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Sumit Chakravarty *Editors*

Land Degradation Neutrality: Achieving SDG 15 by Forest Management

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Preface

Worldwide depletion of forest resources, forest fragmentation, forest encroachment, overgrazing, unscientific and over-exploitation of biodiversity and unscientific agricultural practices are some of the causes of land degradation. Globally, about 25% of the total land area has been degraded. Land degradation has been estimated in 25% of the total land area, globally that affected more than 3.2 billion people. Land degradation can be explained as a consequence of the violation of the principles of the circular economy. It is a worldwide phenomenon and is happening in all kinds of climates. Except for activities like mining and clear-felling of forests, land degradation is not apparent visually as it continues slowly and hence can be termed as a "slow killer."

Localised and small-scale efforts through mine spoil rehabilitation and afforestation in degraded lands have been going on in every country; however, the scale and pace of such activities have not been able to match the pace of degradation worldwide. Land degradation, though a global phenomenon, has similar precursors worldwide. It had now been realised that land degradation in one part of the world has the potential of affecting other parts of the world through soil erosion, global warming and biodiversity depletion (food web). A collective effort is required to be done. This is possible by sharing experiences, pooling funds (so poor nations can be supported), knowledge sharing, bringing international consensus, etc.

Land Degradation Neutrality (LDN) has a manifestation in different international programmes such as REDD+ (Reducing emissions from deforestation and forest degradation), SDG 13 (climate action) and SDG 15 (life on land), UNCCD (United Nations Convention to Combat Desertification) and IUCN Global Drylands Initiative (GDI). LDN promises 'triple-win' benefits that include mitigating climate change, conserving biodiversity and uplifting local communities. Multiple ways and strategies need to be adopted to achieve LDN. Through this book, efforts have been made to compile the challenges and strategies to achieve LDN.

The book compiles topics which are directly and indirectly related to achieving LDN. Global forest resources, forest fragmentation and its consequences, drivers of forest land degradation, deforestation and biodiversity depletion, assessing land degradation using SDG indicators, ecological restoration of degraded forests, forest as a means of livelihood, climate change and its impact on the forest, importance of mangroves forest and their protection, mine spoil rehabilitation, tree plantation for carbon sequestration and carbon neutrality, protected area and their role in conservation, role of REDD+ in achieving LDN, case studies on forest degradation, reducing pressure on grasslands and urban forest as a means of achieving LDN.

Editors feel that the contributing authors have done justice in compiling the information on LDN. We appreciate the commitment of the contributing authors and take the responsibility for those important issues still missing in the book, as LDN is a large canvas and cannot be covered in a single manuscript. Editors wish to thank all the contributors for complying with the schedule and bearing with persistent requests and queries made by Editors.

Chandigarh, India — Pankaj Panwar
Cooch Behar, West Bengal, India — Gopal Shukla
Jhansi, Uttar Pradesh, India — Jahangeer A. Bhat
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About the Editors

Pankaj Panwar has research experience of 20 years in subtemperate, dry subtropical and humid subtropical climates. He started his carrier as Assistant Professor (Forestry) in Uttar Banga Krishi Viswavidyalaya, West Bengal. Later, he joined ICAR Research Complex for Eastern Region, Ranchi Centre as Senior Scientist (Forestry). Presently, he is working as Principal Scientist (Agroforestry) at ICAR—Indian Institute of Soil and Water Conservation, Research Centre—Chandigarh since 2014. He has to his credit more than 90 research publications along with seven books. He has also published eight technical bulletin/brochures and one policy paper. At present, Dr. Panwar is working on Natural Resource Management, watershed development and sustainable land management, tree-crop interactions in agroforestry and developing land-use technologies for resource poor farmers.

Gopal Shukla is Assistant Professor of Forestry in Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal, India. He has worked under NAIP, NICRA and SERB Projects funded by Government of India. He has more than 75 peer-reviewed national and international publications, four books and 20 book chapters. He had guided five master's and two doctoral students and handled three externally funded projects. Dr. Shukla received SERB Young Scientist Award in 2011 from Science and Engineering Research Board, Department of Science and Technology, Government of India, New Delhi and Scientist of the Year Award in 2018. The focus of his research and development work is on forest ecology and conservation and sustainable land management.

Jahangeer A. Bhat is currently a faculty member at Rani Lakshmi Bai Central Agricultural University, India. He served as Head, Department of Forestry at College of Agriculture, Fisheries and Forestry, Fiji National University, Republic of Fiji Islands. He has been instrumental in the development of Higher Education (HE) and Technical and Vocational Education and Training (TVET) programmes of forestry and allied programmes at Fiji National University. Dr. Jahangeer worked closely in the area of accreditation with the Fiji Higher Education Commission and with other related forestry stakeholders. He has more than 60 published articles, which include research articles, review papers, conference papers, book chapters and books with national and international repute. His 11 years research in India and the South Pacific Island countries includes many emerging issues in forestry, including biodiversity conservation, traditional plant knowledge and sustainable forest resource management. His main focus of research is on the vegetation ecology, ethnobotany, evaluation of ecosystem services, forest plant biodiversity, climate change and socio-cultural issues in forestry.

Sumit Chakravarty is currently working as a Professor and Head, Department of Forestry in Uttar Banga Krishi Viswavidyalaya, Cooch Behar, West Bengal, India. He has more than 100 peer-reviewed national and international publications, five books and 25 book chapters. He has guided ten master's and five doctoral students and handled four externally funded projects funded by Government of India. He has conducted research on forestry, agroforestry, medicinal plants and climate change. The focus of his research and development work is on forest biodiversity assessment, forest ecology, conservation and restoration of degraded lands.

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Forest Resources of the World: Present Status and Future Prospects

1

Manendra Singh, N. N. Shahina, Subrata Das, A. Arshad, Sajitha Siril, Debidatta Barman, Umrasong Mog, Pankaj Panwar, Gopal Shukla, and Sumit Chakravarty

Abstract

Global forests are the hub of many economic, social, and environmental goods and services that influence the contentment of forest-dependent rural communities, regional and national economies, and achievement of the United Nations Sustainable Development Goals. The extent of the forest area continues to decline at an average rate of 4.7 million hectares per year globally. Around 1.6 billion people directly depend on forest resources for their basic requirements. Forests are recognized for reducing food insecurity, addressing poverty alleviation, and enhancing agricultural and environmental sustainability sustenance of rural people across the world. In addition to the increasing population pressure, forests are also experiencing repercussions from fire, diseases and pests, invasive alien species, developmental projects, improper forest governance, and climate change. To address these issues and conserve the forests and their resources, international fora developed numerous conservation strategies as well as global forest goals. The participation of local communities is also critical in this regard, and market prices for timber and timber products must be nondiscriminatory. The maintenance of the sustainability of forests and other natural resources is possible only through participatory and collaborative forest governance.

Keywords

Forest resources · Threats · Forest sustainability · Forest conservation

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1.1 Introduction

Global forest resources are the primary repositories of terrestrial biodiversity and most productive land-based ecosystems on Earth (Chakravarty et al. 2012; Poudyal et al. 2019; Goals UGF 2019). As per the Global Forest Resource Assessment (FRA) 2020, the total forest area is about 4.06 billion hectares (ha) or 31% of the total geographic area, out of which 54% of the global forests area is confined only in five countries, i.e., the Russian Federation, Brazil, Canada, the United States, and China. Global forests are classified into four major forest groups: the world's tropical forests occupy about 45% followed by boreal (27%), temperate (16%), and subtropical forests (11%). It is estimated that 93% (3.75 billion ha) of forests are regenerated naturally, and only 7% (290 m ha) is planted forest; however, over the period 1990–2020, naturally regenerating forest has been declining and the planted forest area has been consistently increasing (FAO 2020).

Forest is a multitude of functions that substantially influence the environment, economic development, and social and cultural benefits (Kupfer and Karimanzira 1991; Creutzburg et al. 2017; Sing et al. 2018). Around 1.6 billion peoples directly depend on the forest for food, fuel, timber, shelter, and employment (Goals 2019); moreover, forests are providing 86 million green jobs (UNEP 2021a). Forest resources reflect similarities with many other resource systems that make sustainable, rational, and equitable with governance and control challenges (CIFOR 1999). The rapid growth of the world's population is expected to reach almost 10 billion by 2050 (Leeson 2018; Gu et al. 2021); reconciling the need for forest conservation with the increasing basic requirements of humans for food, shelter, and fuel will be more difficult than ever.

Degradation of forest resources is more likely in open-access forests than in private and reserved forests. Traditional forest resource theories assumed that forest users were incapable of coordinating to counter the incentives to overharvest (CIFOR 1999). Tropical forest is experiencing rapid conversion of forest for commercial agriculture (Pearson et al. 2017; FAO 2020). Forest management plans for the conservation of forest ecosystems are significantly influenced by the increasing impact of anthropogenic pressure. However, understanding the consequences of climate change on forests, industries, and forest-dependent communities, forecasting how these effects could vary over time, and incorporating this information into management plans required for forest management to adapt to climate change or minimize the impact (Easterling and Apps 2005) are important. This necessitates a diverse set of skills and novel approaches to forest management choices. Partnerships that bring together researchers from several disciplines with forest managers and local stakeholders can help create a shared knowledge of future difficulties and enhance decision-making in the face of climate change (Keenan 2015). Adapting forest management to climate change entails monitoring and forecasting change, steps to mitigate negative repercussions or capitalize on potential advantages (Levina and Tirpak 2006).

1.2 Global Forest Resources: Current Status and Trends of World's Forests

Forests are vital resources for achieving Sustainable Development Goals (SDGs) such as sustainable production and consumption, poverty reduction, food security, biodiversity conservation, and climate change mitigation as well as adaptation. Global forests provide benefits that extend well beyond their limits, assisting in the preservation of optimal environments for life on Earth. Monitoring the extent and other characteristics of the global forests and their resources helps identify and rectify unsustainable activities, as well as restore and rehabilitate degraded forest areas (EFI 2019).

Over the past five decades, a number of global assessments of forests have been done (UNEP 2020). According to the State of the World's Forest 2020 report, the estimated forest area in the world is 4.06 billion ha, which approximates about 31% of the total land area. Although forests do not have a uniform geographical distribution, this area corresponds to 0.52 ha per person. Tropical forests account for the majority of the world's forests (45%), followed by boreal, temperate, and subtropical forests. The distribution and characteristics of the forest across the major biogeographic regions in the world are depicted in Table 1.1.

In spite of the fact that the extent of global forest area is declining, studies report that the rate of loss of forest has reduced significantly. Since 1990, the earth has lost a net area of 178 million hectares (m ha) of forest, and the rate of net forest loss has slowed significantly between 1990 and 2020, owing to a reduction in deforestation in some countries and an increase in forest area in others due to afforestation and natural forest growth. It is also notable that the total loss of forests also decreased from 5.2 m ha per year during 2000–2010 to 4.7 m ha per year from 2010 to 2020. From 2010 to 2020, the net loss of forest area was highest in Africa (3.9 m ha), followed by South America (2.6 m ha). The increase in net forest area has been seen in Asia, followed by Oceania and Europe (FRA 2020). The present status of the top ten countries or territories in global forest resources is given in Table 1.2.

Global forests can be classified into naturally regenerated forests and planted forests (Muukkonen 2009). Of the total forests in the world, naturally regenerated forests account for about 93%, and planted forests constitute the remaining 7%. Since 1990, the area of naturally regenerating forest has decreased, whereas the area of planted forest has expanded by 123 m ha. In the last decade, the rate of increase in the area of planted forests has also been observed to be slowed. In addition to this, there are plantation forests covering around 131 m ha, accounting for 3% of global forest area and 45% of all planted forest areas. South America and Europe have the highest and lowest proportion of plantation forests, respectively (FAO 2020). Primary forests are composed of native species, the absence of human activities, and undisturbed ecological processes, and they are irreplaceable for sustaining biodiversity (Gibson et al. 2011; Ruiz 2020); they cover about one billion ha. Globally, more than half of the primary forests are found in Brazil, Canada, and Russia. Since 1990, the extent of global primary forest has decreased by 81 m ha. However, more than two billion ha of the world's forests are under management with well-defined

Table 1.1 The distribution and characteristics of the forest across the major biogeographic regions

S. No.	Continents	Forest area (1000 ha)	Naturally regenerating forests (%)	Deforestation (1000 ha/year)	Age of world forest area (%)	Forest in protected areas (%)	Forest management plans (%)
1	Africa	636,639	98	4414	16	27	24
2	Asia	622,687	78	2235	15	25	64
3	Europe	1,017,461	93	69	25	6	96
4	North and Central America	752,710	94	436	19	11	59
5	Oceania	185,248	97	42	5	16	31
6	South America	844,186	98	2953	21	31	17
7	**World**	**4,058,931**	**93**	**10,150**	**100**	**18**	**54**

Table 1.2 The current ranking of the countries or territories in terms of global forest resources

Rank	Forest area	Average annual net loss (2010–2020)	Average annual net gain (2010–2020)	Planted forest	Plantation forest	Wood land
1	Russian Federation	Brazil	China	Bahrain	Bahrain	China
2	Brazil	Democratic Republic of Congo	Australia	Egypt	Faroe Islands	Russian Federation
3	Canada	Indonesia	India	Faroe Islands	Greenland	Argentina
4	United States of America	Angola	Chile	Greenland	Kuwait	Namibia
5	China	United Republic of Tanzania	Vietnam	Kuwait	Libya	South Africa
6	Australia	Paraguay	Turkey	Libya	Ireland	Canada
7	Democratic Republic of Congo	Myanmar	USA	Czechia	Cabo Verde	Brazil
8	Indonesia	Cambodia	France	Netherlands	Belgium	South Sudan
9	Peru	Bolivia	Italy	United Kingdom	Uruguay	Kenya
10	India	Mozambique	Romania	Ireland	Rwanda	Botswana

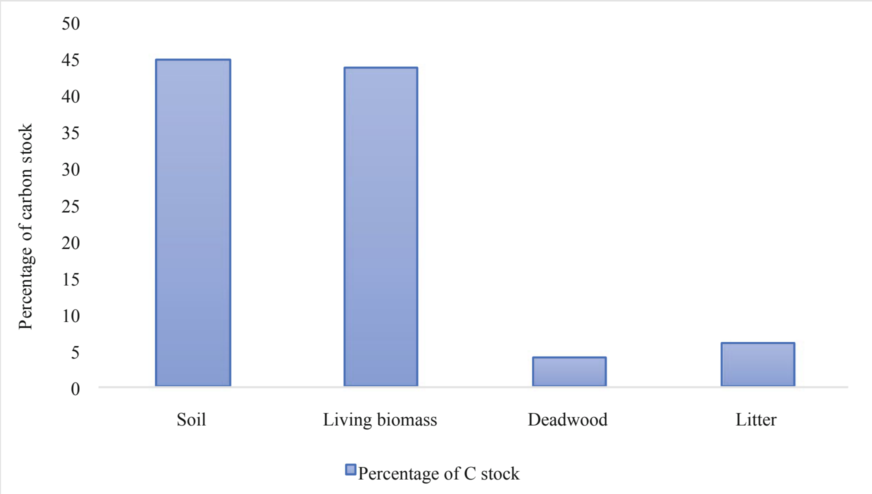

Fig. 1.1 Proportion of carbon stock in forest carbon reserves in 2020. (Source: FAO 2020)

management plans. The extent of forests under management plans has increased by 233 m ha since 2000, reaching 2.05 billion ha in 2020 (FAO 2020).

Due to a net loss in forest area, the world's total growing stock of trees decreased substantially, from 560 billion m^3 in 1990 to 557 billion m^3 in 2020. On the other hand, the global and regional growing stock is expanding per unit area; it increased from 132 m^3 per ha in 1990 to 137 m^3 per ha in 2020. The maximum growing stock (per unit area) is confined in the tropical forests of South and Central America and West and Central Africa, approximately 606 giga tons (gt) of living biomass (above and below ground) and 59 gt of deadwood in the world's forests. Since 1990, total biomass has declined marginally, but biomass per unit area has grown (Sasaki et al. 2016; FAO 2020; UNEP 2020). The majority of forest carbon is found in living biomass (44%) and soil organic matter (45%) of the forest, with the rest in deadwood and litter (Mukul et al. 2020; FAO 2020) (Fig. 1.1). The total carbon stock in forests declined from 668 gt to 662 gt during the period 1990–2020; however, carbon density increased marginally from 159 to 163 tons per ha during the same period (FRA 2020).

Around 1.15 billion ha of global forests are maintained for the production of wood and nonwood forest products. In addition, 749 m ha forests area is assigned as multiple-use forests, including for production purposes. Since 1990, the area of forest devoted only to production has been largely consistent, but the area of multiple-use forest has plummeted by around 71 m ha. Approximately 10% of the world's forests are set aside for the conservation of biodiversity.

In the last decade, the rate of increase in the area of forest designated largely for biodiversity conservation has slowed. An estimated 398 m ha of forest has been classified for soil and water conservation, an increase of 119 m ha since 1990 (FAO 2020). In the last decade, the pace of expansion in the area of forest assigned for this purpose has increased. Over 180 m ha of forest is primarily used for social services such as recreational, tourism, education, research, and the protection of cultural and spiritual sites. Since 2010, the allocated area for social service has continuously risen at a rate of 186,000 ha each year (FAO 2020; UNEP 2020).

1.3 Global Forest Goals and Targets (GFGT): Perspective Future Scenarios for Forest Management

A report (Goals 2019) based on the United Nations (UN) Strategic Plan for Forests 2030 offers a universal action framework to prevent forest degradation and deforestation and to maintain the sustainability of different forest ecosystems and trees outside of forests that provide economic, social environmental benefits. The Strategic Plan was drafted during a special session of the United Nations Forum on Forests (UNFF) in January 2017 and then adopted by United Nations General Assembly (UNGA) in April 2017. The Strategic Plan refers to a structured framework of forest-related activities such as international arrangement on forests and their components, pertaining to create greater coherence, collaboration, and synergies across UN entities in support of the vision and purpose. The UN mission is to promote sustainable forest management and protection of the environment by strengthening sustainable development through coordination, political support, and action. The principles and visions of the 2030 Agenda for Sustainable Development provide semantics for integrating and collective GFGT that are both voluntary and universal in nature and are intended to contribute to the progress of sustainable development. These goals and targets aim to encourage and offer a framework for volunteer forest conservation, actions, donations, and greater collaboration by countries and international, regional, and local organizations, partners, and stakeholders from the subregion and nongovernmental organizations (NGOs).

Forests cover a vast spectrum of ecosystems with a wide range of features, including species composition, structure, and the level of change by human and nonhuman causes (Kimmins 2004; Dieler et al. 2017). Therefore, forest acreage alone is insufficient for identifying relevant trends and evaluating progress toward sustainable forest management. Diversity in forest management plans is needed to sustain and provide multiple ecosystem services. The ecosystem service framework provides opportunities to forest management by revealing areas of conflict or co-production and potential trade-offs that may arise from adjusting management intensity driven by GFGT (Table 1.3).

1.4 Conservation and Sustainable Use of Forests and Forest Resources

Food and Agriculture Organization (FAO) described that conservation and sustainable utilization of forests and their resources are important since all the activities and phenomena on the earth directly or indirectly rely on them. They are the source of

Table 1.3 Global forest goals and targets to the 2030 Agenda (Goals 2019)

S. No.	Global forest goal	Targets
1	Managing forest sustainably for its conservation in addition to restricting GHG emission.	(a) Global forest area will be increased by 3%, thus maintaining forest carbon stock. (b) Promote global afforestation and reforestation, prevent deforestation, and significantly restore degraded forest land through afforestation and reforestation. (c) The global resilience and adaptive ability of all types of forests to natural catastrophes and the effects of climate change have been greatly improved.
2	Enhance forest-based economics and social and environmental benefits, including by improving the livelihoods of forest-dependent people.	(a) Extreme poverty of forest dependents will be eradicated. (b) Increase in small-scale forest-based firms and their access to affordable financial services and integration into supply chains and markets, particularly in developing nations. (c) Forests and trees could provide a substantial contribution to food security. (d) Among the natural resources, forests have greatly expanded their contribution to social, economic, and environmental development. (e) The mandates and continuously works on relevant agreements and instruments, the contribution of all types of forests to biodiversity conservation and climate change mitigation and adaptation is strengthened.
3	Globally, protected forest area should be increased significantly and management of other forests for sustainable supply of forest products.	(a) Worldwide protected forest area or area under effective conservation status is ominously increased. (b) The area of forests under long-term forest management plans is significantly increased. (c) The utilization of forest products from sustainably managed forests is significantly increased.
4	Strengthen scientific and technical collaboration and partnerships by mobilizing considerably enhanced, new, and extra financial resources from all sources for the implementation of sustainable forest management.	(a) Provide substantial incentives to developing nations to enhance sustainable forest management, including conservation and replanting, by mobilizing large resources from all sources and at all levels. (b) Forest-related finance from all sources at all levels is greatly expanded, including governmental, intergovernmental, corporate, and charitable financing. (c) In the forest sector, public–private partnerships and triangular cooperation

(continued)

Table 1.3 (continued)

S. No.	Global forest goal	Targets
		on research, technology extension, and innovation have considerably improved and grown. (d) A number of nations have developed and implemented forest funding plans and access to all types of financial sources. (e) The collection and availability of forest-related information on multidisciplinary scientific evaluations have been increased.
5	Strengthen the contribution of forests to the 2030 Agenda for Sustainable Development by promoting governance frameworks for implementing sustainable forest management, especially through the UN forest instrument.	(a) The number of nations incorporating forests into their national sustainable development plans and/or poverty reduction programs has significantly increased. (b) Forest law enforcement and governance are notably improved by national and subnational forest authorities; thus, globally illegal logging and associated trade are decreased. (c) Forestry-related policies and programs at the national and subnational levels are integrated, coherent, and symbiotic across the ministries, departments, and authorities; they are consistent with national laws and engage relevant stakeholders, local communities, and indigenous peoples, fully recognizing the UN declaration on the rights of indigenous peoples. (d) Forestry sectors and current issues are completely incorporated into decision-making processes in relation to land-use planning and development.
6	Improve the coordination, cooperation, integrity, and synergy on forest-related issues among the members of United Nations for collaborative partnership among different stakeholders.	(a) In view of UN, programs on forests are consistent and complimentary that incorporate appropriate GFGT when applicable. (b) In view of 2030 Agenda for Sustainable Development, forestry programs on "Collaborative Partnership on Forests" organized by UN members should be coherent and complementary and integrate the multiple contributions of the forestry sector. (c) Sectoral coordination and collaboration to promote sustainable forest management and to combat deforestation and forest degradation have greatly improved.

(continued)

Table 1.3 (continued)

S. No.	Global forest goal	Targets
		(d) A better grasp of the notion of sustainable forest management is achieved and an allied set of indicators is identified. (e) Implementation of Strategic Plan for sustainable development and the work of the forum are strengthened by inputs and involvement of major stakeholders.

multifarious tangible and intangible benefits such as the provision of timber and other non-timber forest products, modulators of hydrologic flow, conservators of soil and biodiversity (Liang et al. 2016), regulating carbon cycle, etc. The estimated cost of goods and services provided by the world's forests is around US $ 75 to 100 billion per annum. Forests abode 80% of the global terrestrial biodiversity. Moreover, 1.6 billion people (25% population of the world) depend on forest resources for their subsistence, livelihoods, employment, and income (Goals 2019). About 40% of the extremely poor people in rural areas reside in forests and savannahs, and around 20% of the total population in the world, particularly women, children, landless farmers, and other vulnerable categories of the society depend on forests to satisfy their dietary and income requirements. Therefore, the global forests act as socioeconomic safety nets for the people and communities at times of crisis (FAO 2018).

