traditional and cultural practices of the African people and a resource for science. However, some challenges in the region, particularly high rates of deforestation and forest degradation, presence of invasive alien species, the occurrence of adverse events like fire, poor management strategy, African agriculture and food production systems, high unemployment and poverty index, and over- and unsustainable harvesting of forest resources, have significantly led to a continued loss of forested areas within the continent. The forest conservation strategies so far adopted by representative countries have gone through several phases over the years, from precolonial, through colonial to the postcolonial era. Of all, the traditional method of forest conservation, for instance, the sacred grove system, appears to be more effective as a forest conservation strategy than the legislative approach to forest protection which is currently practiced. Consequently, there is a need to re-evaluate the current forest conservation approaches and systems in Africa with a view to incorporating the traditional mechanisms that sustained the forests before the advent of the present colonial systems. Only through this can we have a policy that will ensure an optimal conservation system for the African forests and a system of conservation that the local people are in tune with.

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Chapter 22
Factors Militating Against Biodiversity Conservation in the Niger Delta, Nigeria: The Way Out

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Abstract This chapter is a fallout and synthesis of several EIAs and PIAs conducted in the littoral states of the Niger Delta between 1996 and 2019. It identified four major factors decimating biodiversity of the Niger Delta, namely: (i) anthropogenic activities; (ii) extirpation of native species by invasive or exotic species, (iii) petroleum industry activities; and (iv) the lax attitude of some governments and oil and gas companies in mainstreaming biodiversity conservation in their policy and operations. Among the anthropogenic activities are the following: Slash-and-burn method of preparing farmland for cultivation; massive land-take in developing various infrastructures; urbanization; unbridled exploitation of natural resources (timber, wildlife, fish, and non-timber products), without replacement considerations; plus a series of unhealthy traditional/cultural practices, and de-reservation of forest reserves by landlord communities. Exotics like *Nypa fruticans*, *Eichhornia crassipes*, and *Chromolaena odorata* are displacing many useful native species. The most devastating footprints of the petroleum industry are noticeable during seismic operations that often span through three to four local government areas; construction of several kilometers of pipeline that traverses highly sensitive areas; pipeline vandalism; incessant oil spillages; and dredging operations. It was also observed that some governments and oil and gas companies are apparently complacent about mainstreaming biodiversity in their policy and operation, even though they have the capacity. Several implementable recommendations have been suggested, which will help biodiversity conservation in the region.

Keywords Anthropogenic activities · Traditional practices · Petroleum industry activities · Pipeline vandalism · Biodiversity mainstreaming · Conservation · Niger Delta

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22.1 Introduction

Biodiversity which has increasingly become a buzzword in the realms of environmental science and engineering originated from a renowned ecologist, Wilson (1988). The term is an acronym of two words “bio” (referring to living things) and “diversity” (referring to variability or variety). In other words, it is the variety of living things in a place. It is conventionally defined as “the variability among living organisms from all sources including inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; these include diversity within species, between species and ecosystems”. To a layman, it may be considered to be the totality and abundance level of biological resources (species, genes, ecosystems, etc.) endowed to a place. Biodiversity is fundamental to human welfare and economic development and plays a critical role in continuous sustenance of life, by maintaining the ecological systems upon which our survival depends. Increase in human populations and excessive exploitation of natural resources for food, shelter, medicine, industrial raw materials, and footprints of oil and gas industry have become a major concern for biodiversity conservation or safeguarding. This has become necessary since the rate of exploitation and destruction of biodiversity by man is overwhelmingly higher than the rate of its natural replacement. Hence, the current global concern for the conservation of biological resources has culminated in the emergence of series of conservation movements/initiatives such as the International Union for Conservation of Nature and Natural Resources (IUCN), Convention on Biological Diversity (CBD), World Wildlife Fund (WWF), Conservation International (CI), Birdlife International, African Wildlife Fund (AWF), Nigerian Conservation Foundation (NCF), etc., all of which aim at mitigating biodiversity loss, through diverse strategies.

Niger Delta region is one of the biodiversity hotspots of Africa. A biodiversity hotspot is a region richly endowed with amazing variety of flora and fauna and endemics. The term biodiversity hotspot was first used by Dr. Norman Meyer in two articles he published in the scientific journal, *The Environmentalist* (issues of 1988 and 1990). The bulk of the hotspots happens to occur in underdeveloped and developing countries, where the highly populated, poor, rural communities eke their living from thick forests and aquatic ecosystems around them. With great demands placed on biodiversity by the soaring human population, biodiversity hotspots are under pressure and so are prone to biodiversity depletion (Myers 1988; Myers et al. 2000). This is the situation in the tropical and equatorial rainforests of the world such as the Amazon of Brazil, the equatorial rainforests of West and Central Africa, Seychelles, Madagascar, India, Southeast Asian islands of Borneo, Sumatra, Indonesia, Philippines, Java, Papua New Guinea, etc.

Apart from being a biodiversity hotspot, the River Niger Delta region in southern Nigeria (West Africa) is the major oil-producing area of sub-Saharan Africa with a crude oil production of 2.04 mb/d (De Montclos 1984). The region invariably has been environmentally altered in the last 40 years by the oil industry activities (De Montclos 1984; Singh et al. 1995; NDES 1998). It has been estimated that over 95% of the pristine rainforest has disappeared and that over 5800 km of oil pipelines have been built throughout the Delta since 1958, many of which have been repeatedly broken, causing catastrophic oil spillages (Carbone 2002) and undermining the biodiversity of the area. For instance, between 1986 and 1996, there were 1796 cases of oil spills in this region, totaling about 2,500,000 barrels of oil spread across the natural environment (Carbone 2002).

The factors that drive biodiversity depletion in the hotspots globally may vary ranging from the prevailing anthropogenic activities and cultural practices to ecological disasters such as floods, hurricanes, tsunamis, earthquakes, volcanic eruptions, etc. In this chapter, the case of the Niger Delta is brought to focus, with a view to elucidate how the multiple pressures ranging from population growth through anthropogenic activities and development projects to oil industry activities are militating against biodiversity conservation in the region. The data presented here are the products of several studies conducted in the coastal states of the Niger Delta for four decades, plus secondary data from corporate organizations, research agencies, and NGOs (Okpon et al. 1998). The coastal states which include Akwa Ibom, Bayelsa, Delta, and Rivers states encompass an area of 46,420 km^2 (Okali 2014) which has a population of well over 18,151,000 (NPC 2006). The oil and gas industry in these states has a facility covering an area of over 600 km^2 or 1.3% of the area under focus.

22.2 Threat Factors of Biodiversity in the Niger Delta

22.2.1 Population Growth and Urbanization

With the creation of more states and local government areas all over the country since 1996, there has been a rapid rate of development of cities, towns, and villages with various government amenities and infrastructure. The Niger Delta is one of such areas with soaring human population and rapid urbanization, especially as it is the hub of oil industry business in the country. In all the Niger Delta states today, there are several highways, housing estates, University campuses, motor parks, stadia, oil fields, military barracks, general hospitals, etc., which have resulted in huge land take, reclamation of swamps and marshes, etc., with a concomitant loss of wildlife and biodiversity. In most places, the development of these social amenities (to accommodate rural-city migrants, tourists, job-seekers, businessmen, etc.) has culminated in habitat fragmentation and its attendant problems to ecosystem functioning.

22.2.2 Anthropogenic Activities

22.2.2.1 Slash-and-Burn Method of Preparing Farmlands for Cultivation

Agriculture is the major economic base of the indigenous people, as the land is quite fertile and watered by rainfall supplied almost throughout the year by the southwest wind which blows across the region, from the Gulf of Guinea. These features have been considered as the major reason for the amazing biodiversity endowment of the area. However, the slash-and-burn method of preparing the farmlands prior to cultivation has been identified to tell immensely on the biodiversity of Niger Delta basin. Annually, several hectares of riparian forests, secondary forests, and bush fallows are slashed and burnt in preparation for farming. With the soaring human population and economic downturn, more farmlands are cultivated to feed their families. During the slashing phase of the land preparation, most arboreal animals like birds, monkeys, squirrels, genets, pangolins, bats, snakes, chameleons, etc. are displaced from their habitats to strange habitats where they may not survive. The bush burning destroys a lot of ground-dwelling and burrowing animals including snails, earthworms, insects, millipedes, centipedes, skinks, lizards, rats, tortoises, etc.

In effect, there is complete destabilization of the ecosystem, with the slashing and burning of forest causing massive loss of biodiversity and usually just a few species of crop is cultivated, compared to the number of wild plants and animals charred by fire. Because of incessant slash-and-burn practice and reduced fallowing duration, most farming areas in the Niger Delta have degenerated into a derived savanna.

22.2.2.2 Unbridled Logging Without Replacement Culture

The indiscriminate and open access logging in the Niger Delta states is contributing enormously to deforestation in the region. By extracting most of the tall economically important tree species, many forests have lost their two- or three-layer stratification due to this unwholesome practice. The twilight condition even at midday characteristic of the forests is virtually gone, and more sunlight is admitted into the forest, to the disadvantage of shade-loving organisms. Most times as the trees are felled, dozens of young saplings and shrubs are killed as the logs fall on them, leading to further loss; and it takes many years for a timber-producing species to produce timber. The high-pitch sound generated by the sawing machines scares wildlife and keeps them jittery for a long time. When the noise becomes persistent, they are compelled to migrate, sometimes to alien habitats in which they are less likely to survive. Because of the incessant logging, highly priced timber species for which places like Sapele (in Delta State) Abua and Mbiama in Rivers State were popularly known are now critically endangered. Among them are *Nauclea diderrichii* (Opepe), *Milicia excelsa* (Iroko), the Mahogany, Ebony, *Mansonia,* *Triplochiton sceleroxylon* (Obeche), *Terminalia superba* (White Afara), *Terminalia ivorensis* (Black Afara), *Lophira alata* (Ironwood), and others known in international markets. These trees are usually felled during late dry season and stacked near the river banks. By wet season, the dry floating logs are pooled (aided by water current) in great chains to the market. The diversity of trees commonly logged in these states has been recorded by several authors (Werre 1991; Etukudo 2003; Ubom 2010). At other times, tractors or trucks are used to cart away the logs. The use of tractors has its own limitations as it tears up the soil, crushes soil organisms (earthworms, millipedes, centipedes, and beetles), and increases erosion.

The oddity with illegal logging is that it can increase the harmful impact of wind and rain on local ecosystem, reduce carbon sequestration, destroy the valuable wildlife habitats, and cause the soil to become dry and overheated, which may in turn increase the risk of fire or interfere with seedling growth.

The impact of uncontrolled logging is exacerbated in most localities because there is hardly any tree-planting culture to replenish the lost trees. Deforestation problems such as erosion become prominent making recovery of the forest a lot difficult, moreover, as the nutrients have been washed off.

A high felling intensity not only predisposes drier forests to much more severe fire in subsequent years but also causes significant decrease in species richness and diversity. Commonly affected are arboreal animals such as birds, squirrels, bats, chameleons, pangolins, and primates, which are dislodged, and sometimes leave their fledglings as orphans to be picked up by predators.

22.2.2.3 Fuelwood Extraction and Trade

The majority of the rural-poor categories in the Niger Delta states depend exclusively on fuelwood as a source of energy to cook. With a higher population of the lower class than the higher class, the annual fuelwood extraction is very high. Sometimes the fuelwood is collected to eke a living, because of the great demand. This need puts pressure on the unsustainable number of timber-producing species that remains, and on the integrity of forest ecosystem. In the Mangrove zone, communities such as Burutu, Warri, Nembe, Kula, Okrika, etc., have their mangroves cut mainly for cooking and smoking fish and production of charcoal. Because of their hardness, durability, and resistance to termites, the red and white mangroves are commonly extracted for other purposes such as construction of piers, scaffolding/ buildings, canoes, paddles, and cooking utensils and also as a source of tannin. Most sessile marine invertebrates such as oysters, barnacles, tunicates, hydroids, bryozoans, etc., prefer hard substrates for establishment. Mangroves provide such a habitat. Thus, the massive extraction of mangroves for fuelwood may reduce the habitat of such encrusting animals and therefore interfere with ecosystem functions.

22.2.2.4 Gathering and Trading on Non-Timber Products (NTPs)

The Niger Delta forests provide a wide variety of non-timber products (for medicine, food, industrial raw materials, etc.) which invariably attract the rural communities to gather them both for subsistence and/or commercial reasons. Among them are snails, forest vegetables, ropes, honey, mushrooms, wax, resin, oil, nuts, cane, chewing stick, veneer, poles, bamboos, etc. (NDES 1998) and there is always open access allowing great thoroughfare. Among the varieties of NTFPs of great economic uses are the African giant snail—*Archachatina marginata,* the canes—*Calamus deeratus* and *Lacosperma secundiflorum,* the chewing stick—*Garcinia manii,* Indian Bamboo—*Bambusa vulgaris*, and food wrapping leaves such as *Thaumatococcus daniellii* also produce fruits that are sweeter than sugar (Amoru 2002). The current economic downturn and inflationary trends have led to excessive harvesting of non-timber forest products, by the soaring population to the extent that some species such as *Hymenocardia acida*, *Kigela africana* (African sausage tree), and *Cassia nigricans* are threatened.