In the present scenario of the globalizing era, forests also play a pertinent role in the mitigation and adaptation of climate change by preventing global warming and building sustainable societies. Forests serve as the second world's largest storehouses of carbon, after oceans. Global forests sequester around one-third of the total carbon dioxide (CO_2) emission from the combustion of fossil fuels (~2.6 billion tons); thus, forests act like two sides of the same coin in carbon management (IUCN 2021), as forest resources are considered as largest sink of carbon governed by conserved, managed, or planted sustainably, and also the largest significant carbon sources when they are degraded or destroyed (FAO 2003). International organizations, as well as agreements like the Kyoto protocol, Land Use, Land-Use Change and Forestry (LULUCF), and UN Framework Convention on Climate Change (UNFCCC), have revealed the significant implications of the forestry sector in climate change mitigation and adaptation strategies (IPCC 2019).

Forests have enormous potential to reduce poverty by 50%, especially in developing countries, and could thus contribute to the SDGs of reducing poverty. The World Bank (2002) reports proposed that the livelihood of about 90% of the extremely poor people in the world is supported by forest resources. The global forests act as an important source of income and employment for the rural people, particularly the women and children; they are sometimes entirely dependent on these forest resources to satisfy their daily sustenance. A study by Widianingsih et al. (2016) in the Batin Sembilan ethnic group in Indonesia, for example, showed that

36% income of the indigenous household is contributed by the forests. The rural agricultural productivity is also under the influence of forests through the provision of various ecosystem goods and services such as regular water supply, recycling of nutrients, protection against soil erosion, and providing animal fodder. However, poor forest statistics and valuation, systematic and scientific quantification of the forest contribution to poverty alleviation, economic development, and promotion of sustainable livelihoods are not yet explored.

Global forests serve as a hub for a variety of non-timber forest products (NTFPs) that supplement and complement the agricultural income of the rural livelihoods (Angelsen and Wunder 2003). Shackleton and Pandey (2014) reported that the contribution of NTFPs to the income of rural households ranges from 10% to 60%, depending on the characteristic differences in national, economic, and cultural milieu along with the variation between poor and rich households. In addition to that, medicinal and fuelwood supply from the forests enhance the health as well as nutritional security of the forest-dependent communities. For the forest-dependent communities, the collection and sale of non-wood forest products also serve as subsistence and economic buffer during lean periods, during which the agricultural productivity has been dwindling for a variety of reasons (Arnold and Ruiz 1998). NTFPs also act as drivers of economic growth; hence, it is important to conserve the forest for their sustainable collection and utilization.

Forests occupy almost one-third of the earth's surface, serving as the major source of diverse values for humankind. A multitude of ecosystem services is provided by healthy forest ecosystems (Fig. 1.2). The earliest studies show that forest ecosystem services (US $ 4.7 trillion) contributed to a significant portion of the total ecosystem services (US $ 33 trillion per year) benefitted (Jenkins and Schaap 2018). The Millennium Ecosystem Assessment (MEA) also envisaged that "nonmarket" forest services, such as the ecological and social services from the forest, exceeded the market value of timber. Thus, to cater to the continued provision of these services, the maintenance of healthy forest ecosystems is imperative.

Thus, in order to achieve the United Nations Sustainable Development Goals (SDGs), efficiently managed forests and their products are necessary. The significant contributions of forests to food and livelihood security as well as the ecosystem services provided facets in the SDGs. Moreover, SDG 15 itself refers to the sustainable management of terrestrial ecosystems, including forests. Forests also assist directly in achieving other SDGs, particularly SDG 1 (no poverty), SDG 2 (zero hunger), SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), and SDG 13 (climate action). Table 1.4 depicts the role of sustainable forest management in achieving other SDGs.

1.5 Major Threats to the Global Forest Resources

Over the last few years, global forests have confronted several menaces such as fire, pests and diseases, anthropogenic pressure, severe climatic events, and other environmental disturbances. These events can affect the health and vitality and

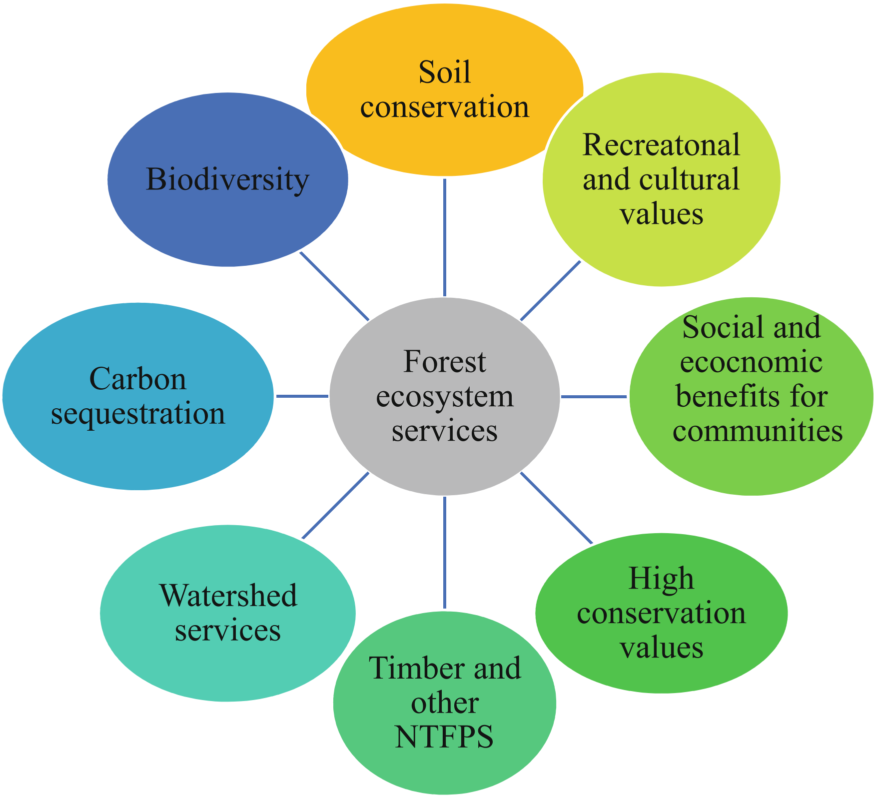

Fig. 1.2 Ecosystem services of forest resources. (Source: MEA 2005)

Table 1.4 SDGs based on forest resource sustainability (Seymour and Busch 2016)

Sustainable development goals	Role of forest in achieving the goal
SDG 1 No poverty	Providing income to fight against poverty
SDG 2 Zero hunger	Providing wild fruits and game
SDG 3 Good health and well-being	Provision of medicinal plants
SDG 6 Clean water and sanitation	Supply of fresh water and maintenance of water cycle
SDG 13 Climate action	Carbon capture and storage
SDG 15 Life on land	Maintaining biodiversity

potentiality of the forests detrimentally by causing mortality of tree species, altitudinal shift of vegetation, and reducing the ability of forests to bestow goods and services. The fire hazards have the most disastrous effect on forests and ecosystems (Bowman et al. 2011; Giglio et al. 2013). Sometimes, fire has actually been used as a management tool, for instance, weed control, preventing natural fires during fire season, improving the hunting ambiance, agriculture, grazing, etc., by humans for millennia. However, the uncontrolled wildfires accompanying traitorous

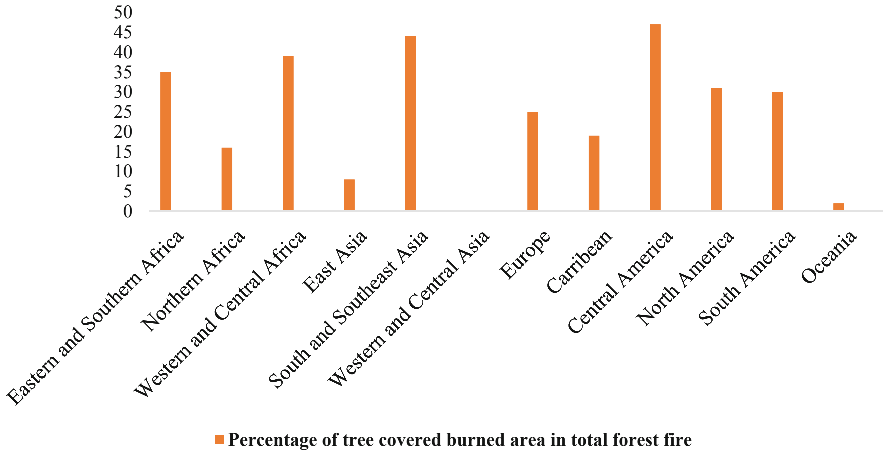

Fig. 1.3 Tree-covered burned area in total forest fire by region or subregion (2001–2018)

meteorological parameters like high wind speed, low humidity, elevated temperatures, and lack of precipitation result in considerable loss of biodiversity and landscape degradation and thus a decline in the production and productivity of terrestrial ecosystems (Westerling 2016; Abatzoglou and Williams 2016). Areas that are frequently affected by fire are prone to other types of disturbances like drought (Cook et al. 2015) and outbreaks of insect pests (Bentz et al. 2016).

In addition, severe fires have enduring impacts on the carbon sequestration potentiality of the forests through mortality and associated decomposition of trees (Campbell and Fontaine 2016; Ghimire et al. 2012). The severity of the fire influences the carbon stock management in the forest ecosystem. For example, according to a study in south-eastern Australia, high severity wildfires significantly reduced the short-term carbon stability while low-intensity fires increased the carbon stability, particularly by enhancing the soil carbon stock (Bennett et al. 2017). Wildfires also result in a change in the form of carbon through pyrogenic carbon production, one of the most stable soil carbon components (Reisser et al. 2016). FAO estimates that during 2001–2018 period, more than two-thirds of the forest fires occurred in Africa. About 29% of the total geographical area in the world was affected by forest fires from 2001 to 2018 (FAO 2020). Figure 1.3 depicts the percentage of tree-covered burned areas in forest fire by region or subregion. In the tropical, subtropical, temperate, and boreal ecological domains, 4%, 2%, 1%, and 1% of the forest area were affected due to the fire in 2015, respectively (FAO 2020).

Global forests are facing increasing strenuous conditions of fire weather, prolonged fire seasons, and intensive fires significantly governed by climate change (Bowman et al. 2017; IUFRO 2018; Sankey 2018). The potential increment in the annually burnt area in Europe was by 120–270% above the average in the period 2000–2010; by 2090, continuous increasing occurrences of fire incidents are expected to have colossal costs in terms of biological diversity, ecosystem services, sustenance of humans and their livelihoods, and national and international economies (IUFRO 2018).

Disease incidence and pest infestation are also recognized as dominant sources of disturbance to forests by reducing the potential productivity of forest ecosystems (Hartig 1900). Continuous and the rate of mobility of people and other wood and wood-based products are the basic reasons underlying the surge of pest and pathogen attacks on trees in the forests (Wilson et al. 2009; Brasier 2008). The diversity of the pests and pathogens is also increasing; for example, the number of pests and pathogen in a forest plantation in Vietnam increased from 2 in 2011 to 17 in 2020 (Thu et al. 2021). Climate change also plays a potential role in intensifying the distribution and abundance of insects and pathogens in forests by reducing the tolerance level of trees along with favoring the spread of pathogens by enhancing the reproductive potential, mobility, and physiological mechanisms (Weed et al. 2013). Therefore, species composition and forest structure are changed and subsequently resulted in the deprivation of ecosystem functions in terms of nutrient and carbon cycling, ecosystem productivity, and loss of wildlife habitats. The economic losses due to pests and disease attacks in forests are not yet fully understood; however, it is likely to be in the order of billions of dollars per year (Lovett et al. 2016). Improved hygiene in nurseries, adoption of scientific silvicultural practices reducing physical damage to the vegetations, selection of genotypes that are resistant to insect pest attack, and reinforcing national and international policies on quarantine and biosecurity measures are essential to minimize the impacts of pests and diseases in the future (Silva et al. 2021). Adoption of remote sensing technologies to detect the trees under stress and usage of sentinel plantings also appears to be an effective approach to controlling insect-pest damage (Britton et al. 2010; Thu et al. 2021).

Invasive alien species are one of the greatest threats to global biodiversity today, second to habitat loss (Vitousek et al. 1997). The international movement of species followed by the establishment, spreading, and increasing of the density of non-native species or invasive alien species have devastating effects on the ecosystem, including the loss of biological diversity, economic loss by reducing the productivity of the desired species or increased cost of management of the forests, etc. (Loo 2009; Aukema et al. 2011; Liebhold and Griffin 2016). In the United States, out of 958 species listed, 400 species are threatened or endangered due to invasive alien species (Pimentel et al. 2000). In forest ecological systems, the greatest threats are caused by invasive fungi, insects, and nematodes. The attack of these species on dominant forest trees will result in prolonged cascading effects on the host, its associated species, and interrelated services of the ecosystem. For instance, the introduction of invasive alien species in North America resulted in a significant reduction in the frequency and relative dominance of seven native tree species (Liebhold et al. 1995) and subsequently caused negative impacts on the population, ecosystem, and economy at a global scale (Roy et al. 2014). Due to globalization and an increase in the activities of trade, transport, and tourism, the introductions of these species are rising sharply and are likely to increase significantly in the near future (Seebens et al. 2017). The international community has developed numerous international and regional instruments for effectively controlling the spread of invasive

Table 1.5 Management of non-native species in forests (source: Moore 2005)

S. No.	Instrument	Year of initiation	Objective
1	IPPC (International Plant Protection Convention)	1952	To secure plant health and environmental protection via ten regional plant protection organizations (RPPO)
2	Ramsar Convention (The Convention on Wetlands of International Importance)	1971	To address the ecological, social, and economic impacts of invasive alien species on wetland ecosystems
3	CITES (The Convention on International Trade in Endangered Species of Wild Fauna and Flora)	1975	To ensure that the survival of the wild animals and plants is not threatened by the international trade of these specimens
4	CMS (The Convention on Migratory Species)	1979	To conserve and sustainably use terrestrial, aquatic, and avian migratory animals and their habitats
5	CBD (The Convention on Biological Diversity)	1993	To conserve biodiversity, its sustainable use, and fair and equitable sharing of the benefits from the use of genetic resources
6	IUCN ISSG (Invasive Species Specialist Group)	1994	Acknowledging IUCN members, conservation practitioners, and policymakers regarding the threats of invasive species and the methods for control or eradication
7	World Trade Organization SPS (Sanitary and Phytosanitary Measures Agreement)	1995	To allow each country to formulate their standards to protect human, animal, and plant health or life
8	GISP (Global Invasive Species Program)	1997	To address threats caused by invasive alien species globally
9	ICAO (International Civil Aviation Organization)	1998	To reduce the risk of introduction of invasive species through civil air transportation
10	Cartagena Protocol on Biosafety to the CBD	2000	To protect biodiversity from the potential risks from biotechnologically modified organisms

alien species in forestry (Moore 2005). Table 1.5 describes the ten most important international instruments that directly or indirectly manage the impacts of non-native species in forests.

Developmental projects can cause serious conservation issues like habitat loss and landscape fragmentation (McKinney 2002; Borgmann and Rodewald 2005), affecting the well-being of global forest resources. Such projects are direct, considered as direct causes of the destruction of natural resources and the expansion of artificial areas (Hansen et al. 2005; Munroe et al. 2005). Permanent habitat loss governed by forest fragmentation and subsequent perturbation of ecological processes ensued due to prompt expansion of linear developments, including roads and powerlines (Ramachandra et al. 2016). For instance, in the Kodagu district of Karnataka, India, about 27.14–40.47% of the evergreen forest has been lost due to nonforestry interventions such as roads and built-up areas (Ramachandra et al. 2019). Laurance et al. (2014) have estimated that there will be a 60% increase in the total road length in 2050 as compared to 2010. Such barrier effects generated by linear corridors hinder the mobility of wildlife species, modify their home ranges, and thus result in enhanced inbreeding and reduction in genetic diversity (Holderegger and Giulio 2010). Even though such projects are restricted by the Environmental Impact Assessment (EIA) programs and other regional and national policies, they have to be revised and elaborated for safeguarding and sustainable use of forest resources (Jung 2009).

1.6 Forest Governance and Conservation Strategies

Forest governance is associated with five types of fictions that are procedures for a comprehensive ethical framework based on the power dynamics of government and any organization. These fictions are established with path-dependent processes supported by the orientation of actors, materialities, and practices with consigned interests in system safeguarding and progress (Arthur 1989). Delabre et al. (2020) have identified five myths of forest governance. These are as follows: (a) national authorities maintain forests autonomously for public benefit; (b) small and marginal farmers and forest-dependent peoples try to intimidate sustainable forest management; (c) markets are the alternative to habitat destruction; (d) what is officially recorded through valuation and counts; and (e) involvement of local communities in decision-making process toward the sustainable forest governance.

Global forests are under the threat of severe loss and degradation because of the wider recognition of the multiple benefits provided by them. The international community developed several global forest conservation strategies to address the issues and for sustainable conservation of forest resources. On a global scale, to combat the rate of loss of forests and their degradation, Forest Landscape Restoration (FLR) has recently been emerging as an expedient and progressive approach that mainly aims to restore the functionality of forests such as the goods, services, and ecological processes that the forest provides at the landscape level. FLR is a collaborative learning and adaptive management process that integrates different rural development and natural resource conservation management principles to restore degraded landscapes with healthy forest ecosystems (Maginnis and Jackson 2003). The operational implementation of sustainable forest management is supported by the participation and contributions of all forestry-related stakeholders, such as scientific and academic organizations, local communities, indigenous peoples, and private sectors, including forest-based enterprises and NGOs (Goals 2019).

Another important focus of forestry in recent years is the trees outside forest (TOF), which operates with the FLR approach in an integrated manner. TOFs involve the growing of trees in various agroforestry systems such as home gardens, farm forestry systems, and other tree-based systems like avenues, roadsides, shelterbelts, and woodlots. This approach helps in sustaining the livelihoods of the rural communities by supporting agricultural production systems, reducing poverty, and maintaining a stable and secure food supply for the rural poor (FAO 2001). Concomitantly, the dependence on natural forests is also reduced since TOF provides wood, nonwood forest products, fodder and fuelwood, and shelter while aiding in the sustainable management of forests (Chakravarty et al. 2019).

In the developing world, community forest management and decentralized governance have gained acceptance among the national and international communities as a strategy for promoting sustainable management of forests as well as development. The evolution of a new form of participatory and collaborative forest governance that acknowledges local communities as primary stakeholders in the conservation of forests and the provision of incentives such as ownership or user rights and benefit-sharing mechanisms will encourage the local communities in forest protection and management. For instance, the Gambian model of community forest policy evolved in 1995 is a successful innovation, where the state could achieve sustainable management of forests and alleviation of poverty by engaging local communities who make use of the forest resources. Gambia, being a poor country, could increase its forest cover by 8.5% over the last two decades (Tomaselli et al. 2013). The National Forest Policy of Rwanda, initiated in 2004, intended to develop forestry as one of the bedrocks of the economy. Novel approaches such as agroforestry and forest management education were implemented to promote large-scale reforestation of indigenous species with the involvement of local communities. Presently, Rwanda is expecting to reach its goal of expanding the extent of forests to 30% of the total terrestrial area by 2020 (WFC 2011). According to FAO (2003), by 2050, about 40% of the global forests will be under the management or ownership of individuals and communities. Although management of forests has proven effective under public ownership in many countries, decentralization is not a panacea since it has its own risks and challenges. Novel decentralization policies in Indonesia intensified the pressure on forests. The effectiveness of the decentralization policies depends on the existing situations of social and political structures. Hence, it is critical to ensure the establishment of adequate capacity among the most marginalized sections of the community so that robust conflict resolution mechanisms will take place (Ribot 2002).

A number of forest policies have been devised by the international communities with the aim to bring the issues of forest destruction to the forefront and create awareness about the notable benefactions of the forests to the earth and its populace. At the international fora, there is wide recognition regarding the role of forests in livelihood sustenance, contribution to food security and poverty reduction, and other environmental services. In 2000, under the Economic and Social Council of the United Nations (ECOSOC), the United Nations Forum on Forests (UNFF) was established for the management, conservation, and sustainable development of forests across the globe. Another important international forum for the forestry sector is the CBD (Convention on Biological Diversity), which operates under an ecosystem approach (UNEP 2021b). Accordingly, the Strategic Plan for Biodiversity 2010–2020 and associated 20 Aichi Biodiversity Targets were adopted with the aim of protecting at least 17% of terrestrial and inland water areas by 2020. Also, through the adoption of SDGs, particularly 14 and 15 recognized the importance of conservation of the terrestrial ecosystem and biodiversity (Jones et al. 2020). The United Nations Conference on Environment and Development (UNCED), Intergovernmental Forum on Forests (IFF), Intergovernmental Panel on Forests (IPF), Food and Agricultural Organization (FAO), and International Tropical Timber Organization (ITTO) are some other international fora where the global policies for forest conservation are developed. Furthermore, several countries have also revised their regional policies on national forests and formulated national forest programs, involving stakeholders from different sectors for the better conservation and sustainable utilization of the forest resources.

1.7 Recommendations for Sustainability in Forest Resource

Over the last two decades, climate change mitigation techniques in forest management have emerged. Ecological patterns can be sustained in their present state by realizing a feasible management goal (Hagerman and Satterfield 2014). However, the governance procedures combine different perspectives and functional information in the aspect of ambiguity and examine potential trade-offs connected with those perspectives (Hagerman and Pelai 2018). Actionable strategies for biodiversity conservation and management with changing climate depend on specific ecological and geographic information (Heller and Zavaleta 2009). International Institute for Sustainable Development (IISD) 1994 recommended various measures to ensure sustainability. The first recommendation is to strengthen the efforts in conservation and sustainable management of forest resources. It is critical to ensure local community participation, and all national policies and strategies must indicate the forest area set aside for forest conservation and the sustainable production of goods and services. In this context, developing nations must have access to new and extra financial resources, as well as the transfer of eco-friendly technology. The second one is to ensure further sustainable forest conservation and management, market prices for timber and timber products must fully reflect both their replacement and environmental costs, and trade in forest products must be nondiscriminatory, with any unilateral measures restricting and/or prohibiting their trade removed or avoided.

Furthermore, the costs of sustainable forest management, such as reforestation and afforestation, must be included in the cost of all types of forest-based output. Maintaining and improving forest cover, reforestation, or afforestation will entail costs, either from forfeited chances for other uses or from advantages lost from present land uses. Policy responses must take this into consideration (IISD 1994). Countries' lawful rights to their natural resources must be protected. An equitable system must be developed to pay fair remuneration to nations that act to sustainably manage their forests in the larger interests of global environmental improvement. All nations should seek to increase their forest cover over a certain time period, and steps should be taken to design and implement national forestry action programs and/or plans for forest management, conservation, and sustainable development. Countries with less than 30% forest cover but the means must make active efforts to grow their forest cover, whereas affluent countries that are hampered by physical and climatic conditions to increase their forest cover should aid poorer nations in increasing and upgrading their forest cover. Countries with more than 30% forest cover should be recognized, and suitable incentives should be provided to encourage them to enhance the quality of their forests.

1.8 Conclusion

Forest resources are recognized as the most productive land-based ecosystems directly connected to billions of lives. Advancement in forestry-based enterprises is emphasized in plantation forestry programs supported by various organizations. Only half of the world's forests have proper management plans; therefore, continuously increasing anthropogenic pressure is the main cause of deforestation and forest degradation in unmanaged forests. Forest Landscape Restoration emerging as a convenient and liberal tactic mainly aims to restore the functionality of forests and ecological processes. Implementation and achieving the SDGs through participatory and collaborative forest governance are necessary to maintain the sustainability of forests and other natural resources. Thus, strengthening the contribution of forests for sustainable development is required by promoting governance frameworks for implementing sustainable forest management, supported by UN forestry programs. The coordination, cooperation, integrity, and synergy on forest-related issues among institutions, government, forest dependents, and other stakeholders for collaborative partnership will be feasible toward achieving the sustainable development goals through forestry interventions.

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Effect of Deforestation and Forest Fragmentation on Ecosystem Services

2

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Abstract

Deforestation has become a major hurdle nowadays that affects overall ecosystem health and functioning. Illegal timber cutting, logging, mining, and many developmental projects deprive the land quality, soil health, and many other ecosystem services. Forest-mediated ecosystem services maintain environmental health and sustainability. A well-managed forest maximizes biodiversity and strengthens ecosystem services and leads toward ecological stability. Forest fragmentation is also going in parallel that affects floral and faunal distributions, diversity, and related ecosystem services. These activities affect soil health by declining soil fertility and soil organic carbon pools in the forests. Intensive agriculture practices and agricultural land expansion promote forest cutting that affects overall land productiveness. These unsustainable land-use practices minimize forest covers along with releasing many greenhouse gases into the atmosphere leading to climate change. In this context, applying scientific management and protection of forests will ensure healthy, productive, and diverse species in the tropical world. Sustainable forest management will minimize forest degradation and maximize the population and diversity of flora and fauna that ensure healthy ecosystem services. Thus, adopting an effective policy along with better research

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and development would help in enhancing forest regeneration and species diversity with a healthy and productive ecosystem. Also, a regulatory framework and future roadmap must be framed for forest conservation that guarantees soil and food security along with climate and environmental sustainability for ecological stability.

Keywords

Deforestation · Ecosystem services · Environmental sustainability · Forest fragmentation · Species diversity · Soil fertility · Sustainable forest management

2.1 Introduction

Forest is the largest natural resource that harbors a variety of flora and fauna that deliver uncountable ecosystem services. Forest nurtures many soil-inhabiting organisms that maintain soil health and quality. A single forest can store millions of tons of carbon (C) (carbon sink) from the atmosphere to mitigate climate change issues. That's why the forest is regarded as "Carbon land" due to its highest C sink potential (Jhariya et al. 2019a, b, 2021a, b, 2022). Forest delivers direct and indirect ecosystem services for the welfare of human beings. Timber, fuelwood, firewood, non-timber forest products (NTFPs), and several nutritious foods are direct services provided by forests (Banerjee et al. 2020, 2021). Biodiversity conservation, soil fertility maintenance, efficient nutrient cycling, climate change mitigation, and socioeconomic improvement are some of the indirect ecosystem services under well-managed forests (Pawar et al. 2014; Raj et al. 2018a). Moreover, healthy forest ecosystems are key indicators of a healthy and productive environment that sustains billions of populations through the provision of multifarious ecosystem services (Jhariya and Singh 2021a, b, c).

Unsustainable land-use practices, deforestation, and overuse of resources destroy the natural resources and related ecosystem services. Tropical forests harbor approximately 60% of the world's terrestrial species that are under threat due to deforestation (Gardner et al. 2009). However, many species are under extinction due to deforestation activity that also minimizes forest covers in the tropics (Fahrig 2013; Raj et al. 2022). Many species are threatened by the loss of their home due to unstoppable forest cutting and deforestation. As per one estimate, from 2000 to 2012 around 2.3 m km^2 area of forests was lost, whereas seven million hectares (m ha) of tropical forests have been lost in the past decade (2000–2010) (Hansen et al. 2013). These figures are enough to reflect that forests are under threat due to human settlements, food and fuelwood needs, and agricultural land expansions (Kindu et al. 2013). However, land-use change induces both deforestation and loss of biodiversity that further induce natural resource exploitation, pollution, and climate change issue (Lemke et al. 2007; Kobayashi et al. 2019; Roy et al. 2022; Meena et al. 2022; Yadav et al. 2022). Deforestation-mediated climate change issues are another burning topic popular among policymakers, planners, scientists, academicians, and stakeholders. Moreover, the cases of deforestation, agricultural land, expansion, and livestock conversion have been reported in the regions of Asia, Africa, Pacific, and Latin America, whereas natural regeneration and forest plantations have been increased in the regions of Cuba, Costa Rica, Chile, and Uruguay (FAO 2009, 2010). Similarly, deforestation mediated climate change-induced vegetational shifting; for example, shifting of boreal forest northward affects overall diversity and distributions (Burton et al. 2010). Forest fragmentation is another debatable topic among policymakers and planners that causes converting forests into isolated patches due to dispersed and sub-divisions of forest lands. Fragmentation also affects forest covers that entirely influence overall species diversity and distributions (Fardila et al. 2017; Kozak et al. 2018; Raj and Jhariya 2021a, b). Similarly, fragmentation induces an edge of the forest land that affects C sink capacity, which modifies overall ecological stability in the forests. As per Gibson et al. (2013), the edge forest land has less C sink potential up to 50% as compared to the core region of the forests. The forests in Odisha and several parts of Eastern Ghats have reported that deforestation and forest fragmentation affect overall ecosystem richness and services (Krishna et al. 2014). In lieu of the above, this chapter discusses forest covers, their importance, and related ecosystem services. This paper also covers many questions: (a) how deforestation affects valuable ecosystem services? (b) Would an effective policy, governance, and R&D minimize deforestation by ensuring forest conservations? (c) How does sustainable forest management (SFM) minimize deforestation to make a healthier and more productive ecosystem?

2.2 Forest: A Global Context

Forest is the second-largest natural resource after agriculture that spreads throughout the world and plays a key role in biodiversity management along with the livelihood generation of tribal people (MoEF 2002). FAO (2010) has reported forest covers in-country wise in the world, which is depicted in Fig. 2.1.

The forest area (m ha) in the world followed in order: Russian federation (809) > Brazil (520) > Canada (310) > USA (304) > China (207) > Democratic

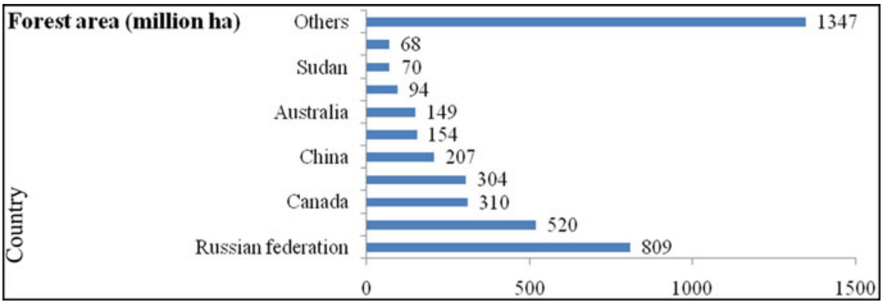

Fig. 2.1 Forest covers in different countries of the world (FAO, 2010)

Republic of the Congo (154) > Australia (149) > Indonesia (94) > Sudan (70), whereas, least area is in India with 68 M ha.

Forests sustain almost 14% of the Indian population by providing various timber and NTFPs (MoEF 2002). India harbors approximately 12% (47,000 species) and 7.28% (90,000 species) of world flora and fauna that represent rich biodiversity (MoEF 2007). This rich diversity can intensify ecosystem services that ensure a healthy and productive ecosystem. Globally, 3999.0 m ha areas are covered by forest cover as compared to global woodland area, i.e., 1204 m ha. This forest cover value is equivalent to 31% of global land areas. As per statistics, only 0.6 ha of this total forest cover is available for each person. Similarly, a single tropical region covered 44% of forest area, which is followed by temperate (26), boreal (22), and subtropical (8%) regions, respectively (FAO 2015). As per FAO (2006), more than 0.5 hectares of land having >5.0 m of tree height along with >10% of canopy cover are denoted as forest. Similarly, Forest Resource Assessment (FRA) has released many reports on the dynamics of forest and agricultural land (Ausubel et al. 2012), deforestation activity (Hosonuma et al. 2012), biogeochemical cycle (Smith et al. 2014), and environmental health and its sustainability (Arrow et al. 2012).

2.3 Forest Ecosystem Services

Forests maintain environmental health and ecological stability by providing multifarious ecosystem services. Timber and NTFPs are major direct services, whereas soil health maintenance, efficient nutrient cycling, climate change mitigation, food, and income security are indirect services through forestry. Thus, the forest plays various functions in making a sustainable environment and ecosystem (Jhariya et al. 2019c). Production functions include tangible (direct) products such as timber, fuelwood, and other NTFPs. Soil water protections, biodiversity conservation, social services, multiple uses of forest products, etc., are recognized functions delivered by forest ecosystems. These functions ensure overall soil-food-climate security at a global level that ensures sustainable development goals (SDGs) (Fig. 2.2) (Fuhrer 2000; FAO 2010).

Land conversion, faulty land-use practices, intensive agriculture, mining, and other developmental projects resulted in deforestation that led to poor diversity and related ecosystem services. Illicit lopping and overexploitation of forest resources must be prevented to improve ecosystem services for a long time. For instance, applying better forest management practices would be effective tools for minimizing deforestation activity that maximizes forest covers and their potential services. Forest has been recognized for soil protection and water regulation services. Soil fertility enhancement, efficient biogeochemical cycling, soil C sequestration, and organic C pools are key services provided by the forest ecosystem (Postel and Thompson 2005). Also, forests consist of diversified flora and fauna that play a major role in a variety of services for supporting many lives. They store beneficial herbs, medicinal and aromatic plants, wild and edible plants, and other NTFPs that are a good source of food for humans and ensure food and nutritional security. Forest

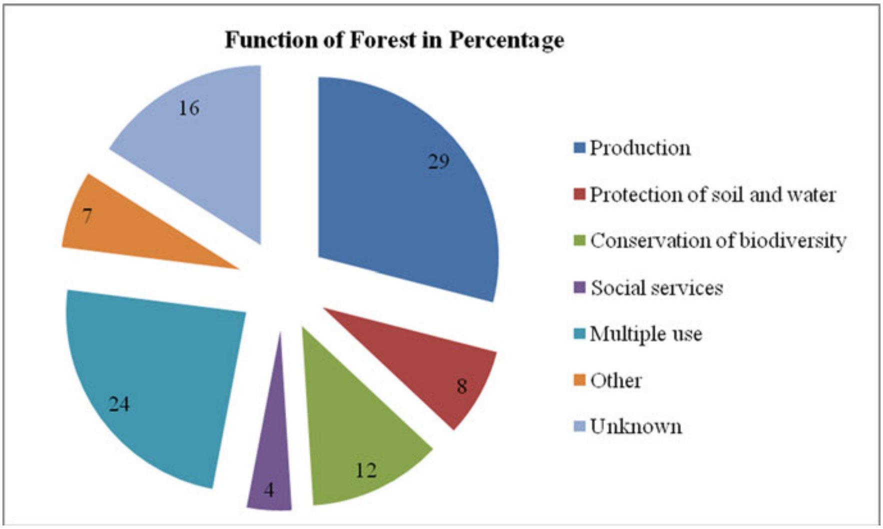

Fig. 2.2 Forest functions for ecosystem stability (Fuhrer 2000; FAO 2010)

also supports a variety of pollinators that play a significant role in plant production and biodiversity maintenance. NTFPs play a key role in the socioeconomic and livelihood improvement of the forest fringe people (Leßmeister et al. 2018). Furthermore, forests delivered other remarkable services such as biomass production, climate regulation, atmospheric C balance, water purification, and efficient pollination to make a more productive and sustainable environment (Mori et al. 2017).

2.4 Forest Fragmentation in the Tropics

Fragmentation is a key driver of biodiversity loss and ecosystem degradation that further affects habitat capacity to provide important ecosystem services. Forest fragmentation may lead to irreversible losses of forest covers and biodiversity that cause alteration of floral and faunal species diversity and its communities. Forest loss due to fragmentation may threaten species populations and their distributions that entirely affect goods and services from the ecosystem (Pereira et al. 2010). Ongoing series of fragmentation and habitat losses altered overall species functional diversity. Thus, a fragmented landscape affects the magnitude of functional diversity, which is challenging (Zambrano et al. 2020). Mangrove habitats deliver key services such as erosion control, climate change mitigation, and shoreline protection. But fragmentation-induced mangroves' habitat in different patches affects overall ecosystem services. Forest conversion into rice plantations and aquaculture systems, along with mangrove loss, was reported as forest losses and fragmentation in Southeast Asia (Bryan-Brown et al. 2020). This fragmentation leads to a change in tropical forest cover that has negative consequences on biodiversity. Similarly, increasing fragmentation leads to a decrease in forest covers, which is justified by using the logistic regression model. These models assessed forest cover changes, degradation, and fragmentation in the Koraput district of Odisha, India (Paul and Banerjee 2020). According to them, the values −0.018 and −0.012 were long-term deforestation rates that have been observed in the current period (1987–2017) and predicted period (1987–2027), respectively.

2.5 Deforestation: Global Overviews

Today, deforestation is a bottleneck problem throughout the world that has negative consequences on flora and fauna diversity and related ecosystem services. Illicit felling of timber, logging, overexploitation of natural resources, mining, urbanization, and other developmental projects lead to forest degradation and deforestation (Nagdeve 2007; Khan et al. 2022). However, the loss of forest resources leads to change in forest covers due to utilizing their products beyond the sustained yield for fulfilling human needs (Basnayat 2009). However, various factors that decline the forest cover are depicted in Table 2.1.

Several works and reports are available on deforestation and related forest cutting activities. For example, single illicit logging and felling of timber lead to a 3.16% reduction in global forest covers (FAO 2015). The areas of forest cutting were 2×10^5 km^2 $year^{-1}$, and 7–11 million km^2 have been reported in 2000–2012 and past 300 years (Foley et al. 2005; Bologna and Aquino 2020). Furthermore, cattle ranching, agricultural land expansion, house construction, palm plantation, etc., caused 25–50% losses of tropical rainforest, which is a major storehouse of greater diversity (Lewis 2006). This type of forest loss due to land conversion has been reported majorly in Southeast Asia (Miettinen et al. 2011). Moreover, 60% of degradation and losses are also reported in a tropical dry and moist deciduous forests in the year 1990–2010 (Chakravarty et al. 2012).

Deforestation in Ecuador and Amazon basin was reported at −0.65 and 0.45% rates in the year 1990 (FAO 2011; MAE 2017). Moreover, the rate of deforestation in Ecuador has been decreased up to −0.48% between 2014 and 2016 (FAO 2015). Illicit logging leads to 70% of forest degradation in Latin America (Kissinger et al. 2012). Thus, intense harvesting of timber and forest cutting also affects forest structure by vegetation loss, tree damage, and C loss (Sist and Nascimiento 2007). Approximately 26% and 17% of biomass losses have been reported under 5.7 and 4.5 tree/ha of logging intensity, respectively (West et al. 2014). Logging activities, forest fires, charcoal, and firewood extraction contributed to about 70% of forest degradation in Latin America (Kissinger et al. 2012). Vegetation losses and tree damage induced reduction in species composition, diversity, and timber volumes, and loss in C storage is directly influenced by overexploitation and improper harvesting of forests (Sist and Nascimiento 2007). About 17.0–26.0% and 48.0% of reduction in stand biomass have been reported due to high intensity of logging activities as 4.50–5.70 and 10.0 tree/ha, respectively (West et al. 2014).

Table 2.1 Causes of forest decline (Chakravarty et al. 2012; Contreras Hermosilla 2000; Jhariya et al. 2019b)

Direct causes	Natural	Natural fires
		Hurricanes
		Pests
		Flood
	Anthropogenic (human activity)	Intensive agricultural practices
		Agricultural land expansion
		Cattle ranching
		Illicit felling of timber and logging
		Oil and ore extractions
		Mining
		Road and dam constructions
		Other developmental projects
Underlying causes	Market failure	Unpriced forest goods and services
		Monopolistic and monopolies forces
	Faulty policy interventions	Improper government investment
		Poor regulatory mechanisms
		Poor incentives
	Weakening governance system	Land ownership concentration
		Improper land ownership and inappropriate arrangement of land tenure
		Corruption and illegal activities
	Political intervention and wider socioeconomic	Burgeoning population
		Population density
		Economic growth
		Distribution of political power and economic
		Extreme consumption
		Toxification activity
		Climate change and global warming
		War
	Forest declining agents	Slash and burn practices by farmers
		Miners
		Loggers
		Cattle ranchers
		Oil corporation
		Agribusiness
		Non-timber commercial corporations

2.6 Deforestation Impacts on Ecosystem Services

Forest provides uncountable valuable ecosystem services that sustain biodiversity. But deforestation and other logging activities reduce the forest cover that entirely affect overall ecosystem services. It has negative impacts that vary both on-site and off-site that cause habitat and biodiversity losses, soil and nutrient loss, GHG (greenhouse gas) emissions, animal migrations, floods, drought, and landslides (Gharibreza et al. 2020). However, logging, mining, intensive agriculture, cattle ranching, and several developmental projects are the major driving force for deforestation (Gharibreza and Ashraf 2014). Thus, poor ecosystem services such as timber production, fuelwood generation, water supply, and NTFP production are reported as negative consequences of deforestation (Kasaro et al. 2019). The tropical forest has declined from 9.5 to 5.5 million ha/year in the year 1990 and 2010–2015 as compared to global forest decline from 7.3 to 3.3 million ha/year in the same year (Keenan et al. 2015). Biodiversity loss, poor water regulation, poor availability of goods and services, species extinction, and loss of natural habitats are the key impacts that have been observed under deforestation (Ricketts et al. 2016).

Forests were converted into various other land-use practices that affect overall ecosystem services. For example, converting forest into wasteland causes poor land quality and fertility, declining soil health and productivity, poor nutrient cycling, and organic C pools, along with the emission of GHGs causing climate change. Similarly, deforestation causes faunal habitat loss that harms faunal diversity, its distribution, and breeding behaviors. Declining faunal ecosystem services such as pollination, pest control, and seed dispersal are also reported under deforestation activity. Wild animals migrate into villages and cities, causing human–animal conflicts along with poor ecosystem services. Forest conversion into agricultural land and intensive agricultural practices has led to biodiversity loss and related environmental services. An intensive agriculture system maximizes GHG emissions due to high synthetic inputs that lead to global warming and climate change. Overall, we can say single deforestation practices minimize biodiversity, leading to poor ecosystem services, which is a key hurdle in achieving the goal of sustainability (Fig. 2.3) (Kumari et al. 2019; Banerjee et al. 2020).

Forest cutting, illicit logging, and land-use changes induce soil erosion and degradation, globally causing a loss of top layers of productive soil (Gharibreza et al. 2013). Forest land is the largest natural resource sustained by soils by providing essential nutrients for better ecosystem health and productivity. Soil-inhabiting microbes decompose forest residues and provide nutrients, which are captured by forests' extensive root systems for their growth and development. Thus, healthy and productive soils provide healthier ecosystem services for better forest health and productivity (Noguez et al. 2008). But deforestation and intensive agricultural practice lead to erosion, nutrient removals, groundwater pollution, and eutrophication that cause poor soil health and quality (Nahayo et al. 2016). The conversion of forest land into other unsustainable land-use practices maximizes the chances of soil erosion that further affect the water quality and other valuable ecosystem services (Dale 2007).

Removal of forest and illicit timber cutting leads to nutrient leaching, losses, and increased transport and sedimentation in lakes, wetlands, and reservoirs. These further increase eutrophication and water pollution and affect overall water quality (FAO 2015). Many studies have reported the impacts of deforestation on the hydrological cycle in the ecosystem. For example, deforestation in Amazon affects

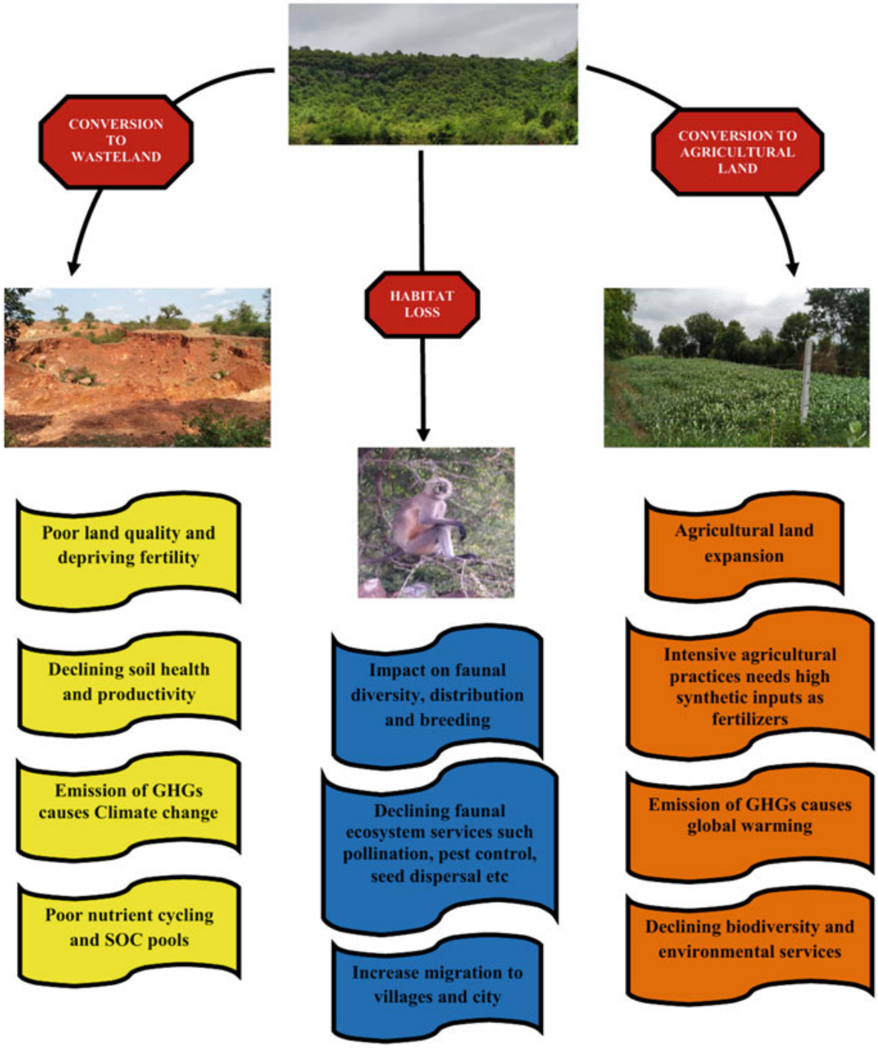

Fig. 2.3 Deforestation impacts on ecosystem services

global and local hydrological cycles, which have been assessed through various modeling studies. Rainforest deforestation has affected rainfall patterns, heat flow and absorptions, albedo, water circulation, cloud formations, and overall surrounding climates (Medvigy et al. 2013). Costa and Pires (2010) have also studied regional and local changes in the hydrological cycle due to deforestation and its impacts on precipitation recycling and evapotranspiration. Similarly, Bosch and Hewlett (1982) have reported decreasing water quantity in stream flow due to the increasing value of forest areas. Increasing water yield has been reported in deforestation compared to reforestation, which leads to decreasing value of water yield

(Andréassian 2004). Similarly, the annual value of water yield has been decreased under the practices of reforestation (Filoso et al. 2017). Deforestation amplifies soil erosion along with lowering soil infiltration causing higher sediment flux and turbidity that leads to poor water quality. Higher soil erosion and lower infiltration lead to poor water quality due to higher flux sediments and turbidity (Zongo et al. 2017), which enhances the treatment cost for drinking water (Singh and Mishra 2014).