22.2.2.5 Overexploitation of Fisheries and Degradation of Spawning Grounds

Fishing is another important economic base of the Niger Delta coastal states. Virtually every dweller resident near the sea, rivers, streams, and lakes, fish either for subsistence or for commercial purposes. There is no control or restrictions over the types of gear used or fishing effort. Thus, the aquatic systems are grossly overfished, because of the high frequency of fishing in the same water, with nets of small mesh sizes. With such practice, both the gravid females, fries, and fingerlings are caught, and the juveniles are never returned to the river to grow, irrespective of their size. The unwholesome use of toxic root extracts and pesticide like Gammalin-20 in fishing (Ezemonye and Ogbomida 2011) is also known to diminish fish stock in the region. Days after fishing with the chemical, the toxicity persists and continues to kill fish, shrimps, crabs, zooplankton, etc. The overfishing problem has gotten so bad that some communities depend on imported "Iced fish" to prepare their dishes, even when the rivers are under their nose. Large-scale artisanal fishing without temporal or spatial closures in the coastal states of the Niger Delta has also been traced to the great loss of fish species. It will be recalled that such overfishing of water bodies has culminated in the vulnerability or extinction of fishes like Bocaccio Rockfish, European eel, Goliath Grouper, Maltese Ray, Blue Tuna, Sturgeon, and Golden fish.

Human impingement and coastal degradation resulting from incessant oil spill, sand-filling, and sand mining have led to the destruction and reduction of fish breeding and nursery grounds in creeks, swamps, mudflats, river channels, estuaries, etc., and is also a contributing factor to overexploitation of fishery resources of Nigeria.

22.3 Mechanisms of Biodiversity Loss

The rapid rate at which species are getting endangered or extinct over the past 150 years is alarming. This has been attributed to myriad of anthropogenically induced factors, among which are the following:

22.3.1 Habitat Destruction

As observed in places where several hectares of forest, grassland, and woodland have been converted to farmland, pastureland, estates, and cities, and where wetlands are reclaimed for residential accommodations, regularly dredged rivers, and areas occupied by wildlife. Most biomes of the world, today, have lost their species and integrity to extensive habitat destruction in the course of project development.

22.3.2 Adverse Changes or Alterations in Abiotic and Biotic Environments Due to Environmental Pollution

It is glaring that over 75% of the Niger Delta ecosystem has had its natural quality lost to incessant environmental pollution. Alteration of water quality by various types of pollutant especially petroleum is rendering fisheries conservation a lot difficult in the Niger Delta. Environmental pollution is defined as the introduction of substances or energy into the environment by man to levels where they are harmful or deleterious to living things or undermine amenities and quality of the environment (GESAMP 1982a, b). The introduction of thousands of chemicals including pesticides, herbicides, toxic heavy metals, petroleum hydrocarbons, radionuclides, nutrient influx, etc. into the environment for long durations has killed many animals and plants. Perhaps the worst form of pollution is the latent (hidden or unnoticeable) type such as the release of colorless chemicals and radioactive radiation into the environment which continues to decimate populations or cause health problems for a long term without detection by human sense organs. A case in point is the Minamata episode in Japan, which gave impetus to heavy metal pollution research. Even minute concentrations of these persistent or recalcitrant pollutants may cause irreparable damage to the whole ecosystem, as the entire food web may become poisoned because of biomagnification along the trophic levels.

22.3.3 Overexploitation of Selected Species

The unbridled hunting and collection of selected groups of plant and animal species for food, profits, medicine, or recreation is an old tradition in many economies, right from the Stone Age. This practice has led to the extinction of most of such valuable species, as there are usually no replacement considerations or culture, and they occur in areas of open access harvesting, without closures or gear control. Hundreds of medicinal plants discovered in Africa are today under pressure due to overexploitation of their roots, barks, leaves, and flowers (Udoh 1999); the same is true of the medicinal plants in Asia. Similarly, animals like Tapir are on the verge of extinction, because of their very tasty meat, which predisposes them to merciless hunting. Even in the present day, hunters and collectors are the major threat to a number of species. Whales, elephants, most of the wild cats, rhinoceroses, many species of snakes, crocodiles, and a number of other species are nudged to extinction because of the heartless hunt for their hide, tusk, or horns (Asthana and Asthana 2009). Despite the laws prohibiting illegal trade of these endangered species, hunters are continually lured because of the huge profit derived. For instance, consumers all over the world are willing to pay 95,000 dollars for the coat of a Bengal Tiger; in western Germany, a coat made of a South American Jaguar costs as much as 40,000 US dollars; the horns of rhinoceroses are highly priced as gold, as they are exported to Asia where they are used for the preparation of medicine.

22.3.4 Habitat Fragmentation

This is the splitting of habitat into smaller and smaller scattered patches or fragments; as observed in places where a network of roads has been constructed; in areas of seismic operation; and where pipeline Right-of-Way crisscrosses a region, etc. Such fragmentation culminates in biodiversity reduction because many tree and shrub species are lost in the process, to wind and encroachment by various agencies. Fragmentation of forests by network of roads or pipelines (Right-of-Way) creates access for nearby communities to further exploit forests, and fishing grounds which hitherto were inaccessible. The margins of the patches which are frequently subjected to encroachment lose much of their species. Large-sized animals like the big cats, elephants, antelopes, buffaloes, birds, etc. that require large continuous territories and serene environment to subsist move into the interior zones of the patches, as their rendezvous. Crowding in this “rendezvous” often results in competition for territorial space, sex mates, food, and water, thereby causing the weaker individuals to perish. The crowding also prompts increased predation or overgrazing which impacts the vegetation, and the animals live under stressful condition. This results in reproductive failures and depression of natality and life span. In the event of any single catastrophic episode such as stormy weather, disease epidemic, or wildfire, these clustered populations may be wiped out. Thus, habitat fragmentation does not auger well for the health of any ecosystem.

22.3.5 Exotic Species

Among the recognized factors in ecosystems that nudge species to extinction are exotic species. These are non-native species that establish and spread outside their normal range. Some of the most threatening invasive species include cats and rats, green crabs, zebra mussels, the African tulip tree, and the brown tree snake. How are exotic species introduced to a new place where they are not native? Introductions can happen inadvertently, for example, when organisms "hitch-hike" in containers, ships, airplane, cars, or soil and are given a ride to a new destination, where they are not native. For microscopic organisms, mere contamination can be a means of transportation. This explains why the laws governing agricultural commerce enforce quarantines to prevent biodiversity disaster such as accidental spread of disease organisms, insect pests, and seeds of weeds, during the importation of biological resources. Advertent/intentional introduction, on the other hand, refers to species deliberately introduced to a place for a specific purpose such as the biological control of pests attacking crops.

Irrespective of the type of introduction, the exotic species on arrival to the new place, may survive, reproduce, establish themselves, or even become invasive. This is because (a) removing a species from its native environment liberates it from natural predators, parasites, pathogens, and competitors that limit its number at its homesite, (b) the abiotic or physical environment of the new place is favorable, and (c) they outcompete the defenseless native species for food, territorial space, nesting site, and other biological resources. Thus, ecologists are usually not enthusiastic about introducing a species into a new ecosystem, because of the ecological and economic impacts they may precipitate.

22.3.5.1 Ecological Impacts

On arrival to a new ecosystem, an exotic species may turn out to be better predator or grazer than the native species in the same trophic level, leading to alterations in the food web. It can out-compete the native species for resources such as food, nesting site, and territorial space and consequently nudge them to extinction. Such loss in biodiversity generates a cascading effect in the food web which jeopardizes the entire ecosystem. Overgrazing by an invasive species can lead to considerable disturbance of soil, loss of habitat, soil erosion, and alteration of nutrient level in soils. Sometimes species intentionally introduced to prey on a pest population, rather than face the pest, finds another species in the ecosystem more palatable and easier to capture and so feast on them, causing another problem in the ecosystem. The exotic species may also come along with a disease parasite to which the native species are not resistant. Thus, any introduction must be done with caution, after sufficient research on the habitat requirements of the species in question. Although there is the tendency for people to assume that introduced species have negative ecological impacts, it is not always so. For instance, the dung beetle (a potential scavenger) which was introduced to Australia, a couple of years ago, is now helping to reduce the problem of excessive cow dung on ranches.

22.3.5.2 Economic Impacts

A major economic impact precipitated by exotic species is when it becomes invasive displacing economically profitable native species. Moreover, it can cost any responsible government or organization a lot of money to research into the eradication of the pest species and restore indigenous species. Besides, an exotic species may cause economic damage by (a) hybridizing with valuable species and producing worthless crossbreeds, (b) carrying or supporting harmful pests, and (c) constituting nuisance and reducing the aesthetic quality and recreational prospects in an area. The hybridization with time may lead to loss or extinction of the pure breed. Furthermore, invasive species may also breed with native species, resulting in potentially dangerous or poisonous hybrids which humans may find very expensive to cure, if consumed.

22.3.5.3 Example of Exotic Species

There are several notable examples of exotic species worldwide. Among them is the Eurasian Zebra mussel, *Dreissena polymorpha* (Pallas), introduced from Europe into the Great Lakes, when a ship discharged its ballast water into one of the lakes, in the mid-80s. Favored by the environment, the mussel has now spread throughout most fresh waters of the Northeastern and Midwestern United States, including the Mississippi and Hudson rivers. The mussel now constitutes a nuisance in some places as it clogs intake valves for pumping stations, power plants, and industrial facilities, and causes obstructions in boating and sports fishing. Moreover, it has caused declines in some native freshwater species thereby upsetting local ecosystems.

Through ballast water also an American comb jelly, *Mnemiopsis leidyi*, was transported from New England to the Black and Azov seas in Europe, where its population exploded and preyed so heavily on plankton that the plankton biomass declined abruptly by as much as 9%. This ugly development affected the anchovies which feed on them. Thus, there followed a sharp decline in the anchovies, causing the local fisheries to suffer.

Pough et al. (2001) reported that in 1872, mongooses were introduced to Jamaica (West Indies) from India to kill rat populations pestering the sugarcane plantations. The mongoose which was diurnal and unspecialized to deal with the nocturnal rats switched over its predation heavily on reptiles and birds. The result was a drastic reduction of several lizard species, including the iguanid, *Cycura collie* and the colubrid snake *Alsophis ater*.

The Nypa palm, *Nypa fruticans*, native to Southeast Asia, is an exotic plant in Nigeria's mangrove ecosystem. Its seeds were introduced into Calabar from

Singapore in 1906 (Keay et al. 1964) during the colonial era. It was specifically planted along the Idua Oron beach in 1912 to check erosion of the beach by tidal waves of the Atlantic Ocean through the Cross River estuary. Favored by the environment, the plant has become invasive and has spread to other coastal towns of the country up to Ondo and Lagos states in the west. Nypa palm flourishes in soft mud and slow-moving tidal and river waters that bring in nutrients. Hence, it forms dense colonies on estuarine or brackish mud, as seen in Khono Waterside and Opobo channel, Andoni and around Kidney Island, Port Harcourt, all in Rivers State. Its rapid spread is attributed to the prostrate underground stem that ramifies in any mangrove mud it establishes. Only the feathery leaves and flower stalk grow upward, usually up to 9 m high, and the shade provided, coupled with the ramifying stem, suppresses the growth of the mangrove plants. Nypa palm in the Niger Delta is disliked and seen to constitute a menace because of its adverse ecological impacts on waterways and marine lives—it has spread, and blocks ed waterways and hinders navigation of small channels which hitherto were used for fish-trapping and periwinkle-picking canoes. It is rapidly displacing the slow-growing but more useful mangroves like *Rhizophora* and *Avicennia* spp (a phenomenon known as allelopathy) which provide the creek dwellers good fuelwood for smoking their fish; termite-resistant hardwood for scaffolding, and construction of piers and bridges, poles; and source of tannin. Moreover, they are rapidly losing the suitable mangrove environment that offers good sites for rice cultivation and establishment of oysters and clams (Etukudo 2003).