Deforestation has also led to the loss of biodiversity, resulting in poor ecosystem services. Illegal removal of forests affects the diversity and richness of living communities that play a great role in providing valuable services. Natural resource degradation and its overexploitation affect the regeneration of most underutilized and valuable plant species. Deforestation results in habitat loss of many fauna and animals that now migrate into the villages and urban cities, resulting in human–animal conflicts. Thus, poor biodiversity due to deforestation deprives important ecosystem services, which affects overall ecological health and environmental sustainability (Gamfeldt et al. 2013).

2.7 Managing Forest to Intensify Ecosystem Services

Forest loss and degradation are the burning topics that have gained rigorous discussion nowadays. However, forest management is gaining prime importance due to delivering multifarious valuable ecosystem services (Khan et al. 2020a, b). An effective conservation strategy is needed for the betterment of forests and related potential ecosystem services. Applying sustainable forest management strategies will play a key role in forest conservation that further promotes species diversity and richness. These sustainable practices maximize biodiversity that intensifies ecosystem services. A scientifically based management strategy would help in ensuring healthy and productive soil resources and related ecosystem services. This will further help maximize productivity and soil organic C pools through better sequestration potential (Raj et al. 2018b). Conserving forests also maintain the habitat of many flora and fauna that also deliver valuable services for a better and more sustainable ecosystem. In this context, many conservation strategies such as protected areas are adopted by the government to protect tropical ecosystems by reducing deforestation (Nagendra 2008). These protected areas are spread over the tropical world and cover almost 27.0% of the forest area (Morales-Hidalgo et al. 2015). Similarly, nearly 20% area of Ecuador's territory has been set aside for protected areas (Cuesta et al. 2015). Thus, the management of forests along with applying an effective conservation strategy ensures productive ecosystem services that promise soil–food–climate security for a sustainable world.

2.8 Policies and Future Roadmap

Deforestation impacts and their negative consequences are becoming bottleneck problems among policymakers, planners, researchers, and stakeholders. Deforestation has irreversible impacts on the ecosystem and environment. An effective policy along with scientific research and development is needed to minimize deforestation activity that can ensure healthy regeneration along with better forest health and productivity. Adopting effective policies, good governance, research, and development along with future roadmap strategies would help in maintaining forest covers by reducing anthropogenic deforestation. Thus, it would help to maintain a better forest ecosystem and its proper functioning. In this context, a policy, roadmap, and research and development for forest management are represented in Fig. 2.4 (Raj et al. 2020; Raj and Jhariya 2020).

Impacts on the soil as soil fertility losses, declining health and quality, and poor C pools are key topics to discuss in future policy and accordingly strengthen the effective roadmap (Khan et al. 2021). Increasing agricultural land along with intensive agricultural practices affects overall forest cover and its distributions. An

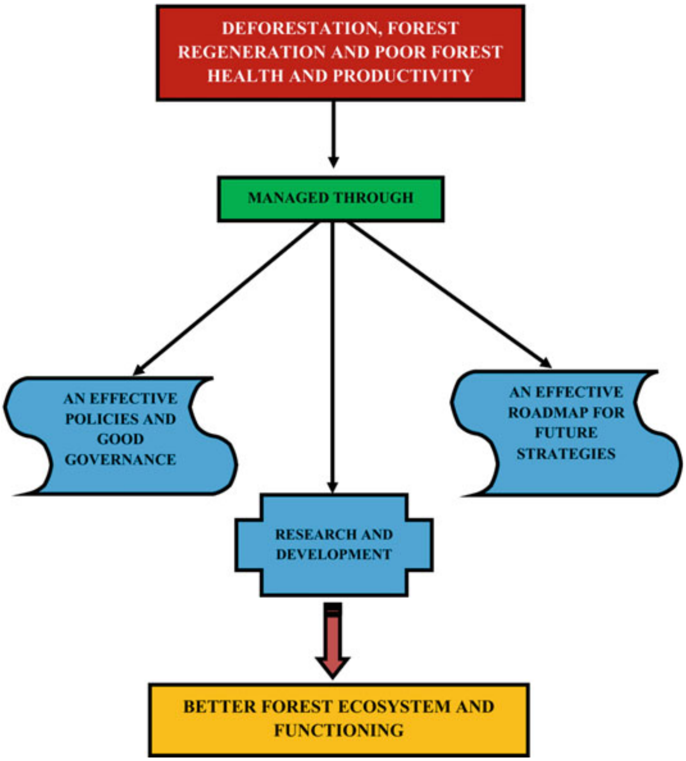

Fig. 2.4 Policies, roadmap, and research and development for forest management (modified: Raj et al. 2020; Raj and Jhariya 2020)

intensive agricultural system also induces higher GHGs in the atmosphere, leading to irreversible global warming and climate change phenomenon. Water quality regulations, soil conservation, species diversity maintenance, and climate regulation are important topics that should be highlighted in policy and used for making various regulatory frameworks. These would help in delivering both production and protection services through forests for ensuring environmental sustainability and ecological stability (Karamage et al. 2016).

2.9 Conclusion

Increasing population and human needs maximize forest removal for their consumption, shelters, food requirement, and different land-use practices. Forest cutting, logging, and other illicit felling of timber are practiced even today. Changing forest land into other land-use practices is another hurdle that not only deprives soil fertility but also affects overall flora and fauna population, compositions, distribution, and diversity along the forest gradients. These practices will affect the habitats of many fauna and wild animals, and they will enter into villages and cities, increasing human and animal conflicts. In this context, applying a better conservation practice minimizes deforestation activity along with the promotion of valuable ecosystem services that sustains many lives on the earth. Also, an effective policy and good governance are needed for forest management and conservation that ensure healthy and productive ecosystem services for a sustainable world.

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3

Impact of Deforestation on Faunal Diversity and Its Management Strategies

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Abstract

The practices of forest removal, illicit felling of timbers, and deforestation are increasing at alarming rates. Anthropogenic activities such as extensive logging, hunting, mining for industrial development, and practicing intensive agriculture and its expansion will lead to deforestation and affect forest health and productivity. However, deforestation not only influences the floral component but also affects the diversity and richness of faunal species and related ecosystem services. Forest provides tangible and intangible benefits along with harboring many faunal species such as mammals, arthropods, reptiles, avian species, and some invertebrates by providing shelter and food and protecting them from other environmental stresses. In turn, these faunal species deliver many environmental services such as pollination, seed dispersal, pest control, herb control, nutrient cycling, and climate regulation. Sustainable forest management practices must be employed for better health and productivity of faunal species that would be the pillar for sustainable development. Good governance and effective policy are needed along with a regulatory framework that can check deforestation activities in parallel to faunal diversity and richness in the tropical world.

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Keywords

Deforestation · Environmental services · Intensive agriculture · Logging and faunal diversity

3.1 Introduction

Removal of existing natural forest cover is referred to as deforestation. Increasing population necessitates timber, fuelwood, and food requirements that increase the rate of deforestation and timber cutting. Similarly, the rising population leads to forest cutting for the shelter of people and expanding agricultural land areas through practicing an intensive agricultural system. Deforestation affects more than 70% of terrestrial floral and faunal biodiversity residing in the forests. Deforestation along with poor regeneration of forests causes land degradation and leads to soil erosion and river sedimentation. Therefore, deforestation can directly or indirectly affect the climate due to changing vegetation cover and related ecosystem services (Jhariya et al. 2019a, b; Yadav et al. 2022; Khan et al. 2022). According to Oglesby et al. (2010) and Hasler and Avissar (2007), forest removal can modify moisture budgets and surface energy by changing the albedo mechanism, surface roughness, and evapotranspiration for long durations. The conversion of forest land into nonforested permanent lands occurs for agricultural and grazing practices and urban development (Khan et al. 2020a, b). The rate of deforestation is accelerated further and is expected to twice in the tropics causing shrinkage of green areas, loss of biodiversity, and greenhouse effects (Myers 1994; Barraclough and Ghimire 2000; Roy et al. 2022). Deforestation activity contributed 20% of total greenhouse gas (GHG) emissions, which are mainly shared by developing countries in the world (IPCC 2007). As per UNFCCC (2006), a decrease in the value of crown cover below 10–30% of the threshold value is considered deforestation. Several factors such as intensive agriculture, human settlement, fire, and logging have altered the diversity, composition, and richness of both floral and faunal species along with soil attributes (Gonzalez-Zamora et al. 2009; Jhariya et al. 2012, 2014; Jhariya and Singh 2021a, b, c; Raj et al. 2022).

Tropical forests harbor half of the global flora and fauna species along with a greater recognition due to playing an efficient role in the carbon cycle and climate system of the world. Overexploitation of these forest resources, forest fragmentation, deforestation, introducing invasive/alien species, and changing climate have deleterious impacts on the biodiversity of tropical forests and related ecosystem services (Raj et al. 2018a, b; Meena et al. 2022). About 60% of deforestation was observed in tropical forests between 1990 and 2010, especially in dry and moist deciduous forests (Chakravarty et al. 2012). Habitat loss, forest fragmentation, and land degradation resulted in species extinction, and some are under threatened and vulnerable species. Almost 65% of the global 10,000 endangered species are supported by tropical forest that also harbors two-thirds of all species in the world (Myers and Mittermeier 2000). The forest sustains the lives of a variety of fauna to make a healthy and vibrant ecosystem. Efficient management of this forest promotes biodiversity that intensifies ecosystem services for a better environment. But forest degradation and its conversions lead to harmful and irreversible changes in the faunal biodiversity, distribution, and richness. For example, deforestation results migration of wild animals into the forest fringe villages and urban areas where human–animal conflicts are common nowadays. These human–elephant conflicts caused the death of 20 elephants and 50 persons annually in the hotspot areas (Sukumar et al. 2003; Mangave 2004). As per Zakaria et al. (2016), only tropical rain forests harbor more than 50% of total world animal species along with wealthy floral species composition as >250 species ha^{-1}. These faunal species play a key role in ecosystem structure and functioning. But deforestation and forest removal practices affect their habitat, breeding behaviors, food availability, health, and productivity. Thus, the practices of forest fragmentation, deforestation, and unsustainable land-use systems may alter microclimatic conditions of faunal habitats that modify their behavior, health, and productivity. In this context, efficient utilization of forest resources along with proper land management can prevent forest destruction and large-scale species extinction. There must be a balance between demand and supply of forest resources in a sustainable manner. In lieu of the above, this chapter represents the deforestation scenario and its impacts on the diversity of faunal species. Moreover, a comprehensive discussion is made on environmental services through faunal species along with their intrinsic relationship with forests in the tropics.

3.2 Deforestation: A World Scenario

Forest provides various ecosystem services in tangible and intangible ways. A tangible service includes provisions of timber, fuelwood, and non-timber forest products that ensure food and nutritional security. Biodiversity conservation, soil protection, water regulation, climate change mitigation, wildlife management, and efficient nutrient cycling are intangible ecosystem services through the forest that ensure soil and climate security. Thus, a healthy and productive forest community delivers a variety of ecosystem services that ensure environmental sustainability and ecological stability for a long time. In this context, Fig. 3.1 represents various ecosystem services provided by the forests (Raj 2019; Banerjee et al. 2020; Raj and Jhariya 2020a, b).

The forest cover status in India for the last 32 years (1987–2019) is presented in Table 3.1 (FSI 2017, 2019). In the past three decades, the change in forest cover was inconsistent until 2005. However, it increased from 2009 to 2019. This indicates an effective policy, governance, and management practices that were not implemented and followed effectively between 1987 and 2005 as compared to the last decade. Scientific management of forests (SFM) practices can ensure healthy and productive forests along with enhancing forest covers in tropical countries, ensuring better ecosystem structure and functions that promise soil–food–climate security.

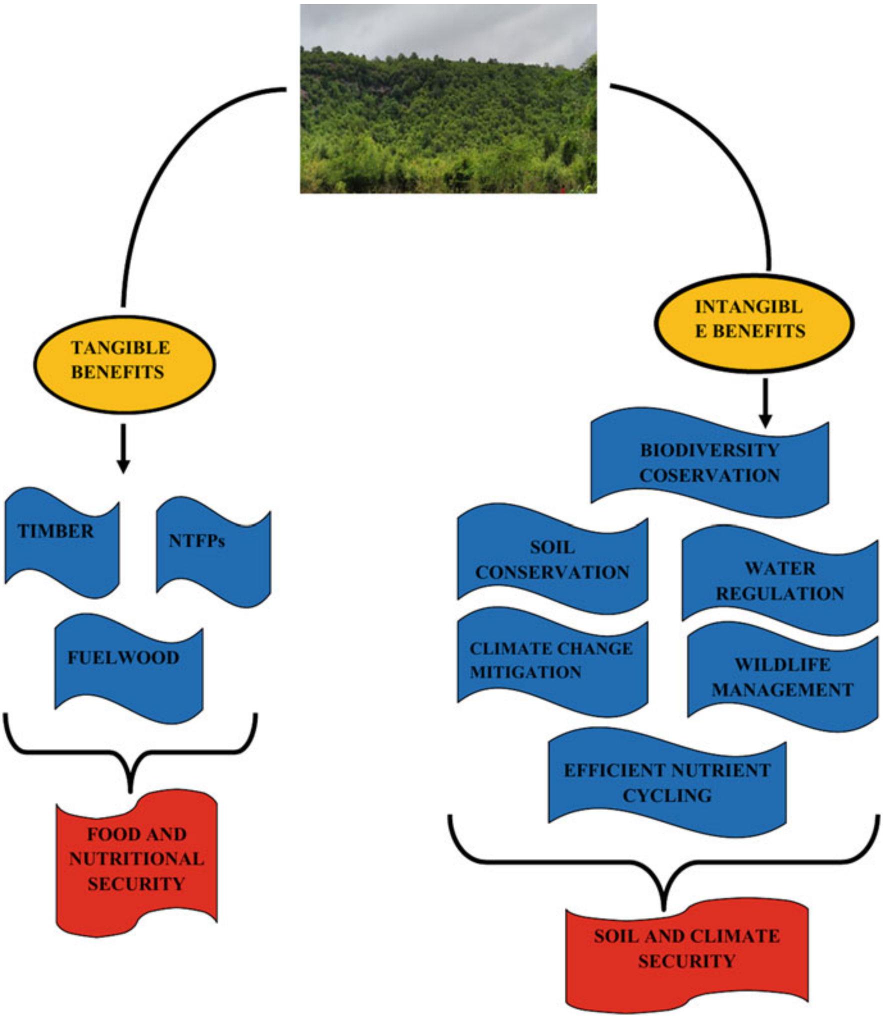

Fig. 3.1 Forest ecosystem services. (Compiled: Raj 2019; Banerjee et al. 2020; Raj and Jhariya 2020a, b)

However, overexploitation, illicit felling of timber, urbanizations, and industrial development including mining resulted in permanent loss of forest cover along with negative impacts on various ecosystems and the environment (Nagdeve 2007; Kumar et al. 2017; Khan et al. 2021a, b). The main reason is the burgeoning population and related increasing food and shelter demands. The forest resources are depleted beyond the sustained yield to satisfy human needs along with greater changes in net forest cover (Basnayat 2009). As per one estimate, the global population is expected to increase from 7.6 to 10 billion in the next three decades, with an increase in food demands by 50% (Department of Economics and Social

Table 3.1 Status of forest cover in India for the last 32 years (1987–2019) (FSI 2019)

Year	Forest covers (%)	Forest cover changes (%)
1987	19.49	0
1989	19.43	−0.31
1991	19.45	0.1
1993	19.45	0
1995	19.43	−0.1
1997	19.27	−0.82
1999	19.39	0.62
2001	20.55	5.98
2003	20.64	0.44
2005	20.60	−0.19
2009	21.02	2.04
2011	21.05	0.14
2013	21.23	0.86
2015	21.34	0.52
2017	21.54	0.94
2019	21.67	

Affairs 2015). Furthermore, approximately 3.16% reduction in world forest cover has been reported due to illicit felling of timber during 1990–2015. Also, 31.6% of forests were reported in the year 1990 as compared to 30.6% of total forest covers as per the global forest resource assessment (FAO 2015). Deforestation activity occurs basically in natural forest areas that are removed for fulfilling human needs for shelter and other tangible products. As per FAO, permanent removal of forest, i.e., tree canopy reduction below the 10% of the threshold value, is referred to as deforestation. This forest land conversion to other land systems is performed for intensive agriculture practice, logging, and other development projects, including mining. As per Foley et al. (2005), about 7–11 m km^2 area of forests were cleared over the past 300 years. Similarly, about 2.3 m km^2 areas of forests were cleared between 2000 and 2012, which represents the 2×10^5 km^2 $year^{-1}$ (Bologna and Aquino 2020). The tropical rain forest is very rich and diversified that covers more than 50% of known floral species and covers less than 10% of the global land area. This forest also harbors a variety of faunal species, but it has been declining due to several anthropogenic activities and human interference (Fisher et al. 2011). Deforestation and land-use change activities for agriculture expansion, palm oil plantations, mining, cattle ranches, and house constructions have resulted in the loss of tropical rain forest by 25–50% (Houghton 2003; Lewis 2006). This type of land-use change has been reported to be highest in the region of Southeast Asian countries as compared to others (Miettinen et al. 2011).

3.3 Faunal Diversity in Tropical Forest

The tropical forest holds a great diversity of fauna such as mammals, reptiles, arthropods, amphibians, and some invertebrates. This faunal composition was not only confined to limited space but spread over large areas for food, space, and reproduction. The diversity and richness of faunal species vary as per varying habitat, soil types, topography, biotic interference, and climatic situations in the forest. For example, the bird population is very diverse and occupies a wide range of habitats in the forests. They fly and move from one place to another for food, shelter, and reproductions. Therefore, bird species depend on vegetation types, structures, and compositions on which they merely depend for their survival (Nadkarni et al. 2004). They reflect themselves as a functional group of forest ecosystems due to playing a significant role in pollinations, seed dispersal, and insect-pest control (Whelan et al. 2008). Similarly, faunal species variations are also observed in different layers/strata of particular forests. Some species of birds, reptiles, amphibians, and mammals stay in ground vegetation, which is a safe place for breeding and shelter. Thus, the height and density of trees and understory vegetation along with logs and snags play an important role in the distributions, diversity, and richness of avian species (DeSanto et al. 2002; Munoz et al. 2004). Likewise, ground vegetation comprises herbaceous and regeneration plants that are a safe place for reptile shelters and their breeding purposes. Species diversity in the tropics of the world is depicted in Table 3.2.

3.4 Environmental Services Through Faunal Diversity

Faunal communities also deliver some important environmental services such as pollination, seed dispersal, pest control, herb control, nutrient cycling, climate control, etc., that ensure a healthy and vibrant ecosystem. Environmental services through fauna are depicted in Fig. 3.2 (Kunz et al. 2011; Tuanmu et al. 2016).

The greater diversity and richness of fauna play a key role in multifarious environmental services, which is better for forest ecosystem health and productivity. Rich biodiversity can intensify ecosystem services that ensure ecological stability and environmental sustainability. Tropical forests are blessed with diversified forest species that promote the diversity and richness of faunal species (Raj et al. 2022). For example, a group of mammal species intensify certain environmental services such as seed dispersal, insect-pest control, herb controls, and efficient nutrient cycling and promote food production. Moreover, these faunal species deliver additional services to forest-dependent people by providing a variety of foods (meat, milk, fur, oil, musk, and skin) and recreations that are economically viable (Fa et al. 2003). Likewise, certain species of reptiles have greater potential to control many harmful pests, beetles, caterpillars, bugs, termites, mice, rats, arthropods, etc., that cause rigorous loss of forest due to defoliation and wood damages. Moreover, amphibians play a key role in controlling pests (Rajpar and Zakaria 2014a, b).