The water hyacinth, *Eichhornia crassipes* (Mart.) Solms—a free-floating aquatic weed—is another example of invasive species in Nigeria. The floating macrophyte is a bulbous plant of the lily family: pontederiaceae. It was originally native to the Amazon River Basin and in recent times has spread to more than 50 countries in five continents. Water hyacinth has been reported in water bodies of several West African countries including Ghana, Benin, Togo Cote d'voire, Cameroon, and Nigeria. The weed reportedly entered Nigeria's lagoon system in 1984, and its incursion into Nigerian coastal waters has been traced to the Porto Novo creek in Benin Republic through which it gained entry into Badagry Creek in Nigeria which connects the two neighboring countries. Ever since, the weed has invaded nearly all water bodies in the southern part of the low salinity lagoon in Lagos State to freshwater streams and creeks in the coastal areas of Ogun, Ondo, Edo, Delta, Bayelsa, Rivers, Akwa Ibom, and Cross River states. It is estimated that the weed has invaded over 60% of Nigeria's fresh and brackish coastal waters.

The sporadic spread of this weed in Nigeria has been attributed to a number of factors: (a) the intricate interconnectivity of our creeks and streams, driven by tidal current, wind, etc., (b) dispersal by rivercrafts timber and fishing activities, (c) its excellent buoyancy (as both roots and shoots are filled with numerous air spaces) which facilitates its transportation, (d) it is highly adaptable to both brackish and freshwater habitats, (e) it has an unusual reproductive vigor; being able to reproduce both sexually and vegetatively, and more of the latter; a single plant under ideal conditions can reproduce 3000 others in 50 days and also cover an area of 600m^2 in a year, (f) the maximum fruiting environment of 90% humidity and 22.5–35 °C required by the weed is met in Nigeria, and (g) nutrient-rich water in which the roots float.

Dense mats of *Eichhornia crassipes* constitute a menace in various waterways; they have been observed to hinder navigation and fishing activities of the artisanal fisheries sector and alter the ecological balance of affected areas. Such clusters are unsightly and thereby reduce the aesthetic and recreational values of the rivers and negatively impact the socioeconomic activities of communities around as it interferes with the use of waterways for transportation, washing, swimming, food fermentation, etc. Mats of water hyacinth are capable of causing accidents when their stolons hook on the propeller of a racing speedboat. They also interfere with irrigation by greatly reducing the flow rate of water to irrigation equipment, thereby increasing pumping times and costs. As the flow rate gets to zero, the water becomes a fertile breeding ground for mosquitoes.

The Siam weed *Chromolaena odorata* (L.) King and Robinson, is another graphic example of exotic species. This weed is widespread in West African farmlands. In some parts of Nigeria, it is locally known as "Awolowo weed."

22.3.6 Natural/Ecological Disasters

Natural/Ecological Disasters—other drivers of biodiversity loss include catastrophic events or natural disasters. When they strike, various species of plants and animals are not spared. They can be classified as follows:

- *Geologic Disasters*—which originate from movements of the earth's crust such as earthquake, tsunami, volcanic eruption, landslide, subsidence, etc.
- *Meteorological Disasters*—which are outcomes of weather events such as hurricane, typhoon/cyclone, blizzard, flood, drought, thunderstorm, wildfire, etc.
- *Biodiversity Disasters*—arise from outbreak of disease-causing organisms such as bacteria, viruses, fungi, etc. reaching epidemic or pandemic levels, e.g., SARS, Ebola virus, Covid-19.
- *Man-made Disasters*—arise from riots, disorder, and war, leading to destruction of lives and properties, setting of bushes on fire, e.g., the Amazon bush fire of 2020.

Although natural disasters are temporal and localized, a high frequency can be very disastrous to biodiversity, directly or through habitat alteration.

22.3.7 Global Warming/Climate Change

Global Warming/Climate Change—has enormous impact on biodiversity. Large volumes of literature have accumulated in recent times indicating that climate change originates from the global emission of heat-trapping (greenhouse) gases produced by vehicles, power plants, industrial chimneys, gas flaring, bush-burning, etc. As these greenhouse gases accumulate and act like a big blanket, disallowing the deflected radiant heat from the earth surface access into outer space. Thus, the heat remains below the troposphere and continues to warm the earth—what is referred to as global warming. Today, the world has become hotter than any time during the past 1000 years. Predictions of climate models reveal that global warming will continue if this emission of heat-trapping greenhouse gases continues to be in ascendency. Since biological processes are optimal at certain temperature, global warming/climate change will upset the processes and ecosystems. This will eventually lead to the following abnormalities or maladies:

- Changes in intensity and frequency of storms, flood, droughts, and fires, (which is already ravaging various regions of the world, e.g., the United States of America, Australia, etc.).
- Melting of ice in the polar regions, and rise in sea level with consequent flooding and erosion of low-lying coastal cities and wetlands. It is projected by meteorologists that the Niger Delta could lose well over 15,000 km^2 by the year 2100 with a one-meter sea-level rise
- Protected habitats and their wildlife may no longer have the right climate that supports them, and ecosystems will be jeopardized as the food webs get disrupted.
- Saltwater intrusion into the hinterland (due to rise in sea level) will disrupt freshwater ecosystems killing several freshwater plant species and oligohaline fishes.
- Elevated global temperature would affect sea turtles immensely. This is because the sex of sea turtle hatchlings is temperature-dependent. At higher temperatures, the hatchlings are predominantly females. What this means is that with global warming more female turtles will be hatched, and males will continue to diminish and will eventually go extinct. Thus, the extinction of the males will spell reproductive failure for the turtle population, as there will be no males to fertilize them, and turtles will go extinct.

22.3.8 Improper Waste Disposal

Large volumes of municipal wastes have built up very high in the Niger Delta states as a great number of people flock in these oil-producing zones. Both domestic and industrial sewage are usually not pretreated before discharging them into the aquatic environment. Here, they cause objectionable odor, oxygen depletion, and mass kill of aquatic lives, after causing eutrophication in the water body. Solid wastes such as paper, plastics, wood, cans, etc. are transported into the rivers and streams by runoff and gutter water. Some of the containers have remnants of pharmaceuticals, cosmetics, and poisonous chemicals. Fish, molluscs, crabs, and shrimps gain entry into these containers and get killed in the toxic content. Abandoned or lost plastic nets continue to trap fish and even sea turtles at the coastal fringes.

22.3.9 Overhunting and Trapping of Wildlife

Hunting for bushmeat is a major source of wildlife loss in the coastal states—Delta, Bayelsa, Rivers, and Akwa Ibom. The hunters include amateur teenagers while adolescents and adults constitute the professional hunters' group. There are designated bushmeat markets where consumers buy the fresh and dried forms. Among the markets are Omagwa, Obigbo and Akabuka in Rivers State; Swali in Yenagoa, Bayelsa State; Adeje, Mosogoa, and Ologbo in Delta State; and Uyo and Itu-bridge in Akwa Ibom State. Along the highways of Ikot Abasi-Eket, there are also a good number of bushmeat markets that regularly provide meat to highway restaurants and bars. The indiscriminate hunting of wildlife (both in forest reserves and non-protected areas) irrespective of their size for profit increases the risk of extinction. The extinction of an apex predator (a predator at the top of a food chain) can result in catastrophic consequences for ecosystems, because there will be population explosion of the herbivores and overgrazing will follow. In these states, four types of hunting/trapping are observed to be prevalent, namely (a) troop hunting (TH), (b) Wire noose and drift fence trap (WNDFT), (c) snap trap, and (d) others are occasional use of subterranean trap and matchet blows. Of all these methods, troop hunting and WNDFT methods (Fig. 22.1) record higher success compared with other methods of hunting. They are therefore the most devastating cropping methods for wildlife in the area.

22.3.10 Traditional/Cultural Practices

In the Niger Delta, eco-region myriads of traditional practices have been identified which contribute to biodiversity loss.

- Annual hunting ceremony by youth as proof of maturity or manhood. A typical case in point is the culture in some Ikwerre communities in Rivers State. On a

Fig. 22.1 A wire noose and drift fence trap (WNDFT) commonly used by trappers in the Niger Delta

fixed date for the ceremony, all youth who think they are mature get into the bush early in the morning to hunt. At the peak of the event in the evening, every participant arrives at the community playground to display their bounties as the ceremony hits up. Unlucky ones would not show up (because of shame) but wait till the following season. The implication of the failure is that they will always be silenced by their peers in social gatherings, as they could not maneuver even a rat. Such cultural practices tell much about the wildlife of the place, as many animals are caught that day, because of the competition. Among the cultural practices that hasten biodiversity loss in these states also include:

- Honoring hunters of endangered/charismatic species with titles.
- Fishing with poisonous chemicals/herbs.
- Demand for endangered species parts for spiritual healing by native doctors (e.g., demand for lion teeth and hair, eagle feather, vulture egg, etc.) (Tunde 2017).
- Use of endangered species parts (skins, horns, skulls, etc.) for decoration of wrestlers, palaces, shrines, etc.
- Overharvesting of useful medicinal plants (or their parts) instead of planting more of them.
- Keeping endangered species like monkeys, crocodiles, tortoises, otters, parrots, eagles, etc. as pets.
- Sand mining— destroys benthic organisms as sand is scooped from the river beds; this interferes with spawning sites and alters the migratory routes of fishes. Sandmining is common in waterfronts of Orashi, Nun, Forcados, Otamiri, Imo, and Qua Iboe rivers.

22.4 Petroleum Industry Activities

Akani (2008) and Ugochukwu and Ertel (2008) independently evaluated the effects of petroleum industry activities on wildlife and biodiversity of host communities in some Niger Delta states. Akani (2008) established that the greatest biodiversity loss via oil industry footprints is during the seismic activity when several hectares of forest are deforested to create base camp, location road, and seismic lines. The repeated earthquake-like vibrations (of more than 80 dB) for several months deafen people, especially the elderly, disturb their sleep, and aggravate cardiovascular problems.

22.4.1 Impact of Onshore Seismic Exploration

- The seismic lines ramify the entire prospect areas, traversing various habitats—farmlands, orchards, fishing ponds, shorelines, forests, shrines, farm roads, waterfronts, recreational grounds, etc.—to the discomfort of the neighboring communities. Most natives are compelled to avoid the seismic operation sites, which is tantamount to deprivation of their cultural use of their land. The cutting of these seismic shooting lines culminates in biodiversity loss, habitat fragmentation, and disruption of the ecosystem as the seismic workers continue to disturb the ecosystem for several months. The cost of deprivation of cultural use of their farmland, fishing ports, recreational grounds, etc. for months could run into several millions of naira per affected community. Peasants in the area convert the network of seismic lines to access routes to further exploit the forest resources which hitherto were not accessible. Regrowth of seismic lines created in mangrove swamps is known to be very slow.

- The earthquake-like vibration is usually unnerving and impairs hearing in people especially elderly people; interferes with discussion and siesta (afternoon sleep), disturbs the reading population, etc.
- The noise generated keeps both livestock and wildlife jittery as their heartbeats increase each time there is detonation. Akani (2008) observed that wildlife response to seismic detonations included the following: general increase in vocalization, avoidance reaction, nervousness, footprint, and fecal droppings. Sometimes agitated wild animals like antelopes, bush pigs, cane rats, porcupines, mongooses, and snakes are dislodged from their habitat and killed by seismic workers, as they try to avoid the disturbed area. As many as 75 animals may be killed in this way during such terrestrial seismic survey.

22.5 Impact of Gas Flaring

In a study on the effects of gas flaring on the biodiversity of the Niger Delta, Akani (2019) reported that gas flaring scotches the vegetation and crops (e.g., cassava and pepper) around the stack to death. It scares nocturnal animals like shrews, bats, owls, and nightjars to distances far away from the stack. Because of the low relative humidity it causes, amphibians and earthworms to avoid the stack zone. He further stated that raptors instinctively make incursions into the flame zone in search of offals, in order to warm up, while many weavers are attracted to nest around the warm area. Weavers benefit as the warmth enhances hatchability of their eggs. He called these gas flare-loving birds “gasophilic” birds. Thus, gas flaring creates niche expansion for some species and upsets their normal distribution.

22.5.1 Impact of Pipeline Construction and Operation

Pipeline in Nigeria, right from the construction phase to the operational phase is another major footprint of petroleum industry that leads to great loss of biodiversity. This is particularly the case, when vegetations on the Right-of-Way (ROW), which measure 10–15 m wide runs through several kilometers of rainforests, are cleared. The ROW also may traverse environmentally sensitive sites like wetlands, mangrove swamps, orchards, plantations, fishing grounds, rainforests, etc. During the trenching phase which lasts several months, the open trenches (usually 2 m deep) act like pitfall traps, trapping many ground-running animals and predisposing them to hunting. Often trapped are cane rats, giant rats, porcupines, mongooses, antelopes, snakes, tortoises and terrapins, lizards, skinks, anurans, and insects. After construction, most host communities convert the ROW to a thoroughfare, through which trucks cart away agricultural produce like oil palm fruits, yam, plantain, timber, rubber, fuelwood, etc. Sometimes, the oil company, in the bid to save costs, simply lays the pipeline overland at some segments and the communities misuse them. Like the seismic lines, peasants in the area convert the ROW to access routes to further exploit the forests and fishing grounds which hitherto were not accessible.

22.6 Causes of Pipeline Vandalism and Explosion in Nigeria

The incessant pipeline vandalism in Nigeria has been attributed to three major causes: (a) Complacent attitude of some pipeline operators, (b) Economic status and emotional state of host communities, and (c) Patronage of the vandals' "bounty"(Akani 2008).

22.6.1 Complacent Attitude of some Pipeline Operators

Aged and exposed pipelines: In the country, there is an extensive network of old pipelines between oil fields, as well as numerous small networks of flow lines—the narrow diameter pipes that convey oil from wellheads to flow stations—thereby increasing the chances of leakage occurrence (Awojobi 1981). In onshore areas, most pipelines and flow lines are exposed by erosion or laid above ground and the pipeline operators do not see the urgent need to cover them. In this condition, the pipelines are predisposed to vandalism. Besides, such exposed pipes are prone to corrosion and when there are leaks, they are not detected in time till vandals start scooping oil from them. In the process, an explosion might occur. It is believed that some multinational oil companies overlook the replacement of the old pipes, because of the huge cost involved (Epstein and Selber 2002).

Surveillance or patrol on the pipeline routes is grossly inadequate and most times nonexistent. Sometimes the fuel theft goes on for several weeks without intervention of any security agent.

22.6.2 *Economic Status and Emotional State of Host Communities*

Youth in the host community are embittered psychologically because there is abject poverty, unemployment, feeling of neglect, and marginalization, as the companies fail to fulfill agreed terms in their Memorandum of Understanding (MoU).

22.6.3 *Patronage of the Vandals' Bounty*

Because the society patronizes the illegal and impure product of the vandals, the thieves are encouraged to vandalize more pipes and make brisk business. This is in conformity with the adage that says, "society creates the crime and criminals commit it." Invariably, our society creates the crime by patronizing them. If we all ignore the fake products, certainly the business will crash.

22.7 Consequences of the Pipeline Vandalism and Explosion

Incidents of pipeline vandalism in Nigeria have always been disastrous, not only to the human population but also to the habitat and associated flora and fauna—biodiversity (Ugochukwu and Ertel 2008). When the nefarious act is carried out near human settlements (a rural town or city), in which case many opportunists have access to the severed pipeline, many lives are lost. The least spark of fire around can ignite the volatile petroleum product, which vapor had filled the air for hours, could cause explosion of the pipeline, the fire spreads far and wide as more and more of the fuel is discharged from the outfall. Dark smoke engulfs the area. Within a few hours, there are series of outcry and wailing as many people are incinerated or charred to death–including innocent bystanders in the vicinity (Walsh 1998). While some individuals affected by the inferno often died on the spot, some were maimed and hospitalized with varying degrees of burns; others avoided the hospitals to avoid being interrogated by doctors and detectives on the cause of the incident. Thus, a lot of victims die out in hospital, so the records of death toll are often an underestimate. Table 22.1 shows records of such episodes between 1998 and 2008, which reveals that at least 4363 persons died.

22.8 Biodiversity Loss and Ecosystem Effect

When a pipeline is vandalized in remote areas from human settlements, the inferno may not kill many people but often destroys cultivated farmlands, forests, and swamps ecosystems (Oghensivbe 2008). In postimpact studies of Odau-Obedum-

Table 22.1 Some reported cases of oil facility vandalism in the Niger Delta (1998–2008)

S/N	Date	Location/site of vandalism	State	Estimated death toll	Consequences
1	October 17, 1998	Jesse	Delta	1500	Damage to farmlands/loss of biodiversity
2	April 22, 1999	Bayama (an Ijaw community)	Delta	10	Damage to farmland, environmental pollution
3	July 10, 2000	Near Jesse	Delta	250	
4	July 16, 2000	Warri	Delta	100	
5	November 30, 2000	Fishing village near Ebute, Lagos	Lagos	60	Environmental pollution
6	June 19, 2003	Isuikwuato, Umuahia	Abia	125	
7	June 3, 1999	Akute-odo	Ogun	15	
8	October 13, 1999	Ekikpanire	Delta		Damage to farmland, flora and fauna destroyed
9	January 14, 2000	Gana	Delta	12	
10	February 7, 2000	Ogwe	Abia	15	Damage to farmland and pollution of nearby stream
11	March 14, 2000	Umuagbede	Abia	50	
12	April 22, 2000	Uzo-Uwani	Enugu	6	Damage to farmland
13	June 3, 2000	Adeje	Delta		Damage to forest, plus electric poles
14	June 20, 2000	Okuedjeba	Delta		Damage to farmland
15	July 10, 2000	Oviri court	Delta	300	Damage to farmland and environmental pollution
16	March 2000	Osisoma, Aba	Abia	50	Pollution of forest and nearby stream
17	November 3, 2001	Umudike	Abia	3	Several bicycles burnt; 17 persons injured
18	2001	Tarkwa Bay atlas cove	Lagos	500	Environmental pollution
19	June 15, 2003	Onicha-Amiyi-Uhu	Abia	125	Damage to farmland, dozens of people injured
20	January 6, 2004	Elikpokwuodu	Rivers		About 200 hectares of farmland were oiled plus properties worth millions of naira destroyed
21	July 30, 2004	Agbani	Enugu	7	Several people injured

(continued)

Table 22.1 (continued)

S/N	Date	Location/site of vandalism	State	Estimated death toll	Consequences
22	September 16, 2004	Ijegun	Lagos	60	Water pollution
23	December 2004	Imore	Lagos	60	Environmental pollution
24	May 30, 2005	Akinfo	Oyo	16	34 persons injured
25	January 13, 2006	Iyeke	Edo	7	6 persons injured, damage to farmland
26	May 12, 2006	Inagbe village	Lagos	150	Water pollution plus incinerator of bush within 20 m radius, dozens of people
27	October 2006	Awawa kwali	Abuja		Damage to farmland
28	December 2, 2006	Ijeododo	Lagos	1	Damage to farmland
29	December 24, 2006	Egbula/Egba Agege	Lagos	500	Incinerator of 40 vehicles, a dozen homes, including a mosque and two churches, and many business houses. Many families mourned
30	December 26, 2006	Agba-Okwan Asarama, Andoni	Rivers		Water pollution
31	May 16, 2008	Ijegun, Ikotun	Lagos	16	–
32	May 26, 2008	Gbaga village	Ogun	–	Incineration of bushes

Anyim-Ekuniga-Emelego 2005 pipeline leak in Abua/Odua Local Government Area of Rivers State, and the Tebidaba-Igbomatoru 2008 pipeline incident in Southern Ijaw Local Government Area of Bayelsa State, Akani (2008) reported that several hectares of riparian forest and freshwater swamp were destroyed by the fire. Various trees like *Raphia spp*., *Elaeis guineensis*, *Calamus deeratus*, *Hallea ledermannii*, *Terminalia superba*, *T. ivorensis*, *Albizia ferruginea*, *Cleistopholis patens*, *Symphonia globulifera*, and *Alchornea cordifolia* had the greatest frequency of occurrence among trees affected by the inferno at three sites. Among the frequently killed wildlife a few days after, were; Terrapins, *Pelusios spp*., the short-nose Crocodiles, *Osteolaemus tetrapsis*, Freshwater snakes, *Grayia smithyi*, Red and black line snakes, *Bothriophyllus lineatus*. Amphibians were represented by edible anurans like *Xenopus tropicalis*, *Ptychadena spp*., and *Hoplobatrachus occipitalis*. Among the fishes frequently killed are obligate air breathers (that must come to the surface at intervals to take air), namely *Clarias spp*., *Heterobranchus spp*., *Phractolaemus ansorgei*, *Hepsetus odoe*, and *Malapterurus electricus*.

The forest canopy and floor were all affected; all the crawling vertebrates and invertebrates and weeds were charred, leaving a bare, jeopardized, and desolate ecosystem. Eyo-Essien (2008) reported that runoff from oil impacted sites may find its way into the neighboring freshwater source, used by a rural community for domestic purposes and for fermentation of food like cassava and breadfruit.

22.8.1 Impact of Oil Spill on Biodiversity

Oil spill incidents constitute one of the most devastating types of pollution on biodiversity. It is usually rampant in areas of oil production, its transport route, terminal, and ports and often several barrels of crude oil (and refined petroleum derivatives) are lost to water and sometimes on land. In the Niger Delta, where over 80% of Nigeria's oil is extracted several incidents of oil spillage have been recorded (Akani 2008). The potential impacts of oil spill include the following among others:

- Huge loss of biodiversity.
- Destruction of breeding grounds.
- Unsustainability in fish stock (especially if the spill occurs during spawning season).
- Vegetation destruction.
- Perturbation of the ecosystem and upset of the food web.
- Impairment of human health and activities.

The magnitude of the impact usually depends on factors such as the meteorological conditions at the time of the spill, the type and quantity of oil spilled, frequency of oil spills, and the nature of the receiving environment.

22.8.2 Impact of Refinery on Biodiversity

An oil refinery is an industrial process plant where the heavy crude oil which is extracted from the reservoir is turned into useful products like gasoline (petrol), kerosene naphtha, diesel, waxes, condensates, etc. Refineries are usually located near a water body for cooling, and discharge of its effluents. Large quantities of wastewaters are released into the receiving water body to the detriment of all aquatic organisms. The hazardous gases released into the atmosphere affect aerial animals and plant shoots. Also, solid wastes that are difficult both to treat and dispose of are generated in refineries, some of which may leach into the soil and get absorbed by plants. Potential impacts on biodiversity are as follows:

- Ab initio, large expanse of land is taken, (including storage tanks, refinery plants, administration blocks, car parks, etc.) thereby leading to a permanent loss of biodiversity.

- Refinery effluents are toxic and at their discharge point a lot of fin-fish, shell-fish, and littoral vegetation die.
- Prolonged exposure to toxic chemicals emitted from refineries can cause respiratory tract diseases like cough, catarrh, chest pain, etc., and cognitive health problems.
- It is predisposed to fire outbreak and therefore constitutes danger not only to humans but to biodiversity of the immediate environment.

These impacts are noticeable around the two refineries located in the Niger Delta: Port Harcourt refinery in Rivers State and Warri refinery in Delta State. The numerous de facto refineries (illegal refineries) that have sprung up in the Niger Delta today have exacerbated the impact on the region's biodiversity as their operations often result in fire outbreak and loss of fuel into the environment.

22.9 Recommendation: The Way Forward

In view of the multiple factors militating against biodiversity conservation in Nigeria, and relevance of biodiversity for sustenance of life (MEA 2005; Isbell et al. 2009; Cardinale et al. 2002), there is the need for governments at all levels and O & G companies to mainstream biodiversity conservation in their policies and operations. It is our collective responsibility to restore, in all possible ways, the biodiversity we have lost. Every hand should be on deck; communities, local, state, and federal governments all have roles to play to curb the biodiversity crisis in our country.

- All biodiversity-related organs of government such as Ministries of Environment, Department of Forestry and Fisheries, zoological and botanical gardens, forest reserves, etc. need to be revived; empowered with manpower and equipment to effectively mainstream biodiversity in their policies and operations. Nurseries and hatcheries with sufficient number of trained technicians and laborers are the keys to the functioning of the forestry and fisheries departments. To this end, adequate funding should be allotted to biodiversity conservation in government annual budgets.
- There should be a vigorous tree-planting exercise (afforestation and reforestation) in their OML areas and de-reserved forest reserves, in collaboration with the State Forestry Departments of every state for at least a decade.
- The huge land taken for seismic base camps should be reduced. On decommissioning from a seismic operation site, the O & G company should ensure that they undertake a revegetation project along the seismic lines and the base camps, using native tree species from the neighborhood.
- Both lengths of all pipeline Right-of-Ways (ROW) should be replenished with tree species from the neighborhood (like avenue trees) to compensate for the huge loss of trees during the construction of the pipeline.