Table 3.2 Species diversity in tropics of the world

Species	Scientific name	Family	Habitat	References
Birds	*Gerygone magnirostris* (commonly known as large-billed gerygone)	Acanthizidae	Tropical rain forest of the Australian continent	Johnson and Mighell (1999)
	Harpyopsisno vaeguineae (commonly known as papuan harpy eagle)	Accipitridae	Lowland region of tropical rain forest in Papua New Guinea	Tvardíková (2010)
	Spilornis cheela (commonly known as crested serpent eagle)	Accipitridae	Tropical rain forest in the Indian continent	Shankar Raman et al. (2005)
	Alcedo atthis (commonly known as common kingfisher)	Alcedinidae	Hill dipterocarp tropical rain forest in the region of Malaysia, lowland region of tropical rain forest in Papua New Guinea	Tvardíková (2010)
	Chloropsis aurifrons (commonly known as gold-fronted leafbird)	Chloropseidae	Tropical rain forest in the Indian continent	Shankar Raman et al. (2005)
	Piranga flava (commonly known as hepatic tanager)	Thraupidae	Tropical rain forest in the region of Costa Rica	Hughes et al. (2002)
	Psophode solivaceus (commonly known as eastern whipbird)	Psophodidae	Tropical rain forest of the Australian continent	Johnson and Mighell (1999)
	Pycnonotus priocephalus (commonly known as gray-headed bulbul)	Pycnonotidae	Tropical rain forest in the Indian continent	Shankar Raman et al. (2005)
	Iole olivacea (commonly known as buff-vented bulbul)	Pycnonotidae	Hill dipterocarp tropical rain forest in the region of Malaysia, isolated region of tropical rain forest in Malaysia	Rajpar and Zakaria (2014a, b); Estrada et al. (1993)
	Zosterops palpebrosus (commonly known as oriental white-eye)	Zosteropidae	Tropical rain forest in the Indian continent, isolated tropical rain forest in Malaysia	Estrada et al. (1993)

(continued)

Table 3.2 (continued)

Species	Scientific name	Family	Habitat	References
Mammals	*Diclidurus virgo* (commonly known as white bat)	Emballonuridae	Tropical rain forest in the region of Mexico	Estrada et al. (1993)
	Rattus annandalei (commonly known as Annandale's rat)	Muridae	Primary rain forest of Malaysia	Ruppert et al. (2015)
	Leopoldamysed wardsi (commonly known as Edwards's long-tailed giant rat)	Muridae	Tropical rain forest in the region of Indonesia	Boubli et al. (2004)
	Desmodus rotundus (commonly known as common vampire bat)	Phyllostomidae	Tropical rain forest of Mexico	Estrada et al. (1993)
	Callosciurus notatus (commonly known as plantain squirrel)	Sciuridae	Primary rain forest in the region of Malaysia	Ruppert et al. (2015)
	Sundasciurus tenuis (commonly known as slender squirrel)	Sciuridae	Tropical rain forest of Indonesia	Boubli et al. (2004)
Reptile	*Boiga dendrophilia* (commonly known as mangrove blunt-headed snake)	Colubridae	Tropical rain forest in the region of Philippine	Rolex et al. (2010)
	Phyton reticulates (commonly known as reticulated phyton)	Colubridae	Tropical rain forest in the region of Philippine	Rolex et al. (2010)
	Gekko mindorensis (commonly known as mindoro narrow-disked gecko)	Gekkonidae	Tropical rain forest in the region of Philippine	Rolex et al. (2010)
Amphibians	*Ingerophrynus divergens* (commonly known as Malayan dwarf toad)	Bufonidae	Lowland region of tropical rain forest in Malaysia	Gillespie et al. (2012)
	Limnonectes finchi (commonly known as Finch's wart frog)	Dicroglossidae	Lowland region of tropical rain forest in Malaysia	Gillespie et al. (2012)
	Chaperina fusca (commonly known as brown thorny frog)	Microhylidae	Lowland region of tropical rain forest in Malaysia	Gillespie et al. (2012)

(continued)

Table 3.2 (continued)

Species	Scientific name	Family	Habitat	References
	Kalophrynus pleurostigma (commonly known as black-spotted narrow-mouthed frog)	Microhylidae	Tropical rain forest in Philippine	Rolex et al. (2010)

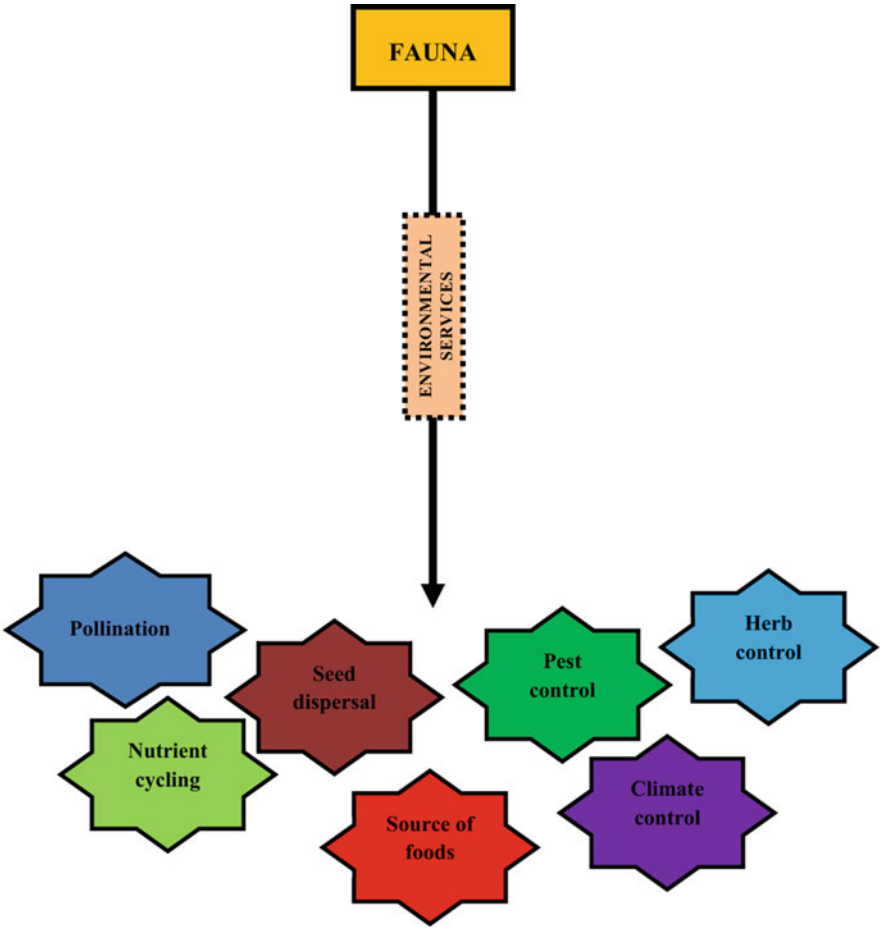

Fig. 3.2 Environmental services through fauna. (Modified: Kunz et al. 2011; Tuanmu et al. 2016)

3.5 Forest and Fauna: An Intrinsic Relationship

There is a great synergy between forest and faunal communities. Forest provides shade to humans and animals. It protects organisms from adverse climatic factors such as high wind speed and sun scorch. Forest also harbors millions of species that aid in the regeneration of forest through pollination mechanisms (Fig.3.3) (Brockerhoff et al. 2017). Thus, forest maintains faunal health, biodiversity, productivity, and related ecosystem services.

Great synergy exists between forest and fauna that is a pillar of the healthy functioning and structure of the ecosystem. Both are interdependent for their mutual survival and existence. The dependency of faunal species varies as per varying forest types, structures, and compositions. For example, some primates like *Diademed*

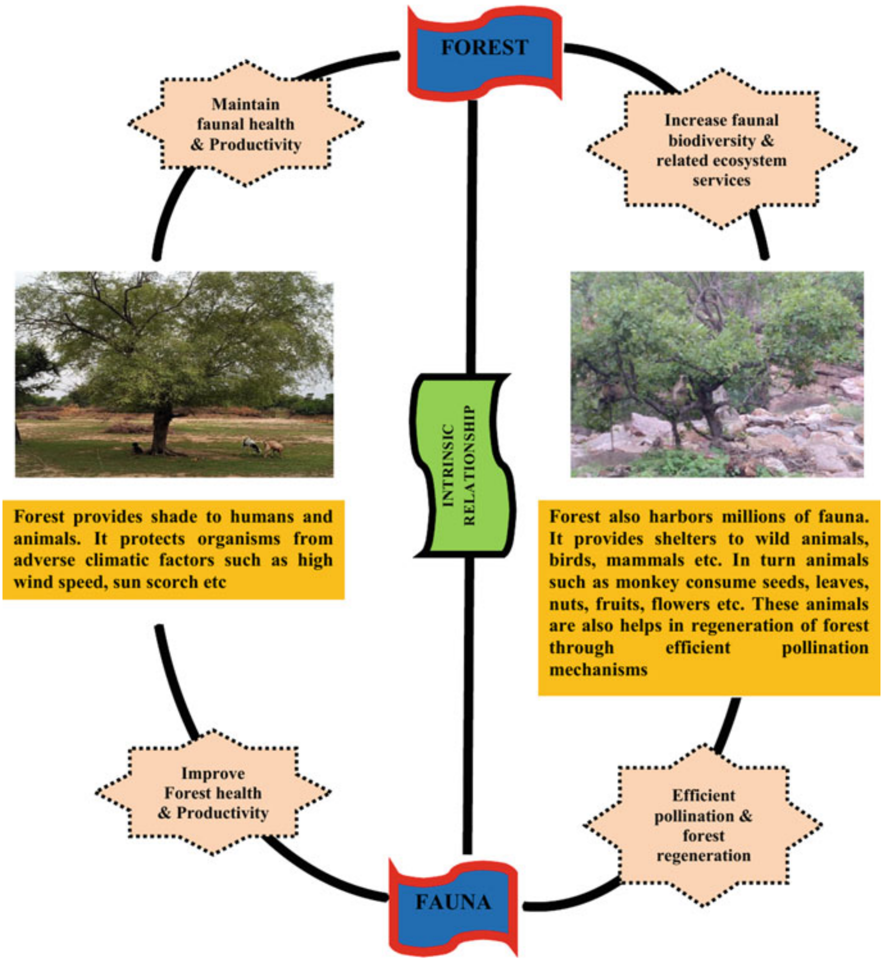

Fig. 3.3 Intrinsic relationships between forest and fauna. (Modified: Brockerhoff et al. 2017)

Sifakas–Propithecus diadema prefer continuous forest rather than a fragmented forest that holds black howler monkey (*Alouatta pigra*) for their existence and survival (Felton et al. 2008; Boyle and Smith 2010). Monkeys are habitat-specific, and their diet habits are influenced by plant compositions and richness in any forest. Generally, they depend on the forest for a variety of foods such as flowers, fruits, seeds, leaves, and arthropods (Boyle et al. 2012). Similarly, amphibians make an intrinsic relationship with the forest community for their survival and existence. They prefer ground herbaceous vegetation and large tree species for food and a suitable place for making a nest for breeding.

3.6 Deforestation Impacts on Faunal Biodiversity

Forest logging, fragmentation of habitat degradation, illicit timber cutting, hunting industrial development and mining, and intensive agricultural practices are major causes of deforestation, which decline faunal biodiversity and distribution, increase predation, and cause poor health and productivity (Fig. 3.4) (Bonaudo et al. 2005; Maxwell et al. 2016; Symes et al. 2018).

Deforestation, hunting, logging, and agricultural expansion were reported to threaten one-fifth of mammal species in the wild to extinction (Hoffmann et al. 2011; Nijman 2010). Changing climate due to human activities is also another driver of the loss of faunal diversity and richness (Visconti et al. 2011). The declining population of birds and mammals due to hunting was reported as 58% and 83%, respectively (Benítez-López et al. 2017). However, the populations and diversity of elephants, rhinoceros, tigers, and Bali starling have been declined due to illegal hunting for international trades (van Balen et al. 2000; O'Kelly et al. 2012; Wittemyer et al. 2014; Haas and Ferreira 2016). Similarly, the one-third population of amphibians has declined due to habitat loss induced by deforestation activities (Bickford et al. 2008).

Land-use change-mediated habitat alteration also affects the avian species diversity, abundance, richness, and density (Hughes et al. 2002). It is strongly assumed that bird community structures are directly associated with the closeness and openness of the tree canopy along with understory and ground vegetation. Moreover, forest fragmentation, habitat destruction, logging, fire, and slash-and-burn agricultural systems strongly affect the overall population and diversity of avian species in forests (Tvardíková 2010). These factors entirely affect the overall structure, composition, richness, and avian diversity due to changing food resources, brood parasitism, and increased nest predations. The food resource availability, diversity, and richness are closely linked with vegetation structure and its composition, including fruits, foliage, barks, and flowers. Furthermore, mammals have been linked with home range-specific food in any forest but due to deforestation and changing vegetation altered their food preference and availability (Kinnaird et al. 2010). Similarly, amphibians and reptiles are also sensitive species and vulnerable to habitat alteration and land-use change (Brown 2001; Sendoya et al. 2013). Around one-fifth of the amphibian population is threatened in Southeast Asia (IUCN 2009).

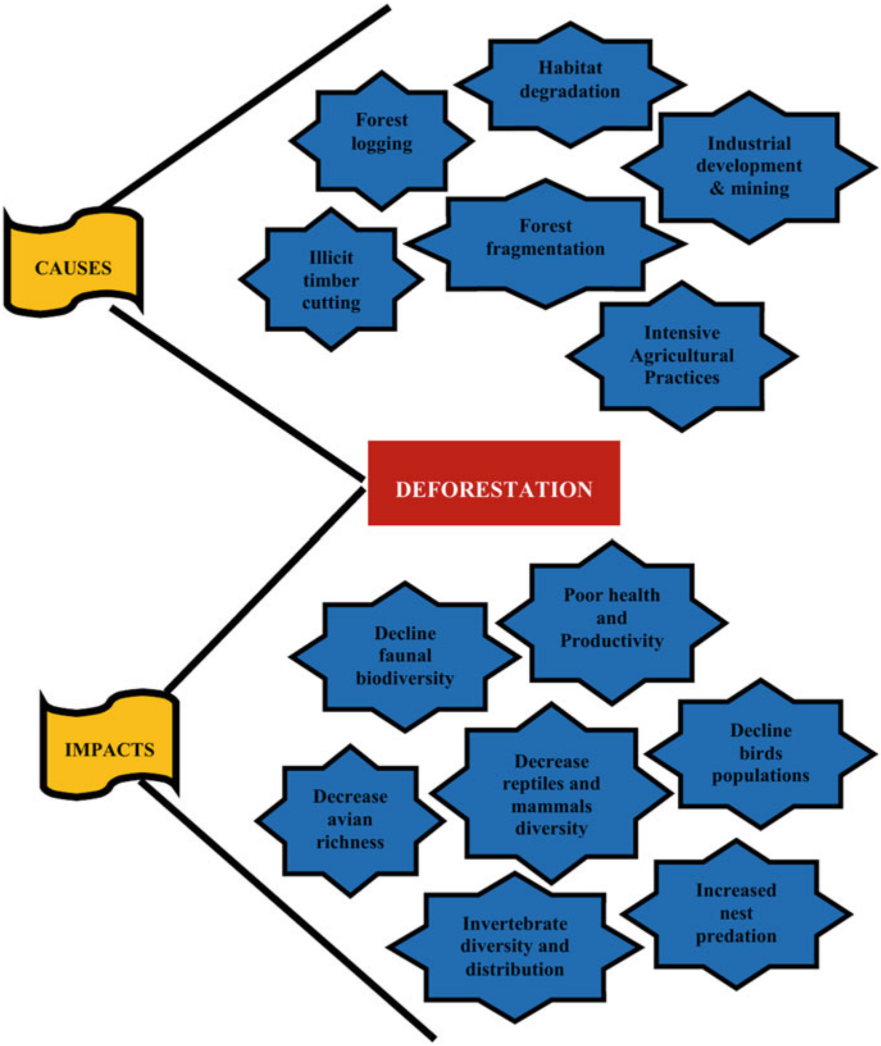

Fig. 3.4 Deforestation impacts on faunal populations. (Modified: Bonaudo et al. 2005; Symes et al. 2018)

It was due to the small home range, which is strongly affected by habitat loss, degradation, and predation (Irschick et al. 2005). Deforestation also leads to poor diversity and richness of reptile communities in tropical rain forests (Rocha et al. 2014). Moreover, over-harvesting of food products, medicine, and illegal pet trades in the natural forest has altered the distribution and diversity of amphibians (Bickford et al. 2008). Logging creates a big gap that affects habitat structure and food availability and alters microclimates that strongly affect the diversity and distribution of invertebrate species (Basset 2001; Laurance and Peres 2005; Santos and Benitez-Malvido 2012).

3.7 Forest Management for Faunal Ecological Services

Forest stores a variety of faunal species that delivers significant ecological services for a healthy and productive environment. But unsustainable and unscientific land-use practices destroy the forest species, further affecting faunal health and productivity by destroying their habitat and breeding sites. In this context, the practices of SFM ensure forest-faunal health and productivity, which in turn provides various tangible and intangible ecological services for a better landscape (Jhariya et al. 2019c). Thus, scientific management of the forest can minimize the various anthropogenic activities, including deforestation, and ensure highly rich diversity and distribution of various faunal species. Maintenance and conservation of forests are necessary for healthy and productive faunal communities that intensify various ecological services for ensuring environmental sustainability in the world.

3.8 Policies and Future Thrust

Forest delivers uncountable ecosystem services for ensuring food–soil–climate security. Tangible and intangible services are important elements delivered through the well-managed forest that ensure sustainable development (Raj and Jhariya 2021a, b). Soil conservation, water regulation, and flora and fauna health maintenance along with climate regulation are important environmental services provided through the practices of SFM (Sheram 1993). Effective policy platforms and actions must be in place for faunal conservation through adopting SFM practices (Jhariya et al. 2019c). A future roadmap for managing forests for healthy faunal communities is needed to promote diversity and richness of fauna that ensure a variety of ecosystem services.

3.9 Conclusion

Deforestation, forest fragmentation, logging, and unsustainable land-use practices lead to land degradation that alters floral and faunal species compositions, disturbing ecosystem health and productivity. Forests are a natural home for wild animals on which they depend for their shelters, nesting, and breeding purposes. These species deliver ecosystem services in tangible ways, such as providing meat, fur, milk, skin, etc. Pollination, insect-pest controls, herb control, efficient nutrient cycling, etc., are intangible services provided by diversified forest-dependent faunal communities. In this context, practicing SFM can ensure a healthy and productive faunal community that promotes biodiversity and intensifies ecological services. Furthermore, effective policy and good governance are needed for the conservation and management of forest, which is the natural home of the faunal communities that play an inevitable role in environmental sustainability and ecological stability.

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4 Drivers of Deforestation, Forest Degradation, and Management Responses in Ghana

Kenneth Peprah

Abstract

The significance of forest ecosystems and the tropical forest of the world are well articulated in the literature. Also, the wanton forest destruction globally has received substantial research attention. Again, the major stakeholders know the causes of deforestation. Hence, the persistence of global, national, regional, and local tropical forest loss is questionable. Primary and secondary data were assembled to digest the drivers of deforestation and forest degradation using Ghana's tropical forest in Asunafo in the Ahafo Region. Using one-to-one matching of drivers-to-causes: parochial interests drive timber exploitation; limited participatory avenues in the Ghanaian economy drives the majority of the population to do crop farming, particularly, cash crop such as cocoa farming; trade and dependency syndrome (market failure) drives mining, essentially, gold and diamond mining; a dearth of knowledge (lack of data and information) exacerbates drought and fire; and culture drives the use of non-timber forest resources to extinction. These drivers are highlighted in this chapter to engender policy attention. International initiatives, public opinion, culture, and direct government actions are driving efforts at sustainable forest restoration.

Keywords

Deforestation · Forest degradation · Timber extraction · Mining · Cocoa farming · Drought and fire · Culture

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4.1 Introduction

Land degradation is a concept notionally constructed in the pejorative sense (Gisladottir and Stocking 2005). It is defined as land deprived of its value, be it inter alia, land quality (Gyasi et al. 2006), land as habitat niche for plants and animals (Safriel 2007), biological or economic productivity of land (Bai et al. 2008; UNCCD 2012), and biodiversity, ecosystem services, and ecosystem resilience (IUCN 2015). In conjunction with this definition, any land undergoing land degradation processes becomes less useful to human beings (Wasson 1987). As such, since 1977 to date, the United Nations Organization has accumulated scientific knowledge and put policies and programs in place to address the land degradation menace (Grainger 2015). Presently, the Goal 15 of the SDGs essentially has targeted environmental degradation in order to stem desertification and land degradation as well as to ensure zero-net degradation globally (Akhtar-Schuster et al. 2016). Specifically, zero-net degradation seeks to reduce the existing rate of land degradation and increase restoration processes of degraded lands so that the combined effect of these two processes will cancel out inevitable land degradation, which may occur elsewhere in the same landscape (Grainger 2015; Akhtar-Schuster et al. 2016). In the context of this agenda, the discussion of the anthropic drivers of deforestation and forest degradation is warranted.

Generally, forest delivers ecosystem services at different scales from the local to the global levels. In developing countries, forest represents natural insurance against various risks, hazards, and threats (Pouliot and Treue 2013). These services are categorized in the Millennium Ecosystem Assessment (MEA) as provisioning of ecosystem goods such as food, water, oxygen, fiber, etc.; regulating climate, flood, disease, etc.; cultural as in aesthetic scenery, natural recreation, education, and spiritual settings; and supporting services such as primary food production, formation of soils, nutrient cycles, etc. (MEA 2005). Hence, forest health is particularly important for it to function properly. In addition, the forest ecosystem embodies a high diversity of plant and animal species hosted by the vegetation, soils, water bodies, and other biophysical resources on which the sustenance of human life depends (MEA 2005). However, environmental degradation (subset—forest degradation) is an aberration in forest ecosystem health and poses a great threat to the sustainability of forest ecosystem services. This threat is aggravated by the occurrence of global and local calamitous climate change impacts (Novacek 2011), global population increase, and increasing demand for ecosystem goods and services (MEA 2005). Within the tropical forest of Africa (western and central parts), deforestation poses a major threat due to demand for farm lands, firewood and charcoal, timber, and mineral ores, as well as ramifications of climate change impacts (Novacek 2011; Janssen et al. 2018; Nyamekye et al. 2021). Research indicates that these factors constitute the main causes of forest degradation in addition to air pollution (sulfur and nitrogen oxides) from industries, transportation, and agriculture (Novacek 2011). Consequently, soil productivity is weakened, forest biodiversity losses are worsened, and ecosystem services are impaired with subsequent socioeconomic problems (Perovic et al. 2021).

Therefore, there is a pressing need to evolve policies to address the degradation of land and the associated drivers (Nkonya et al. 2016). By doing so, a country case study is advocated for due to the specificity of the drivers and the details required (Nkonya et al. 2016). The first step is the identification of the drivers (Pascual and Rivas 2010; Kirui and Mirzabaev 2015).

With categorization, drivers of land degradation are grouped into anthropogenic, anthropic, or human (socioeconomic) as against environmental or natural (biophysical) drivers (Ash et al. 2010; Halbac-Cotoara-Zamfir et al. 2020). These drivers are considered according to temporal and spatial scales. One such category is the combination of climate change, economic development, development of technology, and cultural and political behaviors (Batunacun et al. 2019). Also, the other category of drivers considers direct drivers to include pressures and indirect drivers as driving forces (Pascual and Rivas 2010). The driving forces are described as indirect causes and pressures, while direct drivers are causes of land degradation (Rioux et al. 2017). Again, another category of drivers in the literature is apparent and latent drivers (Halbac-Cotoara-Zamfir et al. 2020). Furthermore, other authors discuss proximate and underlying drivers as a distinct category of drivers in which the former relates to biophysical and unsustainable land management practices and the latter refers to socioeconomic and institutional barriers to land degradation (Mirzabaev et al. 2016). Examples of proximate drivers are environmental in nature, such as the lay of the land (relief), changes in the cover of the land, climate, susceptibility of the soil to erosion, pest and diseases, improper land use practices, and development of buildings. Underlying drivers are exemplified by increases as well as growth in the population, market access, land ownership and usage practices, poverty, access to agricultural support services, globalization, and off-farm jobs.