- Governments should ensure that fish and shrimp trawlers on our coastal or territorial waters have Turtle Excluder Device (TED) fixed to their boat to protect sea turtles arriving at the coast to breed. Our Naval force or Marine police may be drafted to do a routine check on trawlers in our territorial waters to stall trapping of these herps and bring defaulters to book.
- O & G operators should strengthen sea turtle conservation, if sea turtle breeds in their area of influence. For instance, AGIP should support sea turtle conservation in Akassa and Brass where sea turtles are known to breed (Akani and Luiselli 2011), while SPDC and LNG take the responsibility in Bonny, and Exxon Mobil does the same in Ibeano.
- There should be regular patrol by the navy to ensure that trawlers operating in our territorial waters (around Akassa, Brass, Idama, Bonny, Andoni, Oron, etc.) use Turtle Excluder Device (TED) to protect sea turtles arriving our coast to spawn (Formia et al. 2003; Fretey 2001; Akani and Luiselli 2011).
- Agencies should be formed to ensure regular removal and incineration of solid wastes (plastic containers, nets, textile, wood, bottles, etc.) along the coasts. Some of the lost fishing nets in water continue to trap fish and entangle sea turtles. Sometimes sea turtles mistake floating "pure water bags" for jellyfish (their food). They get choked by the plastic bags and eventually starve to death (Castro and Huber 2005).
- O & G operators should brace up to their responsibility, and ensure implementation to the letter, the mitigation measures recommended by EIA studies in their areas of influence.
- Whenever an oil spill occurs along the coast, a biodiversity rescue team from the affected O & G company should be drafted (in a flying boat) to patrol and rescue any suffocating or moribund birds, reptiles, or mammals and take them to a Marine Research Laboratory for rehabilitation/resuscitation.
- O & G operators should establish a forest reserve near their major footprint or operational area to serve as refuge for displaced wildlife due to their facility, e.g., Gbaran FLT of SPDC in Bayelsa and Finima Nature Park (FNP) managed by NLNG, in Bonny Island. Such protected areas should be properly guarded against poachers from their neighborhood.
- O & G operators develop aquaculture systems at convenient sites and annually generate fingerlings and release them at appropriate times, as compensation or replacement for mass fish kill during oil spills. Native species should be used and this should be done in collaboration with fisheries and aquaculture department in the nearest university.
- Burning of oiled forests and habitats (due to oil spillage) should no longer be allowed as more damage is done to the ecosystem than when nature is allowed to mop up the oil.
- Troupe hunting and trapping with wire noose and fence should be prohibited by law as these two techniques are the major causes of wildlife depletion in the Niger Delta region.
- Washing of motor vehicles and bikes on the shores of rivers and streams, which introduce fuel and grease and other petroleum hydrocarbons into the spawning

grounds' habitats of amphibians and fish, should be prohibited by law, as the freshwater ecosystems and services are disrupted.

- We must stop giving titles to killers or hunters of charismatic species like elephants, lions, leopards, gorillas, chimpanzees, monkeys, manatees, etc. Such ego-boosting titles such as "Ogbuenyi," "Ogbuagu," and "Ebube-dike" (meaning elephant killer, lion killer, great-one-of-amazing-aura, respectively) empower the hunters to get more at all costs.
- Government should establish a functional NIGER DELTA NATIONAL PARK and more forest reserves to protect the vanishing populations of elephant, chimpanzee, Sclater guenon, and Red colobus monkey, in the Niger Delta region (Powell 1995; Werre 2000; Akani 2008). It is indeed an oversight, and a lapse, that the fragile Niger Delta ecosystem with its rare and endemic species, and diverse wildlife habitat and wetland has no national park. Such a park is necessary to safeguard the huge genetic diversity and ensure continuing evolutionary processes.
- Government presence should be manifested in the forest reserves through building administration blocks at the entrance of the reserves, researchers/tourist camps, trails, and mounting warning signs against poaching, policing the forest with well-trained and well-paid rangers properly equipped with uniform and forest-guarding gadgets.
- Government should not allow anybody, O & G, and/or agency to transverse or construct any road across a forest reserve or national park.
- Law enforcement agents should be given special training in enforcement of biodiversity and environmental laws. Defaulters (poachers) should be paraded on TV and taken to court for legal action. Any confiscated live animal should be handed over to the nearest zoo.
- People should be sensitized to know that handling, buying, and selling endangered species or their parts anywhere in the world are unlawful. CITES frowns at it. So, when people are shopping overseas they should ensure that the product they are buying is not made from an endangered species. They should also be educated on the role of Convention on International Trade on Endangered Species (CITES).
- Government should establish and fund a breeding zoo in each of the states to encourage the propagation of endangered species. Every zoo should be equipped with dart guns charged with tranquilizers to sedate any carnivore that jumps the cage. Zoos should be equipped to have an animal farm from which animals will be sourced to feed the carnivores. Sheep which produces sizeable litter is a promising candidate for feeding carnivores like lions and leopards in zoos.
- Government should establish grasscutter farms to provide the bushmeat cherished by the people. With the grasscutter breeding venture, animals in the wild will be left alone to survive.
- Environmental Impact Assessment (EIA) is a major process prior to any O & G facility development to ensure minimal disturbance of the natural environment. Several useful literatures are available which have exquisite guide on ideal EIA processes in Nigeria (Okafor 2006; Ofunne 2010). Investigations into the way the

study is conducted reveal that the O & G companies have more to do, to preserve biodiversity. Most of the EIAs lack thoroughness and are bewitched by personal interest from some barons and powerful politicians.

- Most EIAs in Nigeria are short-lived, to save cost (for logistics and security). Consequently, they lack the necessary details. Biophysical experts are compelled to depend almost exclusively on hunters' reports to get their data; there is scarcely any time for pitfall trapping and setting of mist nets. Thus, quantitative data are difficult to compile and calculation of diversity indices is not possible. What is always seen is just species list. The checklists for wildlife are also considered incomplete because data on nocturnal animals are not collected since there is no provision for night sampling. All too often, night sampling reveals new species unknown to science. This means that O & G companies should include and pay for night sampling and make adequate security arrangement for the consultants.

  – Arthropods and other invertebrate fauna are rarely reported in EIAs and they are important components of food chains in ecosystems traversed by petroleum industry projects. Besides these invertebrates, insects particularly are vectors of parasites which can cause devastating effects in the ecosystem long after a project has begun.
  – Emphasis is often on economic tree species, while weeds, climbers, epiphytes, mushrooms, etc. are rarely reported. The same is true of plant diseases (phytopathology). An existing plant disease before an EIA may continue to devastate the vegetation after the project has begun, and people would erroneously shift blames to the project as responsible for the impact.
  – The O & G companies should develop a referral biodiversity museum for flora and fauna (with pictures) around their areas of operation. The biodiversity museum will house reports on biodiversity issues in the States and should be made available to the reading public at no cost. Such museums will provide taxonomists the opportunity to compare specimens collected from the field with voucher specimens confirmed by the museum, even when the curator is not available.
  – O & G companies should also endeavor to develop a Marine Biology Research Station/Laboratory along the coast where they operate, for effective and continuous monitoring of marine fauna, and changes in sea level. This is necessary as much is yet to be known about our marine mammals, birds, and turtles, and the dynamics of our plankton. A short EIA or Post Impact Assessment (PIA) done along the coast cannot give the true picture of environmental change or change in population size of a given species. The Marine Biology Research Station should include a "rehabilitation clinic" for resuscitation of rescued oiled wildlife from oil spill sites along the coast and "Mangrove Research Unit" for bioremediation of affected mangrove swamps.
  – O & G companies should ensure that mitigation measures prescribed by consultants on Biophysical or Biodiversity issues in EIA process are implemented.

– Regulators drafted to regulate the sampling techniques adopted by consultants in the field are often inexperienced and unqualified, compared to the consultants they are regulating or supervising. Most of them learn on the job from the senior lecturers and professors they are "regulating." Some regulators do not even enter the forests or board the boat in cases of aquatic studies but return to base with "doctored" reports.
– EIA legislations require that EIA processes should be carried out prior to the commencement of any project. The philosophy behind this policy is to ensure sustainable development; that the project does not precipitate any negative side effect in the environment. Hence, it should be a proactive process. But in practice most EIA reports are actually "postmortem" contrived to "fulfil all righteousness" and fence off resistance from concerned NGOs and affected host communities (Ofunne 2010).

22.10 Conclusion

This review has identified and highlighted some weaknesses, commonalities, and gaps associated with various issues concerning biodiversity conservation in Nigeria, that need urgent attention. For instance, the huge loss of biodiversity annually to slash-and-burn method of preparing land for cultivation, overexploitation of forest, wildlife, and fisheries resources and some cultural practices that drive biodiversity loss. Oil and Gas companies add considerable stress on biodiversity through seismic operations, pipeline construction, oil spill incidents, etc. The report has also brought to focus the crucial roles that governments and O & G companies need to play in potentiating biodiversity conservation, i.e., by mainstreaming biodiversity conservation in their policies and operations. They need to employ professionals (specialists) and provide the necessary working equipment and fund annually. Commensurate budgetary allocations are required to encourage research and capacity building in biodiversity conservation. The issue of pipeline vandalism which has severe, devastating effects on the terrestrial and aquatic ecosystems should be properly addressed in line with best practices, to stem further loss of biodiversity.

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Chapter 23
Challenges of Biodiversity Conservation in Africa: A Case Study of Sierra Leone

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Abstract Biodiversity across Africa still plays a critical role in maintaining ecosystem function, services and human well-being especially in rural Africa. Biodiversity conservation in a developing country like Sierra Leone remains a challenge for natural resources decision- and policymakers. Sierra Leone is endowed with considerable natural resources like forests, fish, minerals, agricultural resources, timber and fresh water. Different ecosystems in Sierra Leone face different biodiversity conservation threats and challenges. Forests, wetlands and fresh water, montane ecosystem, coastal and marine ecologies and the savannah ecosystem are the main ecosystems that faced immense biodiversity conservation threats in Sierra Leone. The threats to biodiversity conservation in Sierra Leone are mainly attributed to uncontrolled anthropogenic activities due to weak and obsolete policies. In such, deforestation, illegal logging, unsustainable slash-and-burn agricultural practices, illegal mining, climate change, illegal artisanal fishing, livestock rearing, wildfire, uncontrolled fuelwood collection, charcoal burning and urbanization among others are the major threats that biodiversity conservation faces in Sierra Leone. Despite the establishment of the Ministry of Environment and the formation of the National Protected Area Authority agency, the institutional framework on biodiversity conservation remains weak in policy enforcement, synergies and the sustainable management of forests and other natural resources. Biodiversity resources have contributed to rural livelihood and serve as a source of balanced diet and good nutrition food supplements. In addition, biodiversity serves as a source of income, spiritual fulfilment and has contributed directly or indirectly to the economic development of Sierra Leone. The obsolete Wildlife Conservation Act of 1972 is still the legally binding legislature charge with biodiversity protection in Sierra Leone. Other

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national policies supporting biodiversity conservation are the National Biodiversity Strategy and Action Plans 2003–2010, the National Biodiversity Strategy and Action Plans 2017–2026 and the Fifth National Report on the Convention of Biological Diversity. Although Sierra Leone ratified the convention on biodiversity in 1996, the country lacks a comprehensive biodiversity conservation plan and road map that is specifically designed to minimize the threats facing biodiversity conservation. The study concludes that biodiversity conservation and maintenance are crucial for the provision of ecosystem services and functions for the current and future generations of Sierra Leone. Furthermore, biodiversity is central in improving the various ecological processes such as flood reduction, soil formation and nitrogen-fixing. It is recommended that government introduce biodiversity conservation topics in schools and colleges and provide adequate incentives for experts.

Keywords Biodiversity · Sierra Leone · Forests · Challenges · Conservation · Vegetation

23.1 Introduction

23.1.1 Status of Biodiversity Conservation in Sierra Leone

Sierra Leone is a small West African country endowed with a host of remarkable variety of biodiversity and landscape (Brown and Crawford 2012). In Sierra Leone, biodiversity is considered a resource upon which rural families and communities relied on for fuelwood (energy), medicines, food and other essential commodities (NBSAP 2003). The country is made up of two key forest ecosystems namely: the Guinea-Congo forest biome and the Sudan-Guinea savannah biomes, respectively (GOSL 2017). The main vegetation types include (a) Montane forests; (b) Lowland rainforests; (c) Coastal and marine estuaries; (d) Savannah woodlands; (e) fresh water and wetlands; (f) Farm bushes; (g) Swamp forests and (h) Mangroves (USAID 2007; World Bank 2011). Recent vegetation statistics indicate that bush fallows and farm bush comprise 50% of the vegetation, followed by secondary forests with only 3–5% being classified as closed high forests (GOSL 2017). Closed high forests in Sierra Leone can only be found within the Gola Forests National Park and the Outamba Kilimi Park. These ecosystems are rich in relation to endemism, threatened and rare fauna and flora. Literature suggests that the country's indigenous flora is over 2000 species of which 74 are regarded as endemic to West Africa while 90 of the species are listed as threatened or near threatened by the IUCN (2017) listing (GOSL 2017). Over 1900 terrestrial and aquatic fauna have been recorded in Sierra Leone including 15 primate species, more than 500 bird species and 18 antelope and duiker species, respectively (World Bank 2011; IUCN 2017).

Despite the importance of biodiversity to developing countries like Sierra Leone, the resource is at great risk than ever before. Additionally, ecosystems hosting a variety of biodiversity in the country are constantly at risk. A great number of biodiversity resources are being eroded and lost due to anthropogenic activities such as constant wildfire, slash-and-burn agriculture, deforestation, urbanization, land degradation, mining, wetland destruction, illegal hunting and logging and overgrazing among other factors (USAID 2007; NBSAP 2003). These human activities have diminished the ecosystem function and service delivery capacity over the past decades. Similarly, these actions have resulted in erosion and sedimentation of aquatic ecologies (World Bank 2011).

23.1.2 Forest Biodiversity of Sierra Leone

The diversity, composition and distribution of forest resources are major factors stimulating the debate about the role of forests in combating climate change and sustaining livelihood (FAO and CIFOR 2019). Currently, majority of the county's forests are classified as farm bush and forest regrowth (Government of Sierra Leone 2021). According to the FAO (2016) estimate, Sierra Leone forests cover an area of (2613.8 ha) or 38.1% of land area. Of the 2613.8 ha of forested land, 113,000 ha is characterized as primary and considered the most biologically diverse ecosystems in Sierra Leone. The two most prominent forest types in Sierra Leone are the "**tropical moist evergreen**" and the "**moist semi-deciduous"** forests, respectively (Government of Sierra Leone 2021). These forests are largely located in the south-east and north of Sierra Leone. For instance, the Gola Rainforest National Park forests reserved cover an area of 750 km and is part of the Upper Guinea forests block situated in three districts, namely: Pujehun, Kailahun and Kenema and are considered a biodiversity hotspot in West Africa (Beentje et al. 1994). The northern part of Sierra Leone is however characterized by savannah vegetation. Other types of vegetation common in this region are mixed woodlands and other grassland ecosystems. The largest track of savannah ecosystem in Sierra Leone is located within the Outamba Kilimi National Park (GOSL 2017). Sierra Leone has 48 designated protected areas that comprise national parks, forest reserves, conservation areas and wildlife sanctuaries among others (Fayiah 2020; Blinker 2006; USAID 2007, 2010; GOSL 2019). Among the 48 designated forest reserves, only 29 protected areas are under some form of strategic management and protection (GOSL 2017). On the contrast, the recent Updated Country Environmental Profile argue that although the protected area titles are in place for these forests, yet the management is poor and weak. Nonetheless, the recent Greening European Union Cooperation report (2020) stated that protected areas are the host to the largest stands of primary forests in the country.

23.1.3 Coastal Biodiversity of Sierra Leone

Wetland covers about 4837.9 km of the surface area and comprises mangroves, swamp forests and riparian ecologies (Blinker 2006). Sierra Leone's coastline is of economic and ecological importance to the country's economic development (Massaquoi 2020). Literature has reported that 47% of the coastal line of the country is covered with mangrove ecosystems. About 500,000 ha of mangrove swamps fringe occupy the coastal line of the country (Sierra Leone's fifth National Report to the CBD 2021). These ecosystems play a crucial role in sustaining livelihood of surrounding communities (Massaquoi 2020). Along the coastline, fishing is regarded as the major livelihood activity for the surrounding communities (Sierra Leone's fifth National Report to the CBD 2021). The mangrove ecologies are characterized by oysters, fish, prawns and mangrove creeks (World Bank 2011). Nonetheless, mangrove forests have decreased by 45% between 2000 and 2010 due to intense anthropogenic activities like agriculture (World Bank 2011). The coastline drainage system is made up of some major estuaries, namely the Great Scarcies, Rokel, Jong, Little Scarcies, Moa and Sewa, respectively (Sierra Leone's fifth National Report to the CBD, 2021). The coastal mangrove vegetation of Sierra Leone comprises five major species, namely *Rhizophora racemose, Laguncularia racemose, Rhizophora, harisonni, Avencenia nitida* and *Rhizophora racemose* are found along different riverbeds. In addition, the mangrove and estuaries ecosystems are characterized with high fishes, crabs, shrimps, lobsters, Molluscs, snails, Polychaetes, Echinoderms and Protochordates populations (Government of Sierra Leone's fifth National Report to the CBD 2021).

23.2 Biodiversity Conservation Benefits in Sierra Leone

Underdeveloped countries like Sierra Leone have been benefiting from biological resources since its inception as a nation. Biological resources like forests are grouped into two broad values: the extractive and non-extractive forest values. The latter refers to non-removable biodiversity and is categorized into two: preservative value and ecosystem services (Jackson 2015). Biodiversity has proven to have direct and indirect benefits to society over time. Biodiversity has contributed to rural livelihood, health and socio-economic prosperity especially in remote communities within Sierra Leone. Indirectly, biodiversity has been serving as an adaptation resource to climate change uncertainties and vulnerabilities across rural and coastal communities in Sierra Leone. The following are some of the ways biodiversity has been contributing to the development of Sierra Leone.

23.2.1 Biodiversity Contribution to the Gross Domestic Products of Sierra Leone

Scientific evidence has proven that biodiversity contributes to the economic growth of nations especially countries with global biodiversity hotspots that attract tourist visitation and investment (Blicharska et al. 2019; Guo et al. 2010). Biodiversity enhances great economic productivity for countries endowed with massive biodiversity resources like Kenya, DR Congo and Brazil among others. Biodiversity resources contribute directly or indirectly to economic development of Sierra Leone (GOSL 2017). The sale of biological resources in the form of timber and other non-timber forest products serves as a source of revenue for most Sierra Leoneans. Indirectly, the biodiversity of Sierra Leone plays a key role in attracting tourists to Sierra Leone. The recreational and aesthetic scenery of forest ecosystem attracts nature-loving tourists to Sierra Leone thereby providing foreign income to the country. According to Jackson (2015), forest resources are characterized with intrinsic economic value and hence need to be conserved so that they can meet the needs of the current and future generations.

The annual contribution of biological resources to the GDP of Sierra Leone is presented in Table 23.1. The average contribution of forest resources is 5.5% of GDP annually.

23.2.2 Biodiversity Contribution to Rural Livelihood

In the recent UNDP Human Development Index ranking, Sierra Leone is placed 182 out of 189 and categorized among the 10 least developed nations on earth and below the average of sub-Saharan Africa (UNDP 2020). Also, 60% of the population of Sierra Leone live on a mere US$ 1.25 a day (UNDP 2020). Furthermore, the Human Capital Index (HCI) ranks Sierra Leone 151 out of 157 nations in 2019. In Sierra Leone, majority of the population live below the poverty line hence almost half of the population depends on natural resources for their livelihood and economic well-being. In rural settings across the country, forest edge inhabitants depend on biodiversity for traditional medicine, food, energy, recreational activities, sacred groves function and cultural fulfilment. For instance, along the Freetown peninsular coastlines, artisanal fishing remains an important socio-economic activity supporting economic and family livelihood (USAID 2007). The abundance of biological resources in Sierra Leone has provided jobs for charcoal burners, woodcutters, hunters, loggers and NTFPs traders among others. In such, biodiversity resources are the backbone of livelihood activities and source of employment, income and spiritual fulfilment for most Sierra Leoneans.

Table 23.1 Percentage of sectors contribution to the gross domestic product of Sierra Leone Source: (Statistics Sierra Leone 2020)

Sectors	2016	2017	2018	2019	2020
Forestry	5.4	5.3	5.6	5.6	5.6
Fisheries	6.7	6.6	6.8	6.8	6.9
Livestock	2.1	2.0	2.1	2.0	2.1

23.2.3 Biodiversity Contribution to Food in Sierra Leone

Over the past decades, the human race has relied on biodiversity and ecosystem services and they function to provide adequate alternative food supply to remote communities in Africa. In such, biodiversity offers great benefits that support our environment, economy and society (Blicharska et al. 2019). These benefits maybe generated locally or elsewhere and may either be at a smaller or larger scale (Blicharska et al. 2019). Biodiversity in most parts of Africa serves as a good source of balanced diet and food supplement. In other regions of Africa, biodiversity enhances food security through various plant and animal products derived from the forests. In most remote parts of Africa and Sierra Leone in particular, biodiversity is the source of nutrition and well-being to vulnerable homes especially during crisis periods. Across Sierra Leone and in other parts of Africa, certain insects, birds, reptiles, plants and other wild animals are considered food and have been supporting and sustaining the food chain production system over the past decades (FAO 2019, 2021). Global statistics estimates that about 6000 plant species are used as food supplement (FAO 2021; IPBES 2019; Pilling et al. 2020). However, the recent IUCN (2021) reports suggest that 20% of wild plant species, ocean fish stocks and freshwater fish stock used as food for humans are being threatened globally.

23.3 Biodiversity Conservation Threats and Challenges

Biodiversity is facing both direct and indirect threats from nature and human activities. In Sierra Leone, biodiversity resources are under huge exploitation pressure due to the country’s economic status and poverty level. The threats to biodiversity abundance can be broadly categorized into (1) anthropogenic threats and (2) nature-based threats. However, the bulk of the threats facing biodiversity sustainability in Sierra Leone are anthropogenic in nature (Fig. 23.1). According to Fig. 23.1, the major threats to biodiversity abundance in Sierra Leone are conventional farming methods, timber logging, wildfire outbreak, poverty, climate change, food security and pet trading, population growth, land-use- urbanization and mineral mining, civil conflicts and fuelwood collection, illegal poaching and charcoal burning (GOSL 2003; 2017; USAID 2007; Lindsell et al. 2010; Brown and Crawford 2012; Blinker 2006; World Bank 2014).

23.3.1 Conventional Farming Method Threats to Biodiversity Conservation in Sierra Leone

The ecological capacity, ecosystem services and wild flora and fauna habitats in Sierra Leone are subjected to immerse exploitation pressure from the traditional

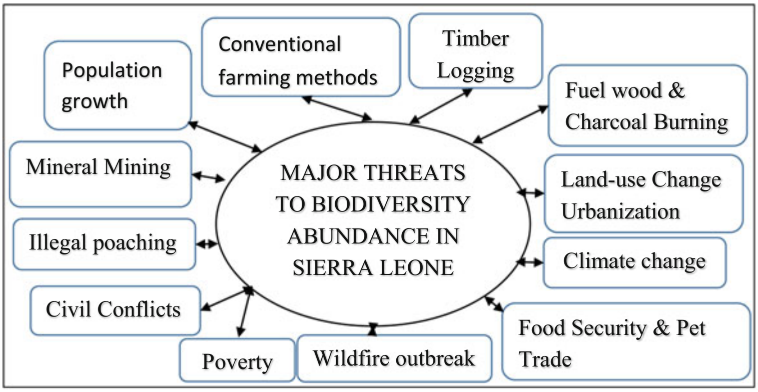

Fig. 23.1 Major biodiversity threats in Sierra Leone

farming method being practiced. Although the twenty-first century is characterized by modern farming methods and implements, however, developing nations like Sierra Leone are still accustomed to the use of crude tools and conventional farming practices like the slash-and-burn farming method. The normalization of short fallow periods in the farming system and the cutting down of primary forests annually have contributed to the massive decline in the country's biodiversity (World Bank 2011; Koroma 2004; GOSL 2003). The conventional farming approaches still being practiced in Sierra Leone are blamed for the drastic decline in biological resources in a once forested nation (GOSL 2003). Exposed farmlands serve as erosion catalysts and lead to the environmental degradation and biodiversity loss. In such, farm bush and secondary forests have become the by-products of the conventional slash-and-burn farming technique still being practiced across Sierra Leone (GOSL 2003). These post-slash-and-burn vegetations are mostly detrimental for primary forest dependents, flora and fauna species. Also, the country's drive for food self-sufficiency has attracted investment in industrial and commercial agriculture hence widening forests clearance scope (Brown and Crawford 2012). As such, slash-and-burn farming method stimulates deforestation, erosion, species extinction, invasive species, wildfires and decline in biodiversity (Brown and Crawford 2012). The quest for primary forest vegetation to practice the annual slash-and-burn farming method across Sierra Leone has made protected areas, national parks and forest reserves unsafe and vulnerable.

23.3.2 Population Growth as a Threat to Biodiversity

There is a direct correlation between population growth and natural resource use especially in Africa. As human population increases, the quest for survival becomes stronger hence natural resources become the target to satisfy human-unlimited wants via unsustainable harvesting methods. Scientific literature reported that when human population increases, exceeding the environment carry capacity, the decline in biodiversity is certain (Chu and Yu 2002). "As human numbers have grown, the number of species with whom we share the planet has declined dramatically" (Mazur 2012). The nexus between population increase and biodiversity decline is complex and is the by-product of mass extinction of biological resources on the face of the planet. Human reproduction is consistent from time immemorial and the population in turn needs to grow and survive and the only means to support the growing human population is altering the ecosystem and replacing species with artificial resources. Some schools of thought believe that close to 30,000 biological resources go into extinction on a yearly basis (Mazur 2012) due to population increase pressure.