By definition, drivers of degradation are process indicators or proxies. Hence, drivers relate to cause–effect mechanisms that border on indicators that constitute drivers of land degradation and those that do not (Mirzabaev et al. 2016). In the literature, drivers are expressed severally using different terms. For instance, in the Pressure-State-Response (PSR) framework, words such as pressures, driving forces, control variables, or process variables are used in place of drivers (Ash et al. 2010). Again, in the Millennium Ecosystem Assessment (MA) framework, drivers are replaced by words like indirect drivers or pressures (Tomich et al. 2010). Elsewhere, the indirect drivers are termed as underlying drivers (Ash et al. 2010). In this chapter, drivers are distinct from the causes of land degradation. Hereafter, drivers are defined as forces that propel the causes of land degradation to take place. For instance, timber extraction causes deforestation and forest degradation, but the drivers behind timber extraction are the parochial interests of the people in the timber industry. Also, cocoa farming in Ghana is a cause of deforestation and forest degradation, which is underpinned by a lack of participatory avenues in the Ghanaian economy. In addition, mining, essentially gold and diamond mining, is a cause of deforestation and forest degradation in Ghana, which is triggered by trade and dependency syndrome (market failure). A dearth of knowledge (lack of data and information) propels drought and fire. Finally, forest resource harvesting, particularly, of non-timber forest products (NTFPs), is a cause of deforestation and forest

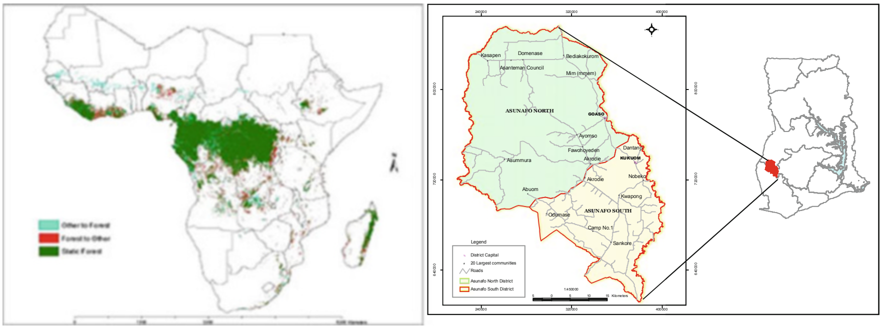

Fig. 4.1 Forest land cover change 2001–2009 and Asunafo area in Ghana's tropical rain forest. (Source: Nkonya et al. 2016; Peprah 2013a)

degradation underlain by culture of Ghanaians. It must be restated that mining as a cause of forest degradation in Ghana could also be driven by parochial interest and market failure. It is for convenience of explanation and style to simply match one cause of degradation to one major driver. In actuality, there is one driver to many causes of land degradation and the reverse is also true or, many-drivers-to-many-causes and vice versa. The critical question is why is deforestation and forest degradation happening in Ghana persistently? The literature shows that Ghana lost about 80% of its primary forest between 1900 and 1999 and about 33% between 1990 and 2010 (Andoh and Lee 2018).

4.2 Methodology

Direct field engagement with forest degradation and sustainable land management assessment spanned from 2002 under a project named "People, Land Management and Ecosystem Conservation"—UNU/PLEC-Ghana, which was funded by the United Nations University. This was mainly a series of interactions with farmers and scientists, both local and foreign, on the forests in the Eastern and Central Regions and the savannah of the Northern Region. In addition, this chapter draws heavily on my Ph.D. research in the Asunafo forest in the Bono and Ahafo Regions with data collection from 2010 to 2012. Primary data were sourced from 264 farmers drawn from 774 total farmers. Secondary data were gathered from Ghana Meteorological Agency on temperature, rainfall, sunshine, and relative humidity on the Asunafo area, Ghana COCOBOD, and passbooks of cocoa farmers. In 2018, both primary and secondary data were sourced from farmers doing cocoa farming in the Volta Region of Ghana to write a book chapter on Cocoa Plant, People, and Profit. Data from these sources have been synthesized and added to the desk study to produce this chapter. As per Fig. 4.1, the map of the study area, it is still tilted heavily toward the Asunafo forest; the data refer to this area. Forest land cover change from 2001 to 2009 was computed by Nkonya et al. (2016) for Africa.

It is used in this study to show the tropical forest of Ghana together with the others in the continent. Also, it helps in the clarification of the cocoa frontier, which has moved from the east of the forest to the west in Ghana's context. Within Ghana's tropical forest is the Asunafo forest.

4.3 Results and Discussion

4.3.1 Parochial Interests with Little or No Consideration of Ecosystem Value

The consideration of drivers of land degradation in the literature often concentrates on direct drivers (pressures/proximate/causes) and indirect drivers (driving forces/underlying drivers). The examples of these two streams of drivers are either socio-economic or biophysical (Ash et al. 2010; Pascual and Rivas 2010; Mirzabaev et al. 2016; Rioux et al. 2017; Batunacun et al. 2019; Halbac-Cotoara-Zamfir et al. 2020). However, the anthropic drivers that are very fundamental and explain human behavior behind the causes of land degradation are largely ignored. A major example of anthropic drivers of deforestation is timber industry investors' parochial interests and their show of little or no consideration for the value or wealth of the ecosystem besides timber. In Ghana, timber activities are the main threat to the maintenance of larger and contagious forest cover (Appiah and Agyemang 2020). This section uses timber extraction in Ghana from colonial times to the present to explain the parochial interests of the operators, which drive deforestation and forest degradation. The availability of timber species in the tropical forest in Ghana in the nineteenth century caused governments and commercial entities to construct transport routes to exploit the resource (Boni 1999). The development of railways is an example so that timber could be sent to the seaport for export to Europe (Tsey 1986). The traditional authority under indirect rule also traded timber in the forest reserves with timber merchants indiscriminately (Teye 2010).

The timber industry in the hands of independent Ghana has been used to serve both international and local market demand. The political independence of Ghana did not change the practices of deforestation by the timber industry. The desire to get rich quickly through investment in the timber industry is the order of the present timber extraction (Peprah 2013a). In the 1990s, there was a policy change based on the general view of abundant availability of timber (Owusu et al. 2010), allowing the export of a whole timber log. The glut saw lots of the logs gotten rotten at the seaports at Sekondi-Takoradi. This period saw wanton deforestation and forest degradation. Later, the establishment of plywood industry in the country saw *Ceiba pentandra* categorized as timber species, being the biggest tree ever in the forest since there was no use for it during the colonial period, independence, and immediate post-independence era. A third wave that is threatening the remaining forest is an illegal chain saw timber operations (Acheampong and Maryudi 2020). Such operators defy all odds to carry out their activities, sometimes deep in the night. These activities could only be attributed to the parochial interests of such indigenous investors as the main driver behind deforestation and forest degradation. Currently, in the local timber market, the buyer has to choose between buying sawn timber as "bush cut" from the illegal chainsaw operation or "sawmill." The "sawmill" is a bit longer in length than the "bush cut" and it is also straight; hence, it is sold at a slightly higher price. Buttressing the parochial interests of timber investors is the research finding that there is exchange (patronage) networks between and among forestry officials and the exploitative groups (Teye 2010). Finally, the harvesting of rosewood (*Pterocarpus erinaceus*) in the savannah woodlands clearly shows the parochial interests of different stakeholders, including the state. There have been state bans on felling and exporting by listing rosewood on CITES Appendix III and later moving it to Appendix II, but to no avail (Dumenu 2019). There could be an argument between international market demand for rosewood and parochial interests as to which is the main driver. It is argued that the market demand is also driven by parochial interests with little or no regard for the value of the ecosystem that hosts the rosewood.

From the discussion of the parochial interests of timber industry investors, one issue that stands out is the lack of respect for the value or wealth of the forest. From the colonial time through immediate independence, post-independence, and the present period, there was and is complete disdain for the value of the forest by timber investors. The capitalist interest of resource extraction and use for now with no regard for the future cuts across all the periods from the colonial time to the present. Presently, deforestation and forest degradation have reached a stage where timber availability to feed local sawmills is a huge problem (Acheampong and Maryudi 2020), hence leading to the collapse of many sawmills in the country. The second issue is the desire to extract timber for the benefit of only the people in the timber industry. For example, during the colonial era, major timber firms, such as Gliksten West Africa Limited, disallowed farmers from using the timber roads in the forest. Also, both the colonial and the independent Ghanaian governments used timber concessions to disassociate host communities from the benefits of the timber industry (Hansen and Lund 2011). Recently, a Voluntary Partnership Agreement with European Union's Forest Law Enforcement Governance and Trade (FLEGT) has been identified as usurping the local land user rights to trees in their cocoa farms (Hirons et al. 2018). This international initiative to stem deforestation is inadvertently reinforcing the status quo. "The council is experiencing some difficulties with Timber Contractors in the area who often fail to compensate for farmers' crops destroyed during their operation" (District Commissioner 1960)."Most farmers interviewed rather prefer the operations or chainsaw operators, since they get payments when trees are cut on their lands" (Teye 2010). The literature indicates that over eight decades of forest management in Ghana there is a failure to engender sustainability and social equity and that timber extraction is a major culprit (Hansen et al. 2018).

4.3.2 Limited Participatory Avenues in the Economy

In this section, the focus on deforestation dwells on limited participatory avenues in the Ghanaian economy as one of the main drivers. The Ghanaian economy is relatively small and has limited entry and sustaining avenues for the progressively growing population. From the checked history of the economy of Ghana, the agricultural sector has been the main avenue for entry and participation in the economy by the majority of the population. The prolific agricultural sector consists of large subsistence food crops and small-scale cash crop farming (*Theobroma cacao*—cocoa, oil palm, and cotton as traditional exports and recent additions of nontraditional exports, e.g., pineapple). This section focuses on cocoa cultivation, population increase, and nationhood as the main causes of deforestation and forest degradation driven by limited participatory avenues in the economy. The *Theobroma cacao*—cocoa is a tropical cash crop originally from the Honduras (Ulua Valley) in South America. Its journey to Ghana is traced from its introduction in the British Empire in the seventeenth century in Central America, then to Sao Tome and Fernando Po in West Africa around 1822 and 1854, respectively (Grossman-Greene and Bayer 2009).

Following the unsuccessful cocoa cultivation trials in the Gold Coast, Tetteh Quarshie's experiment with cocoa farming at Mampong-Akwapim in 1879 flourished. Between 1891 and 1911, commercial cocoa farming and exports gained roots in Ghana, with exports of 40,000 tons (Grossman-Greene and Bayer 2009). This means the conversion of the original tropical forest into cocoa farm agroforestry. In the description of Ghana's cocoa frontier, deforestation and forest degradation started from the tropical forest in the Eastern Region (1880s), then to Asante after Yaa Asantewaa war of 1900 (1910) and Brong Ahafo Regions (1920s and 1940s), and then the final frontier in the Western Region (1960s) (Knudsen and Agergaard 2015) where cocoa started increasing in the 1940s (Boni 1999). The cocoa frontier therefore refers to the movement of cocoa farmers or investors from one forest region in Ghana mainly westwards in search of fertile lands for cocoa cultivation (Knudsen and Agergaard 2015). Cocoa cultivation and production in the 1920s has been described by Professor of Geography as Ghana's "green revolution" (personal communication Prof. George Benneh [late], 1999). By 1939, cocoa exports contributed about 80% of direct foreign exchange (Grossman-Greene and Bayer 2009). This implies forest conversion for cocoa cultivation, that is, reduction in tropical forest size and cover. During the colonial period, avenues for entry into the economy were indeed limited to cocoa farming from 1902 onward, timber from 1940, and mining at elsewhere not the Asunafo forest (Peprah 2013b). Relatively, cocoa farming was more attractive and lucrative. There were huge income gaps between cocoa farmers and other urban sector workers, leading to the terms rich Ghanaian cocoa farmers (Konadu 2008).

Under Governor Guggisberg, nation building was an important agenda. However, the rapid development of railways under the governor was to aid cocoa production, mining, and timber. Hence, the development of the northern territories was suspended to provide railways to link cocoa production centers. Another

Plate 4.1 Cocoa agroforestry at Asunafo Forest, Ghana 2012

Plate 4.2 Cocoa Agroforestry with limited tree inclusion

nation-building decision was to bring labor from the northern territories to cocoa farms, timber, and mining firms (Tsey 1986). This decision also meant increased impetus in converting a lot more forests to cocoa farms. At this point, it is important to introduce the national population dynamics at the time. The British indirect rule principles indicated that government business was for the colonial British people and day-to-day control of the population through the chiefs. The population of the country excluding the Trans-Volta Togoland had increased from 764,613 people in 1891 to 4,501,218 in 1948. However, the main employment avenues remained cocoa farming, timber, and mining. Plate 4.1 shows a very good cocoa agroforestry, but there are instances in which tree integration is limited, as seen in Plate 4.2.

These cocoa trees are shade-loving trees. Another implication of the Asunafo forest conversion is the degradation of forest wildlife, essentially elephants, chimpanzees, and buffaloes (Peprah 2013b). There are several reports of elephants marauding in the 1960s, where elephants destroyed cocoa and food crop farms, prevented the cleaning of forest reserves, and even killed two farmers. The ravages of elephants continued during the 1970s, 1980s, and 1990s. About 45 elephants were killed in a period of 39 years (1960–1999). Presently, elephants and chimpanzees are no longer encountered directly or their traces found in the forest (Forestry Commission 2001a; Peprah 2013b). The wildlife and the forest were sacrificed to grow cocoa, the main avenue for entry into the small national economy.

So far, this section has argued that the limited avenues of entry into the small national economy during the colonial period forced most of the population to do cocoa farming. The farmers used slashed and burn or slashed and no burn farming practices, resulting in a reduction in the original forest cover. During the colonial history of Ghana, many people became cocoa farmers due to a limited avenue of entry into the national economy. This situation improved immediately after independence with the introduction of import substitution industrialization drive, civil (now public) service sector, education service, police and security services, and government corporations (Kolavalli and Vigneri 2011). However, the cocoa farmer remained relatively richer than employees of the government (Konadu 2008). Hence, some government sector employees saw the cocoa sector as a personal pension scheme and invested in cocoa farming, a clear indication that cocoa farming is a formidable investment avenue in the Ghanaian economy. Presently, the industrial and service sectors are doing very well in employment generation, but the cocoa sector has improved tremendously employing about 700,000 farmers (Kolavalli and Vigneri 2011). The attention is more focused on nation building than on the cocoa farmer. Also, with the forest degradation, cocoa farming has become a lot more expensive with the use of agrochemicals including chemical fertilizers.

The current cocoa production policy is cocoa farm rehabilitation which calls on farmers to slash down old cocoa trees of the 1920s and 1940s–1970s, which were shade-loving, and replant seedlings that are sun-loving. Therefore, agroforestry is no longer needed in the present cocoa production. Some of the sun-loving cocoa trees have started bearing fruits (Peprah 2019). The implication for the present cocoa production strategy has dire consequences for deforestation and forest degradation. The process is a bit slow because of the aged nature of the cocoa farmers, who consider the cocoa farm rehabilitation to be tedious (Peprah 2013a). However, the COCOBOD has institutionalized Cocoa Health and Extension Division (CHED) to assist cocoa farmers in undertaking cocoa farm rehabilitation irrespective of the long-term impact on deforestation and forest degradation. This strategy has brought secondary forest fallows, which previously would not have been used for cocoa farms under cocoa cultivation. The gestation period for production of cocoa beans from the sun-loving cocoa tree is relatively shorter than the shade-loving trees. With the limited economic activity avenue in the Ghanaian economy, a new lease has been provided to families with large tract of secondary forest lands to re-invest in cocoa production. Without any frontier cocoa region to move to cultivate cocoa, attention is now drawn to re-use of the secondary fallow forest in all the cocoa growing regions.

4.3.3 Trade and Dependency Syndrome with "Market Failure"

Mineral ores have their traditional markets; however, emerging market economies have offered surprising alternatives. Whereas success in the cocoa industry is attributed to the activities and programs of the state-controlled marketing board, COCOBOD (Vigneri and Kolavalli 2018), the same cannot be said about the mining sector and state institutions managing the mining processes. Hence, the main driver behind the wheel of deforestation and forest degradation is resulting from mining (Nyamekye et al. 2021); essentially, gold mining is identified as a trade and dependency syndrome with "market failure." Since 1874, the Gold Coast, now Ghana, has had two parallel gold and diamond mining sectors (formal and informal) competing for mineral ores (Hilson 2003). The trade in gold and diamonds is difficult to describe as words like illicit marketing, smuggling of minerals, and PMMC buying from illegal and legal gold and diamonds are common in the literature (Hilson 2003). It epitomizes the expression "market failure." In addition, there is too little need for gold and diamonds locally, hence, the dependency on foreign demand or market. This unfortunate situation has characterized the mining industry from the colonial era to the present. The operations of formal and informal sectors and markets for mined products have co-existed over the years of mineral production (Bansah 2019).

Before the encounter with the Europeans at the coast in the 1470s, there were reports of gold trade as part of the trans-Sahara trade between northern Ghana and Arabs, which used kutera (Maria Theresa coin) and cowries as currency for exchange (Ofosu-Mensah 2016; Ntewusu 2015–2017). Again, following the defeat of the Asantes in the Yaa Asante war of 1900, gold trade had become the prerogative of British and European firms in 1902 onward in the colony, Asante, and the northern territories (Ntewusu 2015–2017). Trade and dependence syndrome shifted from the Arabs to mainly the British, and the appropriation of gold and other mineral deposits as concessions began (Ofosu-Mensah 2016). From 1493 to 1600, Ghana produced 8,153,426 fine ounces of gold, that is, about 36% of the global gold output from a little over 30 mining firms (Government of Ghana 2014). After independence, the state assumed ownership of the mines, and it was not until 1983 that the economic recovery program divested to foreign private companies, which, as will be elaborated on later, took the trade and dependence syndrome to a higher level (ICMM 2015). It was not until 1989 that the government recognized informal mining with a formalization law, that is, PNDC Law 218 on gold mining by small-scale firms (Bansah 2019).

During the economic recovery program under the IMF and the World Bank, mining firms from Australia, Canada, the United States, and South Africa invested in Ghana's mining sector, resulting in the mass dislocation of indigenous mining firms and the numerous illegal miners. In some situations, communities had to be resettled away from their traditional homes. The negotiations are done between chiefs and mining firms, generally, the chief acting on behalf of the host communities; also, royalties from the mining activities are paid to the chiefs (Ali et al. 2020). Somehow, attention to environmental degradation caused by mining has been generally attributed to illegal mining activities, probably, because of the ubiquitous and unregulated operations. Even, research attention is shifted mainly toward the problems created by illegal mining in Ghana. By doing so, environmental degradation by large-scale mining is masked. Again, the literature posits that the government has attempted to replace illegal mining with formalized large-scale mining even though the latter is foreign-owned (Hilson and McQuilken 2016; Hilson 2017). The government appears to be caught in the web of trade and dependence syndrome and may not come out any better due to market failure and unfair trade. The skewed attention to illegal mining in Ghana leaves the large-scale mining industry on the blind side of the general public and citizenry to do the traditional land degradation perpetrated by the mining industry. The case for land degradation as caused by mining is very serious presently because of the change from underground mining to surfacing mining by both illegal and legal large-scale mining interests (Andrews 2018). The discussion of mining-induced land degradation and the link to resource curse or Dutch Disease indicates failure of governance by the government of the land; this chapter argues that the problem is driven by trade and dependence syndrome, which offers little or no option for innovations, thereby affecting indigenous livelihoods (Andrews 2018).

4.3.4 Dearth of Knowledge (Data and Information)

Drought is a prolonged period during the rainy season with aberration in rainfall resulting in acute water shortages, which affects industrial, domestic, agriculture, and surface and underground water storages (Peprah 2018). Instead of wetness, the landscape experiencing drought becomes very dry, leading to highly inflammable loads of vegetation, which often results in wildfires (Peprah 2018). The combined effect of drought and wildfire has caused deforestation and forest degradation (Dwomoh et al. 2019). Although drought is a natural climatic occurrence, the dearth of knowledge in the form of lack of scientific data and information remains the driver of the resulting land degradation in the forest. Ghana experienced drought in the years 1977, 1982–1983, and some years in the 2000s; however, the drought of 1970s and 1980s showed a dearth of knowledge, data, and information to handle the situation (Aidam 2013; Gautier et al. 2016). About 50% of vegetation cover in the country and about 35% of standing crops and cereals were destroyed by the 1982–1983 wildfire (Ministry of Environment and Science 2002). There was political instability in the country at the time; the flow of information, particularly to the public, was by state television and radio with no private players in the news broadcast. Electricity supply by grid was limited to a few big towns, and drought affected hydroelectric power generation. Radio was the most common medium for news broadcast; however, the state price control regime at the time made dry cell batteries inaccessible at the time. The universities and research institutions did not help with the data and scientific information that was needed. The period also witnessed brain drained as many in academia and the scientific community gave up on Ghana and sought greener pastures elsewhere. About 1 million Ghanaian repatriated from Nigeria a year earlier (1980/1981) means a lot more mouths to feed with limited food supply. The military government handled the situation the armed forces way. Considering the current provision of boreholes and the way water has been made available to the Ghanaian population through boreholes and the country's performance regarding MDG 7C, as against the water shortages of the 1982–1983 drought period, attributing a dearth of scientific knowledge as an anthropic driver that propelled drought and wildfire in the ensued deforestation and forest degradation is not far-fetched. Thus, this section hammers the point that little or no scientific knowledge is a major driver for deforestation and forest degradation in the biophysical or natural causes of land degradation such as drought. By extension, the present climate change impacts on deforestation and forest degradation require scientific knowledge to aid the combat.

4.3.5 Culture

Culture in this context refers to the way of life of a particular group of people operating a shared domain (Kluckhohn 1951; Lebron 2013). Although Ghana is made up of several ethnic groupings, certain ways of life are considered national irrespective of the various subcultures. Until quite recently, food vendors in the country used broad leaves ("awonomo"—*Thaumatococcus daniellii*, Marantaceae f.) from the forest to serve their clients with food "take away." Even today, two of the local dishes, that is, "waakye"—rice, beans, and brown leaves cooked together and eaten with pepper or chilli source as well as "gari and beans" ('gari' is processed from cassava), are sold in the broad forest leaves (see Plate 4.3 for the leaves).

The leaves were collected from the forest free of charge, sold to middlemen and women for onward retail to food vendors. Presently, the leaves can be found only in the forest reserve. The preference for the leaves over the plastic alternatives can only be explained by culture. Hence, the over-harvesting leading to its shortage in the country is driven by culture. Another example is the use of chewing sticks to clean the teeth. For many people living in the forest area, cleaning their teeth in the morning especially and other times of the day depends on the various forest species available. However, at the national level, "nsoko-dua[1]" was the most popular. Before, the economic recovery program by the IMF and the World Bank, toothpaste was difficult to find and 'nsoko-dua' was the traditional substitute. The local trade boom and the over-harvesting resulted in its extinction in the forest reserves in

[1] *Garcinia brevipedicillata* (Baker f.) Hutch. & Dalziel [family Guttiferae] (stored under name); Garcinia mannii Baker f. [family Guttiferae]—nsoko (auctt.) nsoko-dua (auctt.) (GHANA, TWI), Burkill, H.M. 1985.

Plate 4.3 "Awonomo"—*Thaumatococcus daniellii* in the Bonkoni Forest Reserves

Ghana (Forestry Commission 2001b). There were and are several tree species to satisfy the same tooth cleaning purposes; hence, the preference can only be attributed to culture. Presently, "nsoko-dua" is imported from Liberia and Sierra Leone for use in Ghana.

Other cultural products from the forest are "mortar and pestles" made from wood for the processing of "fufu," comparably the most famous Ghanaian local diet. "Fufu" is eaten every blessed day by a substantial number of households in Ghana in addition to its commercialization in the local restaurants (chop bars). Mortar is the receptacle, and pestles are pounders. Again, bamboos from the forest are used for furniture, housing constructions (rafters and roofing), and fencing. So much bamboos are harvested annually in the country due to cultural uses. However, the ability of bamboo to regenerate to replace harvested ones has ensured bamboo sustainability in the country. The same cannot be said about tree species used for mortar and pestles.