The use of technology to provide adequate human comfort is counterproductive to biodiversity increase and conservation as the elimination of critical ecosystem exposes biological resources to great threats and extinction possibilities. While humans have developed technologies to protect themselves from numerous external threats, other biological resources cannot do the same. As population increases, forest vegetations are converted to human settlement, coral reefs are altered, marine biodiversity is exploited and wild animals have served as food while in some cases serve as human pets. According to FAO (2019), biodiversity aids the sustainable production of food via animal and plant species, aquatic animals and microorganisms among others (Dawson et al. 2019).

23.3.3 Mineral Mining Threats to Biodiversity Conservation in Sierra Leone

Across Sierra Leone, mineral mining is mostly associated with biodiversity loss and destruction. Mining poses serious and highly specific threats to biodiversity (Sonter et al. 2018). Literally, minerals are mostly found in biodiversity hotspots in most parts of the world (Sonter et al. 2018). For instance, most gold minerals are deposited in forest reserves or protected forests. This phenomenon has over the years created a trade-off between miners and relevant stakeholders. The discovery of minerals deposited in forested ecosystem is threatening biodiversity sustainability and has also intensified tension between dwelling communities on the one hand and miners, government and community stakeholders on the other hand (Murguia et al. 2016; Butt et al. 2013). The link between biodiversity conservation and mineral mining is highly complicated. Some schools of thought assumed that mineral mining has little or no impact on biodiversity abundance (ICMM 2010) while others consider mineral mining as the worst threat facing biodiversity in the twenty-first century (Sonter et al. 2017). Mining activities' threats to biodiversity conservation in Sierra Leone differ in terms of ecosystem and destruction (Table 23.2). Mining of sand and stones is

Table 23.2 Forms of mineral mining and their threats level to biodiversity conservation in Sierra Leone

Type of mineral mining	Affected ecosystem	Threats level to biodiversity conservation
Sand mining	Coastal shorelines	Moderate threats to marine life
Stone mining	Terrestrial ecosystem	Moderate threats to fauna & flora
Diamonds	Terrestrial ecosystem	Major threats to biodiversity conservation
Gold	Terrestrial ecosystem	Major threats to biodiversity conservation
Iron ore	Terrestrial ecosystem	Major threats to biodiversity conservation
Rutile	Terrestrial & aquatic ecosystem	Major threats to both marine and terrestrial biodiversity conservation
Bauxite	Terrestrial ecosystem	Major threats to biodiversity conservation
Limonite	Terrestrial ecosystem	Major threats to biodiversity conservation
Petroleum	Marine ecosystem	Major threats to marine biodiversity conservation

considered moderate in terms of biodiversity threats but mining activities like iron ore and diamonds among others are major threats to biodiversity conservation.

23.3.4 Illegal Poaching

On the global stage, illegal poaching activities have increased exponentially in recent years and have created easy wealth for poachers. Illegal wildlife animal poaching and harvesting have been described as major threats that biodiversity conservation faces especially in Africa. In countries with porous borders like Sierra Leone, the illegal hunting of wild animals classified by IUCN as endangered is having a devastating effect on wildlife ecosystem conservation and maintenance. Illegal poaching has contributed to the extinction of critically endangered wild animal species from the face of the earth. For instance in Sierra Leone, the endangering or the disappearance of lions, (*Panthera leo*) Cheetah, *African White-backed Vultur, African Gray Parrot, African Elephant* and *Pygmy hippos* among others may not be unconnected with excessive wildlife poaching over the past decades (GOSL 2003; 2017). Due to the economic status of Sierra Leone, majority of illegal poachers consider their action as the only means of survival even though such actions exploit wildlife resources. Illegal poaching is difficult to detect and stop because most of the activities happen at night when law enforcement agents are fast as sleep. Therefore, illegal poaching in a developing country like Sierra Leone is considered a key threat facing biodiversity conservation in Sierra Leone.

23.3.5 Civil War and Biodiversity Decline in Sierra Leone

The civil war in Sierra Leone not only destroyed human life and properties but also exacerbated biodiversity abundance and decline drastically. Forest ecosystems were affected by the civil conflict in two aspects: directly through the bombardment of forests where rebels were hiding and the absence of law enforcement agents to curb rampant commercial logging and indiscriminate burning among others (Minářová 2012; Sutherland et al. 2009; Squire 2001). According to Minářová (2012), forests in Sierra Leone were directly involved in the war. A research done by Sutherland et al. (2009) stated that civil conflict has direct and indirect negative impacts on biodiversity. During the civil war in Sierra Leone, forest covers were destroyed through bombing and wildfire ignited as a result of exchange firing. Similarly, primary forests were used as a hideout while large vegetations were cleared for refugee camps in most parts of the country. The absence of the rule of law during the conflict also indirectly contributed to the decline in biodiversity as ecosystem exploitation became the order of the day. In such, the civil war in Sierra Leone exacerbated the disappearance of biodiversity habitats and endangered species.

23.3.6 Poverty and Threats to Biodiversity Conservation

Poverty is considered a major source of unsustainable harvesting of natural resources and biodiversity decline in Sierra Leone. Sierra Leone's poverty rate stands at 56.8% but remains high (78.5%) in rural areas (World Bank 2020). The massive exploitation of biodiversity in Sierra Leone is directly connected with abject poverty being experienced by majority of the population. The high unemployment rate in the country has exposed natural biological resources as the only survival alternative resource. Unemployed citizens are constantly exploring forests and other terrestrial ecosystems for food and other resources that could be sold to aid survival. In most forest edge communities, forests and their resources are sources of livelihood for entire communities and households. Across Sierra Leone, natural biodiversity decline is critically connected with poverty especially in rural communities of Sierra Leone. The "*increasing and declining poverty levels coincided with an increase or decline in biodiversity in all possible combination*" (Tekelenburg et al. 2009). According to Alkemade et al. (2006), Tekelenburg et al. (2009), and Kessler (2003), biodiversity exploitation increases due to poverty and denotes a decline in natural biodiversity. Scientific literature, however, has reported that factors such as political, ecological, social and income play a critical role in the biodiversity–poverty relationship. Sierra Leone is characterized by high youth unemployment, illiteracy, poverty and corruption (Greening European Union Cooperation 2020).

23.3.7 Wildfire Outbreak Threats to Biodiversity in Sierra Leone

Sierra Leone has been classified as a vulnerable nation in terms of wildfire outbreak and is experienced mostly during the dry season (November and March). Burnt forest vegetation by wildfire serves as cover, food, forage, protection and home (Smith 2000). Wildfire outbreak has been considered a major culprit in the decline of biological resources especially in Sierra Leone (Fayiah and Tulcan 2021). Over the past decades, natural biodiversity has been negatively implicated due to constant wildfire outbreak especially in the northern part of Sierra Leone. Scientific evidence has shown that wildfire outbreak serves as a source of carbon and by extension, results in global warming, influences available biomass stock, impacts the smooth functioning of various life forms and alters marine ecosystems like the coral reef (FAO 2021). In Sierra Leone, the north records the most number of wildfire events over the past decades hence altering the biodiversity landscape of the region (Fayiah 2020). Wildfire ignition has become more intense over the past decades and releases tonnes of carbon, reduces biodiversity, degrades ecosystems, affects life and properties and impacts livelihood negatively. Constant wildfire outbreak has not only affected biodiversity increase in Sierra Leone but has also altered landscapes and influenced ecosystem habitat productivity (Fayiah 2020; Fayiah and Tulcan 2021; Smith 2000). Wildfire also affects birds especially those who nest in low vegetation (farm bush and secondary forests) by surface or crown wildfire. Similarly, wildfires have been detrimental to both small and large mammal species and their habitat sustainability particularly along the Gola Forests.

23.3.8 Food Security and Pet Trade Threats to Biodiversity

Prior to colonization, humans were solely dependent on biodiversity resources for food and other basic survival needs (IPBES 2019). The drastic and breathtaking decline in biodiversity in Sierra Leone threatens food security especially in the rural localities. The decline also poses a serious threat to balanced diet and nutrition (FAO 2019). Due to biodiversity loss in Sierra Leone, ecosystem services are dwindling with certain plant species facing extinction threats. FAO (2019) warns that when biodiversity is depleted, plants, animals, microorganisms, snails, mushrooms and other non-timber forest products will be difficult to replenish naturally over time. Across Sierra Leone, the biodiversity food production system is currently under threat due to the fast disappearance of flora and fauna. The recent IUCN (2021) report alerted that even domesticated crops and animals found in natural ecosystem are declining at a fast rate and that fish stocks are also over-exploited and threatened by human actions. The unsustainable exploitation of biodiversity is contributing to the current food and economic hardship being experienced in Sierra Leone.

23.3.9 Climate Change Threats to Biodiversity Conservation in Sierra Leone

Sierra Leone is extensively endowed with abundant natural resources like biodiversity, minerals and fish stock and yet still considered vulnerable to the adverse effects of climate change. The country was ranked 26 by the Notre Dame Global Adaptation Initiative index and classified as the most vulnerable country to climate change uncertainties and is the 57th most unprepared country against climate change vulnerabilities (Massaquoi 2020). The country's dependence on natural biological resources has exposed the country to climate change impacts and risks (Government of Sierra Leone 2007). The recent climatic events like landslides, flooding, persistent fire outbreak, drought, rainfall pattern change and desertification unfolding in Sierra Leone are poised to affect biodiversity abundance and conservation. For instance, previous healthy ecosystems rich in biodiversity are being affected by the rise in temperature, flooding, drought and unpredictable weather patterns (Government of Sierra Leone 2020). In coastal ecosystems, climate change impact is forcing many mangrove species to either disappear or adapt to unpredictable climatic patterns. Sierra Leone has been experiencing an increase in climate variability, temperature, extreme weather events and other erratic climatic events that are detrimental to biodiversity conservation over the past few years.

23.3.10 Land Use and Urbanization

Land-use change is described as the altering or clearing of natural ecosystem which in turn disrupts the diversity arrangement of both plants and animals belonging to that niche (Bumpi and Kitone 2009). The loss of biodiversity due to intensive land-use activities is a growing problem within Africa. As the affluent continent population grows, more infrastructure, agricultural lands and ecosystem services are demanded hence leading to environmental degradation and biodiversity loss (Marques et al. 2019). In Sierra Leone, population growth, urbanization uproar, illicit land grabbing and intense deforestation are major culprits contributing to the decline in biodiversity over the past years. Scientific literature has discovered that there is a direct linkage between biodiversity decline and land-use change activities especially in developing countries like Sierra Leone (Bumpi and Kitone 2009; Rodríguez-Echeverry et al. 2018). According to Marques et al. (2019), consumption pattern in Africa is responsible for 26% decline in biodiversity across the continent. The intensification of land-use activities especially in urban and peri-urban settings in Sierra Leone is a threat to biodiversity sustainability and by extension adequate availability of ecosystem services. Ecosystem availability and land-use change are intrinsically connected in Sierra Leone and beyond. Besides the loss in biodiversity, land-use change negatively alters and transforms healthy ecosystem landscapes into degraded territories unsuitable to host biodiversity. The loss of primary forest habitats, coastal ecologies and other ecological habitats in Sierra Leone has had negative impact on biodiversity abundance and conservation. For instance, the Western Area Freetown Peninsular Forest's habits loss contributed to the decline in biodiversity across these once rich biodiversity hot zones.

23.3.11 Fuelwood and Charcoal Burning Impact on Biodiversity in Sierra Leone

Within the African continent, wood fuel remains a critical source of socio-economic activities for over 70% of its affluent population with a clear link to biodiversity decline. Wood fuel or fuelwood is considered the primary source of household energy especially in rural and deprived communities across countries in Africa (Sola et al. 2017; Naughton-Treves et al. 2007). In Sierra Leone, wood fuel collection and harvesting are linked with biodiversity loss and detrimental effects on terrestrial ecosystems. Specht et al. (2015) described fuelwood harvesting activities as potential source of ecosystem disturbance and biodiversity loss. Over the past decades, fuelwood and charcoal burning remains the chronic vegetation destruction source and has negatively affected biodiversity abundance and conservation in Sierra Leone (Fayiah et al. 2018). Besides biodiversity loss, fuelwood and charcoal burning are also linked to poverty, wildfire outbreak and ecosystem degradation in developing countries (Sola et al. 2017). The overdependence of rural communities on fuelwood and charcoal for household energy rivals other sources like hydropower, solar power and nuclear plants in Sierra Leone. According to Fayiah et al. (2018), the decline in forests and their biodiversity is directly correlated with the increase in demand for both charcoal and fuelwood across the nation. The UNDP (2018) report on "National Energy Profile of Sierra Leone" noted that if the constant demand for fuelwood and charcoal continues to soar high, both the populations living adjacent to forest communities and the environment (biodiversity) will be affected negatively.