4.4 Drivers of Sustainable Land Management Responses

In terms of responses to deforestation and forest degradation in Ghana, this section considers drivers that have triggered or propelled sustainable land management responses to offset the degradation. In this section, the discussion focuses on international initiatives and pressures, public opinion, and culture.

4.4.1 International Initiatives with Voluntary Compliance

The international initiatives by the European Union in 2003, which sought to remedy deforestation and forest degradation, are good, but the legality aspect requires re-engineering (Acheampong and Maryudi 2020). The authors argue that normative principles and voluntary compliance are necessary to ensure the success of such initiatives.

4.4.2 Public Opinion

Recently, public opinion has proved successful in getting the government to respond to the illegal mining activities in the country. The impacts of illegal mining on deforestation and forest degradation as well as destruction of rivers (water quality) have been temporarily halted by government actions propelled by public opinion.

4.4.3 Culture

Culture forbids the harvesting of some tree species. In southern Ghana, trees in the cemetery and sacred groves are spared. Some other trees require libation to be said before harvesting. In the savannah woodlands, economic trees such as shea tree, baobab, and dawadawa are equally free from wanton destruction. However, cultural protection of tree species is limited to relatively small number of trees.

4.4.4 Direct Government Participation

The Green Ghana Project has caused government agencies, that is, the Forestry Commission to nurse various tree seedlings for free distribution to the citizenry for tree planting and tending with the support of the International Union of Nature Conservation (IUCN). A special day (June 11, 2021) has been designated as tree planting day in the country. In the year 2021, tree planting day received popular support and was generally successful as compared to earlier ones. Another success factor was the fact that every district in the country had a nursery and the planting coincided with the raining season in the country. The maintenance of existing forest reserves and creation of community resource management area in the savannah woodlands by the Forest Commission and local leaders is helping in forest restoration. Also, the institutionalization of riparian forest buffer by the Ghana Water Resource Commission is geared toward forest protection.

4.5 Conclusion

In Ghana, people who want to get rich quickly enter the timber industry, fell some trees, and process the timber for sale, sometimes without recourse to any law or regulation. This attitude has been captured by this chapter as the parochial interest of timber industry players. It has a lengthy history, beginning from the European imperialism in Ghana to date. Second, the Ghanaian economy is small and the avenues for entry and participation are limited. Crop farming remains the easiest avenue to enter the Ghanaian economy under various land use tenurial arrangements. And, most Ghanaian farmers do so by investing in cocoa farming. Hence, the majority of the Ghanaian labor force is found in crop farming, with about 700,000 directly engaged in cocoa farming. The implication is the conversion of tropical forests to cocoa farms leading to deforestation and forest degradation. Presently, Ghana has exhausted its cocoa forest frontiers, implying that there is no uncut fertile forest land to move to do fresh cocoa farming. Therefore, the COCOBOD decided to move from shade-loving cocoa trees to sun-loving cocoa trees to utilize fallowed secondary forests for cocoa farming. The implication once again is deforestation and forest degradation of the fallow secondary forest. Also, there is ongoing land use competition between the use of fallow secondary forest for food crops or cash crops (cocoa farming) and gold mining. Third, informal sector gold and diamond mining is very tedious and occupationally hazardous but with very high economic returns. Hence, land owners are prepared to offer fallowed secondary forest to miners than to cocoa farmers. The impact of mining on the forest in terms of degradation is quick, massive, and long lasting, particularly the recent surface mining. The demand for gold has increased the search and mining of gold by the informal sector, often without recourse to laws or bye-laws. Such activities are termed illegal gold mining. And, it is driven by trade and dependency syndrome with "market failure." State institutions are finding it difficult to manage the activities of informal gold mining, including its trade. When the state government is prepared to purchase gold from an institution, the state classified as "illegal" tells the story of market failure. It is this market failure that drives illegal mining and the inevitable attendant of deforestation. Fourth, drought and fire exhibited a devastating impact nationwide, particularly in 1982 and 1983. However, there is a general lack of scientific knowledge, information, and data on the impact. And, if these were adequately present, the effects would have been a lot more minimal. Although there were food aids, there was nothing like water aid. Meanwhile, there was so much water underground that could have dealt with the water shortages. Those that sunk local wells could not go to the depths of the boreholes presently. The fire destroyed the forest vegetation, including the vegetation of the protected areas, mainly forest reserves.

Culture could be used to stem deforestation and forest degradation, but in the case of certain forest species, cultural practices and preferences lead to extinction of such species. The species affected are trees used for chewing sticks, mortar, and pestles. Hence, from both historical and contemporary point of views, deforestation and forest degradation in Ghana is driven by the parochial interests of timber investors and limited avenues for entry into the small Ghanaian economy as population progressively increases. In the same vein, trade and dependency syndrome with "market failure" is the underlying driver of the deforestation and forest degradation caused by the mining industry. At the same time, cultural practices and preferences are responsible for the extinction of some forest species used as chewing sticks, mortar, and pestles. The review of the literature has shown that these underlying drivers, so discussed, have been missing from earlier discussions on deforestation and forest degradation. Also, international initiatives, public opinion, culture, and direct government participation drive sustainable land management responses as remedies to deforestation and forest degradation.

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5 Forest Degradation in Nigeria: Case Study of Rugu Forest Reserve, Katsina State

Suleiman Iguda Ladan and Jummai Yusuf Saulawa

Abstract

This chapter analyzes forest degradation in Nigeria using the Rugu Forest Reserve in Katsina State as a case study. Data for the study were generated through field visits to two village settlements located at the fringes of the forest. In addition, structured questionnaires were administered to the residents of seven villages. Additional data were collected through key informant interviews with the forest officers of the zone where the forest reserve is located. The results showed that several factors are responsible for the degradation of the forest reserve. These factors include fuel wood extraction, encroachment for farming activities, insecurity facing the area, inadequate protection and conservation, and declaring the forest reserve as a grazing reserve. Past and the present government have adopted some measures to improve the reserve to make it function effectively as a forest reserve. This chapter therefore recommends tackling the insecurity facing the area to allow for the reforestation of the forest reserve.

Keywords

Forest reserve · Degradation · Rugu forest

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5.1 Introduction

According to the Food and Agricultural Organization (FAO) (2020), forests cover 31% of the global land area and are home to most of the earth's terrestrial biodiversity. Forests supply water, provide livelihoods, mitigate climate change, and are essential for sustainable food production (FAO 2020). Despite this, forest degradation continues at alarming rates, contributing significantly to the ongoing loss of biodiversity (FAO 2020). Forest degradation is the result of a process of degradation over time, which negatively affects the structural and functional characteristics of that forest (Vasquez-Gordon et al. 2018). Forest degradation occurs as a result of human activities, which in turn are driven by a variety of microeconomic, demographic, technological, institutional, and political factors (Vasquez-Gordon et al. 2018). In the majority of cases, the process of forest degradation involves a reduction in biomass and changes to the structure and species composition (biodiversity) of the forest, as well as in its natural regeneration.

A 2020 report from the United Nations Environmental Program (UNEP) and Food and Agricultural Organization found that in the past 30 years, 420 million hectares of forests have been lost through conversion to other land uses and that another 100 million hectares of forest are at risk (UNEP 2021). In the year 2021, a combination of natural and human factors has resulted in forest degradation across the globe in view of the wildfires that have burnt large hectares of forests in the United States, Canada, Turkey, Morocco, Algeria, and the Siberian region of Russia. The 2020 edition of the state of the world's forest produced by UNEP and FAO has shown that global forest area has decreased from 32.5% to 30.8%, which has been lost to agriculture and other land uses since 1990. Forest degradation has existed for many years in the continent of Africa. In Ethiopia, for example, forest degradation occurs as a result of agricultural expansion, increasing demand for construction materials, industrial use, fuel wood and charcoal extraction, lack of forest protection and conservation, and absence of a strong forest administration system, among others. In the Democratic Republic of Congo (DRC), the proximate causes of forest degradation vary greatly in time and space, particularly in diverse and country like the DRC; the study however noted that anthropogenic degradation has been increasing in recent years (Shapiro et al. 2021).

In Nigeria, forest degradation has continued to pose a serious environmental challenge as the country's population increased from 88.5 million in 1991 to 140 million in 2006. Osemoba (2012) observed that forest degradation has increased in Nigeria because agriculture and logging have taken over most of the forest lands in the country. Omolare et al. (2016) studied forest degradation in Old Oyo National Park, Oyo State, and found that from 1990 to 2014, settlement areas in the park expanded by 622.614 hectares at the expense of other land cover types. Olanrewaju et al. (2017) studied forest degradation and livelihoods in Ogun State, and the results revealed that gender, number of households members working and earning income, number of children per household, earning income from tree crops, and earning income from hunting were statistically significant factors influencing forest degradation within the study area. Jeminiwa et al. (2020) studied forest degradation indices in Mokwa forest reserve, Niger state, and the results showed that briquetting for charcoal was the highest cause of forest degradation, followed by commercial farming, overgrazing, and population increase also contributing to the degradation. Buba et al. (2020) studied forest degradation in relation to climate variability in Oluwa forest reserve, Ondo state Nigeria, and the results showed that there is a positive correlation between forest degradation and climate variability in the study area and concluded that the relationship is weak and not strong enough to make generations to cover the country.

In Katsina state, Nigeria, not many studies have been conducted on forest degradation. One of the few studies was the study by Ladan (2013) that studied the status and consequences of encroaching into forest reserves in Katsina urban areas. The results of the study revealed that a low level of importance is given to forest reserves, which leads to the degradation of the forest reserves with negative consequences on the urban environment at present and in the foreseeable future (Ladan 2013). Furthermore, Ladan (2020) showed that human activities have become a potential risk to the sustenance of the Barawa forest reserve in Katsina state. The study recommended strategies to be adopted to ensure the resilience and viability of the forest reserve against human activities. The present study focuses on the largest forest reserve in Katsina state of Nigeria, the Rugu forest reserve. The objectives of the study are to (i) examine the location and history of the Rugu forest reserve, (ii) examine the nature and composition of the Rugu forest reserve, (iii) investigate the factors responsible for the degradation of the Rugu forest reserve, (iv) highlight the efforts of the past and present governments in restoring the Rugu forest reserve, and (v) recommend measures toward restoring of the Rugu forest reserve.

5.2 Study Area

Rugu is a popular name of a community leader in Katsina State who was a fearless and courageous warrior that excelled in hunting and combat during his reign. He used to be praised by his people as "*Rugu Kan Kura Kowa ya taba ka zai kwana lahira*," which literally means Rugu a hyena's head, whoever faces you will die. The prominent warrior and his people lived in a forest in the present Safana LGA of Katsina State. Because of Rugu's popularity, the forest, which he occupied with his people, was named after him and was then called Dajin Rugu (Daily Trust 2012). The Rugu forest is a forest named after a village in Safana LGA, and the village is precisely located at the entrance of the forest. Rugu forest is the popular name of the forest among the people of Katsina state. The official name of the forest is Ruma-Kukar Jangarai forest named after Ruma, a village in neighboring Batsari LGA, and Kukar Jangarai, a tree *Adansonia digitata* located close to an earth dam called Jangarai.

Historically the Ruma forest and the Kukar Jangarai forest lying to the west and east, respectively, were merged together to form the Ruma-Kukar Jangarai forest in the then Katsina Province in 1959 (Jari 2011). However, the two forests were already declared as gazette forest reserves in 1931 by the then Emir of Katsina Muhammad Dikko (Ladan and Rafindadi 2020). By the declaration, the cutting of trees and poaching and killing of wild animals in the forest were forbidden by law under the Native Authority (NA) that was then under the British colonial administration. After the merging of the two forest reserves into one referred to officially as Ruma-Kukar Jangarai forest reserve, the reserve was divided into ten ranges and a cattle grazing scheme was introduced in 1962 (Jari 2011). Edible grasses were planted to serve as pasture for the cattle that would graze in the grazing scheme. According to the Dutsinma Zonal Forest Officer, there are up to 15 earth dams in the reserves, which are given names such as Daki Tara, Kadaura, and Jangarai. The forest reserve covers an area of about 800 km^2 located in the northwestern part of Katsina State, about 80 km southwest of Katsina city, the capital of Katsina state. A greater part of the reserve falls within Safana LGA, while other parts of the reserve fall in Batsari LGA to the north and Dutsinma LGA to the south of Safana LGA.

Rugu is the name of a village settlement in Safana Local Government Area (LGA), and it is from the name of the village that the Rugu forest reserve derived its name. SLGA is located in the Rugu forest between longitudes $7^o8'$ and $7^o20'$ east of the equator and latitudes $12^o22'$–$12^o34'$ north of the equator (Figs. 5.1 and 5.2). The LGA is situated in the northwestern part of Katsina state, covering a total land area of 282 square kilometers or 109 square miles. The LGA has a total population of 185,207 people comprising 93,410 males and 91,797 females, according to the 2006 census final results issued by the National Population Commission (Bawa 2012). The main ethnic groups are Hausa and Fulani; while the Hausas live in villages, the Fulani live in hamlets and isolated settlements around forest areas. The major occupations of these two groups are farming, cattle rearing, trading, hunting, and fuelwood extraction.

In terms of physical setting, the relief of the LGA is part of the high plains of Hausa land of northern Nigeria with isolated hills and an inselberg at Runka and Gimi villages. The drainage consists of a few rivers such as Bunsuru/Karadua, the water of which is tapped upstream to create Zobe dam in neighboring Dutsinma LGA. There are also some seasonal streams that were used to create earth dams in the Rugu forest reserve to supply water for cattle (Ladan 2020). A spring exists at the foot of Gimi inselbergs that is used for domestic water supply in the Gimi village. The climate is a tropical wet and dry climate typified as AW based on Koppen's classification of climates (Tukur et al. 2013). The mean annual rainfall is about 400–800 mm, and a maximum day temperature of about 38 °C is common in the month of April and May before the beginning of the rainy season (Jidauna et al. 2016). The vegetation type is Sudan Savannah consisting of short scattered trees, shrubs, and grasses. The trees grown in close formation in the western part of the LGA bordering the neighboring Zamfara State create the Rugu forest (Fig. 5.1).

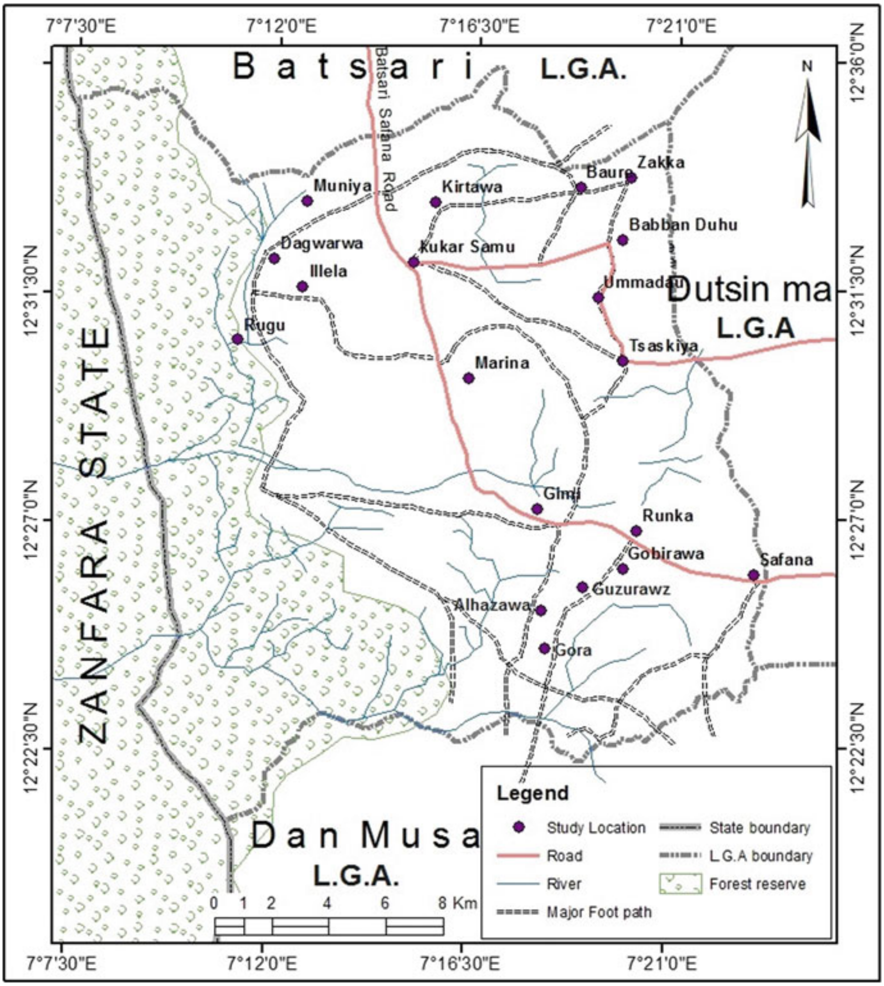

Fig. 5.1 Map of Safana LGA showing Rugu forest reserve

5.3 Materials and Methods

A direct observational technique was used to observe the nature and composition of sections of the Rugu forest located at Runka and Marina villages of Safana LGA. The observations were made during two field visits to the village of Runka made on November 2, 2021, and village of Marina made on November 3, 2021. These two villages are located at the edge of the Rugu forest to the east and western parts of the LGA. During the field visits, a lecturer from the Department of Basic Studies, Hassan Usman Katsina Polytechnic, Katsina, a native of Runka village, served as research assistant.

Fig. 5.2 Map of Katsina State showing Safana LGA as the study area

Additional data were collected by using a structured questionnaire that was administered to residents of seven villages above 45 years of age. The seven villages are Runka, Gora, Rugu, Gimi, Illela, Marina, and Tsaskiya. The residents aged 45 years and above were purposively sampled and selected as they are the only segments of the population that were knowledgeable about the condition of the Rugu forest at least from 1980. A total of 70 questionnaires were distributed to the residents of the seven villages on November 2, 2021, which is the weekly market day for Runka village. A total of 68 questionnaires out of 70 were collected on the market day, representing 97.14% of the questionnaires. This means that 10 questionnaires each were administered to respondents from each of the seven villages on the weekly market day at Runka, when people from the LGA and beyond gather to buy and sell at the market. The questionnaire consists of two sections A and B, with section A questions meant to collect the demographic characteristics of the respondents and section B focusing on the issues of forest degradation in the LGA. The questions in section B are on the nature and composition of the forest reserve, the condition of the forest reserve as at 1980, factors responsible for the degradation of the forest reserve, and measures that would be recommended toward restoring the forest reserve.

In addition, interviews were held with key informants who are officials of the Katsina State Department of Forestry. These are the two Zonal Forest Officers, past and present, who are the forest officers in charge of the Rugu forest under the Dutsinma zone forest office. The zonal forest officers were reached through field visits to the Katsina State Forest Department at Katsina and Dutsinma town on November 15 and 16, 2021. These primary sources were complemented with secondary sourced data collected through desk research. The secondary sources were collected from peer-reviewed journal articles, edited textbooks, historical sketches, government environmental reports, conference papers, and Internet-sourced materials. The data collected from both the primary and secondary sources were analyzed through descriptive statistics in the form of percentages, means, averages, and tabulations.

5.4 Results and Discussion

5.4.1 Demographic Characteristics of the Respondents

The demographic characteristics of the respondents from the seven settlements showed that in terms of gender, the majority (73.52%) were males (Table 5.1). This is based on the tradition in the study area where males are found outdoors and are more likely to engage in activities that degrade the forest, therefore purposively sampled for the study. In terms of age range, various respondents belong to different age groups, with those at the age of 50–54 years constituting 35.29%, which is the highest among the groups. The marital status of the respondents indicates that the majority (85.29%) were married. This is so because only those aged 45 years and above were sampled for the study. The largest family size of the married respondents was with 5–9 children, which constitute 38.23% among them. The number of children in a household is also an important factor influencing forest degradation in this study area, as rightly observed by Olanrewaju et al. (2017) in Ogun state.

Table 5.1 Demographic characteristics of the respondents

Characteristics	Frequency	Percentage (%)
Gender		
Male	50	73.52
Female	18	26.47
Age groups		
45–49	16	23.52
50–54	24	35.29
55–59	14	20.58
60–64	10	14.70
Over 65 years	04	05.88
Marital status		
Married	58	85.29
Divorced	06	08.23
Widowed	04	05.82
Number of wives for the married		
One	15	25.86
Two	30	51.72
Three	10	17.24
Four	03	05.17
Number of children		
1–4	20	29.41
5–9	26	32.23
10–14	12	17.64
15–19	10	14.70
Educational qualification		
Qur'anic education	30	44.11
Adult education	16	23.52
Primary school education	12	17.64
Secondary school education	10	14.70
Occupational status		
Farming and cattle rearing	41	60.29
Trading	14	20.58
Fuel wood collection	08	11.76
Hunting	04	05.88
Place of residence		
Rugu	12	17.64
Illela	11	16.17
Gora	09	13.23
Runka	09	13.23
Gimi	09	13.23
Tsaskiya	09	13.23
Marina	09	13.23

Among the married respondents, majority (51.72%) are having two wives while the others having one, three, and four wives.

The educational status of the respondents showed that the majority of the respondents (44.11%) had no formal education but had Qur'anic education. This status is typical of most of the rural LGAs of the state where formal literacy rates are low. This means that the research questionnaires had to be translated in the local language of Hausa for these sets of respondents to understand and respond. The occupational status of the respondents showed that the majority of the respondents (60.29%) were engaged in farming and cattle rearing as a source of their livelihoods. Other respondents were engaged in trading (20.58%), firewood cutting and selling (11.76%), and hunting of wild animals (07.35%). Among the occupations, those engaging in firewood cutting and selling are those that are directly responsible for the degradation of the Rugu forest. In terms of residential location within the Safana LGA, five village settlements had 9 respondents each, while two village settlements namely Illela had 11 respondents and Rugu had 12 respondents.

5.5 Nature and Composition of the Rugu Forest

The Rugu forest reserve is described as one of the largest forests in northern Nigeria based on aerial coverage. According to the Zonal Forest Officer in charge of the forest, the Rugu forest covers an area of 1,23,000 hectares of land, with much of the forest found within Safana LGA. The forest is a mangrove savanna forest that is evergreen throughout the season in some parts while other sections remain semi-dry (Rugu Katsina 2011). The forest used to be inhabited by many species of wild animals; among them are elephants, lions, hyenas, oxen, antelopes, bears, monkeys, different species of reptiles, and other lower animals (Rugu Katsina 2011).

The majority of the respondents (85.29%) knew that Rugu forest reserve is a savannah forest with dense stands or a collection of trees of different species. Only a minority among the respondents believed that it was a savannah forest with less dense stands or a collection of trees. According to the forest officer, all the tree species found in savannah vegetation zone are found at the Rugu forest reserve. The assertion that the Rugu forest was a dense collection of trees is supported by Mohammed (2015), who stated that the forest reserve was thickly wooded with different variety of indigenous species that grow simultaneously. The prominent tree species in the reserve are *Pilastigma thoningii*, *Diospyros mespiliformis*, and *Anogeissus leiocarpus*. The least numerous species include *Dalbergia sissoo*, *Cambretum glutinosum*, and *Khaya senegalensis* (Jari 2011).