23.3.12 Timber Logging Impact on Biodiversity Conservation in Sierra Leone

Forests are crucial for bio system's sustainability but unprecedented illegal logging across Africa and Sierra Leone in particular, threatens biodiversity abundance and conservation now and in the near future. Across many countries in Africa, timber products demand and prices are on the increase while biological resources are on the decrease. In Sierra Leone, forest loss has been profound due mainly to unsustainable exploitation of timber resources for exportation and income. Rex (2003) noted that intensive logging of forest resources results in massive loss of biological and genetic resources. In forest edge communities of Sierra Leone, illegal logging is an indicator of biodiversity loss especially for threatened species. For instance, illegal logging within the Gola Rainforest National Park has a wide-reaching impact on the conservation of biodiversity as cleared areas alter forest floor regeneration ability and logging noise scares wild animals away. Within the Western Area Freetown Peninsular Forest, timber logging has negatively impacted biodiversity and wild habitat over the past years. In such, biodiversity decline in any given forest is linked to the intensity of logging and other man-made activities ongoing in that forest.

23.4 Biodiversity Conservation Legal Instrument Instituted in Sierra Leone

Globally, the Earth Summit held in Rio de Janeiro in 1992 was among the most outstanding biodiversity summits and its focus was coined “Agenda 21”. Other conventions and treaties on biodiversity are the Nagoya 2010 biodiversity convention held in Japan was focused on biodiversity conservation, equitable biodiversity resource sharing and sustainable use (Husain 2015) and the Bonn Convention on Migratory Species of Wild Animals was held in 1972 and was focused on the management and conservation of migratory wild species. Sierra Leone has over the past few years enacted a hand full of legal instruments designed to deter the alarming rate of biodiversity decline, ecosystem degradation and habitat destruction. Among the few legal policies formulated to protect biological resource, the “National Biodiversity Strategy and Action Plans” 2003–2010 and the National Biodiversity Strategy and Action Plans 2017–2026 have been the two prominent recent legal documents developed by Sierra Leone to conserve biodiversity (GOSL 2003; 2017; USAID 2007). However, the 1972 Wildlife Conservation Act still remains as the legally binding instrument governing the conservation, protection and sustainable management in Sierra Leone. Few projects with biodiversity conservation focus have been implemented over the past decades.

From 1961 to date, Sierra Leone has made significant efforts in joining the global community conventions and treaties geared towards the sustainable development and management of biodiversity and ecosystems. However, the full compliance and implementation of regulations posited by these conventions have been a great challenge for the country (Fayiah et al. 2018). The national biodiversity reports developed by Sierra Leone are presented in Table 23.3. However, there is a possibility that other national biodiversity reports must have been developed in Sierra Leone since independence, but they are hard to come by due to the civil war and the country’s poor record-keeping challenge. Similarly, the legally binding instruments governing the management, protection and sustainable utilization of biodiversity resources in Sierra Leone are presented in Table 23.4, respectively. Although obsolete, the 1972 Wildlife Conservation Act is still the primary legal biodiversity conservation document in Sierra Leone. The different conventions and treaties to which Sierra Leone is signatory are also presented in Table 23.5. Table 23.6 however

Table 23.3 National biodiversity strategy and action instrument

National documents	Scope of biodiversity reports	Date
National Biodiversity Strategy and Action Plans (NBSAP)	Biodiversity of Sierra Leone ecosystem is conserved and protected for the current and future generations	2017–2026
Fifth National Report on the Convention of biological diversity	The convention focuses on emerging biodiversity issues and how they affect national policies, programmes and agenda	2014
National Biodiversity Strategy and action plans (NBSAP)	Provide sustainable measures that will ensure that biodiversity is sustainably exploited so the current and future generations can benefit	2003–2010

Table 23.4 Sierra Leone biodiversity-related legal instruments enacted over the past decades

Instrument	Aim and objective	Enactment date
The Wildlife Conservation Act of 1972	The legislature oversees the protection of wildlife & conservation of wildlife resources (flora and fauna)	1972. The Act is still the legally binding policy
The Forestry Act of 1988	Acts as the principal legislation overseeing forest management and regulation of forest reserves in Sierra Leone	1988. Still the legally binding policy on forest
Draft Forestry and Wildlife Sector Policy 2003	The Act was designed to replace both the wildlife conservation and Forestry Act of 1972 and 1988, respectively	2003. Never adopted formally
Draft Wildlife Policy 2010	This Act was to replace the Conservation and Wildlife Act of 1972 while enhancing full protection of endangered species	2010. Never formally adopted
Draft Forestry Policy 2010	The policy was designed to replace the 1988 Forestry Act. The policy focus was on sustainable environmental preservation & management	2010 never formally adopted
The National Protected Area Authority and Conservation Trust Fund Act, 2012	Act enacted to have oversight authority over National Parks & Protected areas like forest reserves for the purpose of biodiversity conservation	2012
The Bumbuna Watershed, Management & Conservation Authority Acts 2008	To enhance biodiversity conservation through sustainable environmental management along the Bumbuna corridors	2008
National Environmental Policy (NEP)	To conserve natural resources and ensure sustainable utilization and management	1990
Environmental Protection Act (EPA)	To protect both flora and fauna for the current and future generations' need	2008
National Environmental Action Plan (NEAP)	Sustainable environmental management	1995
Draft Wetland Conservation Act 2015	To serve as the legal policy for the protection of wetlands	2015

Table 23.5 Signed treaties targeting biodiversity conservation and protection in Sierra Leone

Biodiversity Conservation related treaties of Sierra Leone	Scope and objectives	Ratified date
Convention on biological diversity (CBD)	Biological diversity conservation, sustainable and equitable utilization of biological resources	Signed & ratified 1994
Ramsar Convention on Wetlands	Sustainable management of wetland and its resources	Adopted 1971 & ratified 2005
International Treaty on Plant Genetic Resources for Food and Agriculture	Ensure the availability of genetic plant resources for food in perpetuity	Signed 2002 & ratified 2004
Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES)	Ensure that the survival of wild plants and animals is not threatened by international trade	Signed 1994 & ratified 1995
The Cartagena Protocol on Biosafety to the Convention on Biological Diversity	Ensure the safe handling, transport and use of living modified organisms (LMOs) emanating from modern biotechnology capable of adversely affecting biological diversity	Signed 2000 & ratified 2003
Convention on the Conservation of Migratory Species of Wild Animals	To conserve migratory wild species through their ranges. Protect wild animal species that move across national boundaries	First signed 2002 & later 2005
World Heritage Convention (WHC)	Seeks to ensure cultural & natural heritage preservation, identification and protection of outstanding world value to humans	Signed & ratified 2005
International Plant Protection Convention (IPPC)	Designed to prevent and control pest outbreak that would affect plants and their products and to coordinate and ensure action is taken	Signed 1997 & ratified 1981
United Nations Convention on the Law of the Sea	The convention set navigation and exploitation limit aim to protect marine environment & organisms	Signed 1981
International Whaling Commission (IWC)	Seeks to conserve and manage whale species globally	N/A
African Convention on Conservation of Nature and Natural Resources	To conserve natural resources and their ecosystems	Signed & ratified in 1968

presents notable biodiversity conservation projects undertaken in Sierra Leone over the past years. In these national biodiversity reports, conventions and legal instruments attest to the effort being made by Sierra Leone in conserving biodiversity amid enormous conservation challenges and threats. These documents present the scope, aim and date of enactment or publication of these documents.

Table 23.6 Notable biodiversity conservation projects in Sierra Leone

Biodiversity projects title	Scope of projects	Project year
Wetland Conservation project	To improve strategic and operational conservation management of wetland areas in Sierra Leone	2011
Biodiversity Conservation project	To assist Sierra Leone in improving the management of selected priority biodiversity conservation sites and enhancing its capacity for replication of best biodiversity conservation practices	2010
The Western Area Peninsula Forest Reserve (WAPFoR) project	To enhance the protection and conservation of the WAPFoR and to decelerate deforestation	2009–2014
Post-conflict reconstruction and Management of Protected Areas in Sierra Leone	To protect and manage forest reserves after the 11-year civil war	2004–2014
Post-conflict rapid Biodiversity assessment of large Mammals in Sierra Leone	To assess biodiversity status of large mammals after the 11-year civil war in Sierra Leone	2004–2005
Capacity Building for Biodiversity Conservation in Sierra Leone	To build the capacity of biodiversity conservation authorities in Sierra Leone	2004–2005
National Marine Biodiversity and Museum for Sierra Leone	To establish a national marine biodiversity museum hub for Sierra Leone	2004–2008
The West Africa Biodiversity and climate change (WA BiCC)	The project's aim was to improve biodiversity conservation alongside climate resilient and low emission within West Africa	2015–2021

23.5 The Way Forward in Conserving and Maintaining Biodiversity Abundance in Sierra Leone

Scholarly literatures have shown that biodiversity conservation, maintenance and protection are critical in achieving the sustainable development goals (SGDs) target and may contribute to the fulfilment of all other sustainable development goals pillars (Blicharska et al. 2019). Biodiversity basically supports the three main pillars of sustainability: environment, society and economy which are interrelated (World Commission on Environment and Development 1987). Sierra Leone has seen a steady decline in biodiversity since independence and that may be attributed to both anthropogenic and natural actions (GOSL 2017). The civil war, weak institutions and weak policy enforcement have been the perennial problems affecting the conservation of biodiversity and ecosystems in Sierra Leone. In order to adequately manage biodiversity for the benefits of the current and future generations of Sierra Leone, the following approaches must be adopted:

1. Sustainable biodiversity resources utilization approaches should be adopted to control the over-exploitation of available natural resources in the country.

2. Land tenures and land ownership retreat issues should be addressed to enhance the holistic conservation of flora and fauna ecologies.
3. The government should develop a coordinated land-use management mechanism to prevent excessive environmental and biological resource degradation and exploitation.
4. Alternative livelihood approaches should be developed in forest edge communities to support the subsistence day-to-day livelihood struggle so that the enormous pressure on biological resources can lessen.
5. Government should improve on the weak institutional framework and outdated regulatory/legislature impeding the sustainable management of the environment and its biodiversity.
6. Institutions like the Environmental Protection Agency (EPA) and Forestry Division and National Protect Area Authority (NPAA) should be strengthened to enhance the protection of the environment adequately.
7. Encourage ex-situ conservation of biological diversity resources across the country.
8. Review and update all outdated biodiversity conservation and management legislations and replace them with an instrument that captures emerging issues and with proposed challenges and solutions to conserve biodiversity.
9. Degraded mining areas across the country should be restored and reclaimed to re-attract native biodiversity once occupying the territory.
10. Protect and properly manage all forest reserves, national parks, wildlife sanctuaries and coastal corridors for the benefits of the future generation.
11. Incorporate biodiversity conservation and maintenance clause in all mining contract agreement.

23.5.1 Conclusion

Biodiversity has been considered an essential component in the sustainable development and livelihood improvement of developing countries especially in rural forest edge communities across Sierra Leone. Biodiversity conservation and maintenance is crucial for the provision of ecosystem services and functions for the current and future generations of Sierra Leone. Biodiversity is fundamental in enhancing various ecological processes like soil formation, nitrogen-fixing and flood reduction among others. Sierra Leone has only enacted few biodiversity-related legal instruments over the past decades.

The Wildlife Conservation Act of 1972 is still the legally binding instrument charged with biodiversity protection in Sierra Leone. The National Biodiversity Strategy and Action Plans 2003–2010, the National Biodiversity Strategy and Action Plans 2017–2026 and the Fifth National Report on the Convention of Biological Diversity are the three most prominent national biodiversity conservation strategies and plans implemented in Sierra Leone. The major threats facing biodiversity abundance in Sierra Leone are mostly anthropogenic in nature. They include; poverty, fuelwood and charcoal production, conventional farming methods, timber logging, urbanization, deforestation, wildfire outbreak, climate change, food security and pet trading, population growth, land-use and mineral mining, and civil conflicts. Biodiversity has proven to have direct and indirect benefits to society over the past decades. Furthermore, biodiversity has contributed to rural livelihood, health and socio-economic prosperity especially within remote communities in Sierra Leone. Biodiversity has over the past decades served as a good source of balanced diet and other food supplement for rural and remote communities especially during the hunger period (rainy season) in Sierra Leone. Similarly, biodiversity is considered a palatable source of nutrition and human well-being therapy in most rural parts of Sierra Leone especially during crisis periods like the civil war. In addition, biodiversity resources serve as the backbone of livelihood activities and source of income, local employment, and spiritual accomplishment for most Sierra Leoneans. Over the past years, biodiversity resources have been found to contribute directly or indirectly to the economic development of Sierra Leone. This study will serve as a baseline for biodiversity conservation challenges in Sierra Leone and the way forward in combating these challenges.

23.5.2 Recommendations

1. The government should introduce biodiversity conservation concept in senior secondary schools, colleges and research institutes across Sierra Leone.
2. Biodiversity regulations and legislations should be enforced and monitored to ensure adequate compliance.
3. Government and universities should train more biodiversity conservation experts and deploy them to strategic biodiversity hotspots.

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