Studies conducted on the composition of forest reserves in northern Nigeria have shown that the reserve is blessed with different vegetation that supports the lives of people in terms of fruits, fuelwood, herbs, fodder, and timber (Maishanu and Mainsara 2019). It is a known fact that most forests and even forest reserves support the lives of the people in developing countries of the world. Many communities are even described as forest dependent as they depend to a large extent on the forest and the resources of the forests. This dependence to a large extent contributed to the degradation of the forest over the years with little or no replacement or reforestation to recover the degraded forests.

5.6 Forest Degradation of the Rugu Forest Reserve

Since 1931 when the Rugu forest was declared a gazette forest reserve under the Native Authority, there were no visible signs of degradation of the forest. The forest therefore had maintained its structure and composition up to the year 1974. However, in 1974, the construction of a road to pass through the forest from Runka to Wagini in Batsari LGA started and the road was completed in 1975. During the construction of the 42 km road through the forest, many trees were removed to make way for the road. Furthermore, the construction of the road through the forest opened up the forest for exploitation by the people for various purposes. Margaba (2011) observed that the construction of roads opened forests to illegal exploitation, such as collection of fuel wood, hunting, grazing, and settlements.

By the year 1980, 5 years after the road construction, the forest reserve had shown signs of degradation in some sections. It is based on the fact that a minority (11.76%) of the respondents described the forest reserve as slightly degraded and less luxuriant in some sections. These are the respondents of settlements along the road, such as Runka, Gimi, and Marina. Majority of the respondents (88.23%) described the forest reserve as luxuriant and not degraded as the parts of the forest where their settlements are not affected by the road construction. Furthermore, up to 1980, there was strict control on the exploitation of the forest and its resources. By the year 1992, Katsina State Government observed that there was an encroachment into forest reserves, including the Rugu forest in Safana LGA. A committee was constituted to investigate the encroachment into the forest reserve, and the committee found out that a large part of the Rugu forest had been deforested and destroyed (Alo et al. 1998). This situation clearly shows that with time forest reserves in northern Nigeria witnessed negative changes in their structure and composition. A study by Badamasi and Yelwa (2010) observed a series of changes in the hitherto protected area of the Falgore Game Reserve between 1975 and 2000 and noted that the dense woodland has already turned to very open woodland within two and a half decades. The degradation of the Rugu forest continues with the forest reserve serving as the main source of fuelwood extraction for the people of Katsina state. The vast nature of the reserve makes it difficult for forest officers, forest guards, and forest extension workers to control the degradation. By the year 2010, well-armed bandits occupied parts of the reserve for launching attacks on rural communities and travelers along roads. Plate 5.1 shows one of the degraded parts of the Rugu forest reserve at Marina village.

Many factors have combined together to be responsible for the degradation of the Rugu forest reserve. These factors are outlined and explained based on the questionnaire administered for data collection and the key informant interviews held with the forest officers; these factors are described below.

Plate 5.1 One of the degraded parts of the Rugu forest reserve at Marina village of Safana LGA in November 2021

5.6.1 Fuelwood Collection

This is the first factor responsible for the degradation of the forest reserve, according to 29.41% of the respondents. The forest reserve despite being a reserve serves as the source of fuelwood extraction for the vast majority of the LGAs in the northern part of Katsina state. The fuelwood collection from the reserve became possible as the state government issued a license to fuelwood merchants who had laborers to work for them by cutting trees in the reserve, which were sold at both wholesale and retail prices. Furthermore, according to the Zone Forest Officer, there was no regulation or prohibition on the type or species of tree to be cut; whether dry or living trees, all were cut and transported out of the reserve to different parts of the state for sale. During a visit to the edge of the reserve at the outskirts of Marina village in January 2015, four truck-loads of fuelwood collected from the reserve were counted coming out of the reserve along the Marina–Gimi–Runka road within a period of 30 min. Fuelwood served as the only cheap and readily available source of fuel for the vast majority of the people in the state. At present, there is increasing demand for fuelwood due to the high cost of other sources of domestic energy such as kerosene and cooking gas.

5.6.2 Encroachment for Farming Activities

Over the years, as the population of the LGAs and the state grows, there has been an increasing desire to expand farmlands and/or create new farmlands by encroaching into the reserve for these purposes. According to 23.52% of respondents, this is the second factor responsible for the degradation of the Rugu forest. This has to be related to the fact that farming is a major occupation in the study area, and as the population grows and expands, the forest reserve is encroached upon for the creation of farmlands. Furthermore, the security situation in the LGA where bandits have created serious insecurity has given rise to a situation of lawlessness. The result is that many people in the villages willingly expand their farmlands or encroach into the forest reserve without any fear of the law or law enforcement agents. For example, in November 2014, over 100 persons illegally encroached into the forest reserve and created farmlands due to the frustration on the lack of political will by the then State Government (2007–2015) to tackle the security challenges affecting the LGA. Again 2 years later, by November 2016, the number of the encroacher had risen to 400, with the extent of encroached land stretching up to 10 km (Ladan 2019).

5.6.3 Insecurity Facing the LGA

According to 20.58% of the respondents, the insecurity facing the LGA is the third factor responsible for the degradation of the Rugu forest reserve. This is because Safana is one of the eight frontline LGAs in Katsina state that have been facing insecurity from the year 2010 to date. The insecurity arises as a result of well-armed bandits who have created camps in the Rugu forest reserves, turning it as a safe haven. From the forest reserve, they move on motorcycles mostly at night to launch attacks on villages in the LGA and beyond. They also mount roadblocks to rob travelers (Ladan and Rafindadi 2020). This insecurity has resulted that the forest zonal officer and his personnel do not go into the forest to check if there is any encroachment into the reserve. The Forest Extension Officers posted to some villages such as Gimi and Baure have since left their duty post due to the fear of the bandits. The Gimi village forest office, for example, has been closed for more than 5 years now, and the office is now used by the bandit leader controlling Gimi to judge local cases involving the people who still remain in the village. Also the bandit leaders themselves have been clearing large areas of the forest covered by shrubs and grasses and converting them into farmlands. For example, according to the zonal forest officer, bandit leader Ruga Kachalla has cleared the forest near Gimi village and converted it into farmlands for his cultivation. Another bandit leader has cleared forested lands of the reserve and converted them to farmland around Guzurawa village. Some bandits that are living at Dagwarwa village have also cleared forests and converted them into farmlands.

5.6.4 Inadequate Protection and Conservation

This is the fourth factor responsible for the degradation of the Rugu forest reserve, according to 17.64% of the respondents. This is because, despite being a forest reserve, the forest was over the years inadequately protected in view of the inadequate personnel assigned to take charge of the reserve. According to the Zonal Forest Office from 1980 to 2007, a period of 27 years, there was no provision of means of transportation in the form of motor vehicles and motorcycles to patrol the vast land area of the Rugu forest. Also, the state government does not implement reports of committees mandated to investigate the encroachment and destruction of forest reserves in the state, including the Rugu forest reserve. The committee mandated to investigate illegal encroachment into forest reserves in the state as in June 1992 found out that large parts were destroyed and deforested. In the long run, the committee's report was never made public or the recommendation of the committee was never implemented (Alo et al. 1998).

Also, forest officers do notice encroachment into the forest reserve by tree felling or laterite excavation. They serve an eviction notice to the person encroaching, but pressure from senior officials at the state level leads to inaction for the notice served. Over the years, the zonal forest officer has observed that traditional rulers are the persons who allocate forest lands for farming to some of their subjects. Then, any attempt to prosecute those who encroached into the forest fails to succeed. The state government usually does not take any punitive measures in cases of encroachment into the forest reserves if the person(s) are highly placed and influential persons, such as traditional rulers.

5.6.5 Declaring the Forest Reserve as a Grazing Reserve

Declaring the forest reserve as a grazing reserve is the fifth factor responsible for the degradation of the Rugu forest reserve, according to 8.82% of the respondents. They indicated that declaring the forest reserve as a grazing reserve since 1962 has opened up the forest reserve to a large movement of cattle and herders who also have contributed to reducing the vegetation cover of the reserve. The cattle rearers who are mainly Fulani by tribe clear the parts of the forest to create temporary settlements during the rainy season to graze their cattle. Also, the seasonal movement in and out of the forest reserve has affected its vegetation by clearing the forest to allow for the free movements of the cattle. Furthermore, the cattle themselves have affected the vegetation of the forest by trampling on grasses and shrubs. Some of the cattle that are reared by the Fulani in the reserve such as goats and sheep, which roam around within the reserve, make it difficult for shrubs and tree seedlings to survive by trampling and browsing on these forms of vegetation. In many parts of the world where forests are declared as reserves, grazing of cattle is not allowed in order to allow the forest to grow and develop strictly as a forest reserve.

5.7 Measures Adopted to Improve the Forest Reserve

Some measures were adopted by the past and present governments in order to improve the condition of the Rugu forest reserve. These measures are outlined below:

(i) In the year 2007, with the coming to power of Governor Ibrahim Shema, the Department of Forestry was moved out of the Ministry of Agriculture and Natural Resources to a department under the Governor's office. This resulted in improving funding of the activities of the forestry department as many tree seedlings were raised and planted in forest reserves such as the Rugu forest reserve.
(ii) The State Government purchased one brand new Toyota Hilux vehicle and six motorcycles for the zonal forest officer and forest extension officers, respectively. This provision of means of transportation enables the officers to carry out routine inspections and patrol of the Rugu forest to check for trespassing and encroachment.
(iii) A planting program was carried out by a nongovernmental organization under the "Service to Humanity Foundation." This planting was carried out at an area in the forest reserve called "Mashigin Katsinawa" where the planted trees were fenced.
(iv) The local government councils under the Dutsinma Forest Zone, namely Dutsinma, Danmusa, Kurfi, Batsari, and Safana, created nurseries and carried out a reforestation program in the reserve by establishing several woodlots to improve the tree cover of the reserve near Marina village. But unfortunately, the woodlots were destroyed by the bandits when they occupied large parts of the forest reserve.
(v) A Special Advisor on Forestry to the State Governor was created and appointed by the state government. This creation and appointment accorded a special status to the forest sector, which generally improved the activities of the department in the forest reserves in the state, such as the Rugu forest.

However, by the year 2015, a new government came to power in the state. The Department of Forestry was moved back to the Ministry and the Special Adviser's office was scrapped. The adequate funding for the forestry department was drastically reduced, which led to a reduction in the activities of the forestry department in forest reserves such as the Rugu forest reserve. Despite the inadequate funds, the government was able to adopt some measures in order to improve the Rugu forest reserve. These are outlined below:

(i) The State Government in the year 2015 announced that encroachment into the Rugu forest reserve would no longer be tolerated. Therefore, the 400 persons that encroached into the over 10 km land area of the Rugu forest reserve were directed to vacate the land or face the law.

(ii) The state government issued a warning notice to traditional rulers such as District heads, village, and ward heads of the LGA to desist from the illegal practice of granting permission to local people to go into the forest and clear the vegetation to create farmlands or collect fuelwood from the forest reserve.

(iii) The state government through the state House of Assembly enacted a law that prohibits the cutting of any living tree from any forest in the state, including the Rugu forest reserve. The law was well publicized to create awareness among the people in order to curtail the rate of deforestation in the state, which was then reaching an alarming rate.

(iv) The state government on August 31, 2021, issued a security challenge containment order that introduced a number of unprecedented measures aimed at tackling the insecurity posed by the bandits who have camped at the Rugu forest reserve and have caused a lot of destruction to the forest reserve.
(v) As part of the security challenge containment order, the state government banned lorries/trucks from carrying fuelwood from the forest and forest reserves in the state, such as the Rugu forest reserve. This order has halted the rate at which trees are cut for fuelwood and transported out of the forest reserve, thereby maintaining the remaining trees in the forest reserve.

5.8 Recommendations

The following recommendations are offered in order to address the degraded condition of the Rugu forest reserve.

(i) A full-scale military operation should be launched in the Rugu forest reserve to flush out the bandits out of the forest reserve to halt the rate of forest degradation caused by the bandits.

(ii) The flushing of the bandits out of the Rugu forest will allow the zonal forest officers, forest extension officers, and forest guards to perform their duties of raising tree seedlings and planting the seedling in the degraded parts of the forest reserve.

(iii) The local government councils under the Dutsinma zonal forest office should be mandated to plant tree seedlings in the forest reserve with a view to reforesting section of the reserve that the zonal forest officers could not cover due to the large expanse of forest lands degraded in the reserve.

(iv) The Forestry Department should come under the jurisdiction of Governor's office and a Special Adviser to the Governor on Forestry should be appointed to ensure special attention to the forest reserves in the state. This change will also guarantee improved funding for the department to enable it to carry out its activities effectively.

(v) The state government should regulate the extraction of fuelwood from the forest reserve. This can be achieved by setting out only a few areas of the reserve for fuelwood extraction and encouraging the people to cut only trees that are dry or old while allowing the young trees to grow and regenerate.

5.9 Conclusion

The Rugu forest reserve is one of the largest and most important forest reserves in Katsina state in view of a large number of tree species and a variety of wildlife that once existed in the forests. However, the policy by the successive state government to grant licenses and permit the cutting of trees to extract fuelwood has led to the serious degradation of the forest reserve. This was followed by inadequate priority and funding of the forest sector by the present state government despite the importance of the forest reserve. Recent developments have shown that the federal and state governments are planning for the establishment of a cattle ranch development program in the Rugu forest. It is therefore recommended that utmost care should be taken to ensure that the forest reserve is improved and not degraded further while adopting the other recommendation outlined in this chapter to resuscitate the forest reserve.

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Deforestation and Degradation in the Mangrove Ecosystem: Implication on Environment and Livelihoods

6

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Abstract

Coastal areas are the fundamental boundary between the two major components that are the land and sea that cover our planet. They are designed to provide multiple ecological services and harbor diverse groups of semi-terrestrial and marine species. Coastal communities living in close proximity to these areas depend on marine and coastal resources to secure income and food, especially in developing countries. Coastal ecosystems are usually under severe pressure due to various economic interests and development needs by humans coupled with climate change. The future of the mangrove is uncertain; despite various policy approaches by authorities to sustain mangroves from imminent loss, mangrove forests are still being severely destroyed or left degraded at an alarming rate 3–4 times faster than terrestrial forest types.

Keywords

Mangroves · Deforestation · Degradation · Diversity · Livelihoods

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6.1 Introduction

Mangroves are highly dynamic tropical as well as subtropical plants that assemble and thrive in the semi-tidal (semi-terrestrial) zones that form littoral vegetation and estuarine forests. The morphological and physical characteristics that best identify this ecosystem are the presence of saline brackish water, tidal areas plus current, and aerial, knee, prop/silt, or pneumatophore dynamic root systems. Above all, a dense compact structural assemblage provides numerous vital "free services," including habitat for juvenile marine species, the basis of the food chain, coastal stabilization, and filtration of nutrients and sediments. Mangrove loss affects coastal ecological systems and human communities that depend on healthy mangrove ecosystems (Feller and Sitnik 1996; FAO 2007; Nagelkerken et al. 2008; Ellison 2014; Haynes 2011; Romañach et al. 2018; Pearson et al. 2019). Located in the precinct of increasing human population, mangrove areas are at risk from human, climate change, and natural phenomena and are in a conflict of management priorities.

There are nearly 73 recognized species as true mangroves and mangrove hybrids globally, including trees, palms, shrubs, and ferns (Spalding et al. 2011). Other studies have given a rounded number of around 70 species of mangroves, and their hybrids are known worldwide depending on the taxonomic classification. Mangrove plants occur in over 123 countries in the warm temperate areas, subtropical and tropical zone of the globe (FAO 2010; Polidoro et al. 2010). The largest proportion of mangroves is found in Asia (~42%), followed by Africa (~20%), North and Central America (~15%), Oceania (~12%), and South America (~11%) (FAO 2007). The Indo-Malaysian region has 48 mangrove species, the world's highest biodiversity. Mangroves are categorized among the most threatened and endangered marine habitats worldwide. Over the past 50 years, human activities have greatly influenced mangrove's distribution and diversity. This has led to the decline or, in some cases, expansion of the mangrove areas due to rehabilitation programs in some countries. These wetlands have unique ecological values well-known to humans; however, on average, they are disappearing around the world at up to 1–2% a year (Sharma et al. 2020). As a consequence, there has been a dramatic loss of ecosystem service from mangroves with vast losses in area and function as remnant patches progressively deteriorate. A number of projections estimated earlier that the global mangrove area will decrease by a further 25% by 2025, especially in developing countries (FAO 2007).

The rate of mangrove deforestation may have decreased globally, but uncertainty is high as Asian countries (such as Myanmar and Malaysia) are still experiencing high rates of deforestation due to targeted developments (Friess et al. 2019). A total of 3363 km^2 (2.1%) of the global mangrove area was lost between 2000 and 2016, with an average of 0.13% per annum. Anthropogenic causes accounted for almost 62% of the total global mangrove area loss between 2000 and 2016. A remote sensing-based datasets by Hamilton and Casey (2016) and Sharma et al. (2020) documented a global mangrove annual deforestation rate of 0.26–0.66%. Region-wise loss between 1996 and 2016 is given in Table 6.1.

Table 6.1 Net mangrove losses between 1996 and 2016 by region (Worthington and Spalding 2018)

Region	1996 (km^2)	2016 (km^2)	Loss (km^2)
Australia and New Zealand	10,332	10,037	370
Pacific Islands	6410	6327	146
Eastern and southern Africa	7630	7329	424
Western and Central Africa	20, 107	19,857	422
East Asia	159	159	12
South Asia	8701	8492	435
Southeast Asia	46,789	44,060	3308
Middle East	334	319	19
North and Central America and the Caribbean	22,702	21,072	2196
South America	19,632	19,063	1106

In Oceania, mangrove forests are accredited specifically crucial to the traditional lifestyle of the coastal people. It is a valuable foundation/source for many types of food, including fish, prawns, shellfish, crabs, mollusks, gastropods, and seeds or propagules, which are vastly consumed in many parts of the Pacific. Mangroves are also an important source of firewood and house building materials, along with other products such as dyes that are used in designing traditional cloth. Likewise, mangrove modules such as leaves, barks, and roots are used as folk medicine to cure illness among the pacific islanders. Mangroves throughout Oceania are being degraded or devastated due to overexploitation, land reclamation to make room for housing, urban development, tourist resorts, and other infrastructure such as jetty and bridges, as well as degradation through the proliferation of squatter or informal settlements in mangroves due to rural–urban drift with no proper sanitation standard. In addition, domestic wastes are expelled into the mangroves. Some rural communities use mangroves for rubbish dumping sites, adding to the coastal crisis.

Goldberg et al. (2020) stated that human activity had been a predominant cause of mangrove forest loss, but since 2000 its impacts have decreased; this was because the priority to conserve and rehabilitate mangroves was recognized. The Global Mangrove Alliance recently set a goal of increasing the global mangrove area to 20% by 2030. The initiative was to inspire widespread restoration and rehabilitation projects around the world (Friess et al. 2019; Goldberg et al. 2020). The PICs (Pacific Island Countries) have national protocols and regional and international collaborative partnerships to manage their marine resource; however, they lack the capacity and resources to implement environmental strategies, planning, and regulation (Singh et al. 2021). Net mangroves loss in PIC is given in Table 6.2.

Friess et al. (2019) highlighted that a holistic view of mangrove dynamics is necessary; scrutinizing their past, present, and likely future status and the relative contribution of anthropogenic drivers with climatic drivers and geological factors is paramount.

Table 6.2 Net mangrove losses in the Pacific Island (FAO 2005)

Pacific island country	Surface area covered (ha), 1980	Current area cover (ha), 2005	Loss (ha) in 25 years
Melanesia			
PNG	545,000	380,000	165,000
Solomon Islands	64,400	41,500	22,900
New Caledonia	20,850	16,600	4250
Vanuatu	3000	2500	500
Fiji	47,000	36,600	10,400
Micronesia			
Federated States of Micronesia	8500	8500	0
Guam	88	55	33
Kiribati	260	250	10
Marshall Islands	Data not available	Data not available	–
Nauru	2	2	0
Northern Mariana	7	6	1
Palau	4700	4700	0
Polynesia			
French Polynesia	Data not available	Data not available	–
Samoa	1000	350	650
Tonga	1500	1300	200
Tuvalu	50	40	10
Cook Islands	Data not available		
Wallis and Futuna	25	25	0

6.2 Deforestation and Degradation in the Mangrove Ecosystem

6.2.1 Mangrove Deforestation Through Human Influence

Physical disturbance by human interference is prevalent in mangrove forests around the globe. Land converted to agriculture, coastal development, shrimp farming, illegal logging/deforestation, degradation, and other drivers of deforestation and degradation such as pollution and oil spillage cause a decline in mangrove areas globally, regionally, and nationally.

6.2.1.1 Aquaculture

During the second half of the twentieth century, the main cause of mangrove deforestation was onshore aquaculture for the production of carp, crustacean, tilapia, shrimp, seaweed, shellfish, marine, and coastal fish, particularly since the aquaculture boom in the mid-1970s and early 1980s (Martinez-Alier 2001; World Bank 2019). Across South America and Asia, an analysis of eight countries showed that almost 52% of mangrove cover was lost since early 1970, with almost 28% transformed into aquaculture ponds for commercial purposes. In the Philippines, approximately 50% of the 279,000 ha of mangrove removed within a period of 37 years (1951–1988) were converted to aquaculture ponds. Aquaculture has also affected neighboring mangroves by changing their hydrology cycle, effluent from aquaponics waste water, toxic chemicals, and high levels of nutrients, leading to eutrophication (Primavera et al. 2007; Friess et al. 2019). Since the 1990s, large mangrove areas have been cleared, specifically for shrimp farming and salt pans for solar production. The remaining lopped waste timber is used for charcoal production for additional revenue generation (Spalding et al. 2011). Globally, coastal aquaculture, predominately shrimp farming, has been strongly criticized due to its devastating environmental impacts, including mangrove forests and surrounding marine ecosystems (Ahmed and Glaser 2016).

The continuation of the decline in mangrove forests in the twenty-first century was largely due to the conversion of mangrove forests to aquaculture, rice farms and oil palm plantation, land reclaims for urban development, and aquaculture accounted for the largest share (Goldberg et al. 2020). More than 60% (4,678,900 ha) of the world's mangroves are found in Southeast Asia (FAO 2005; Spalding et al. 2011), and almost 2.5% (114,000 ha) have been converted to aquaculture ponds from 2000 to 2012 (Richards and Friess 2016). Aquaculture has been a fast-growing demand in the international market with high economic yields, resulting in unregulated and unplanned shrimp farming, causing widespread mangrove destruction in several countries, especially Southeast Asia (Bangladesh, China, India, Indonesia, Myanmar, Sir Lanka, the Philippines, Thailand, and Vietnam), Brazil, and Mexico (Ahmed and Glaser 2016; Duke et al. 2014; Worthington and Spalding 2018). The economic value of mangrove loss is estimated to be US \$ 2000–9000 ha^{-1} $year^{-1}$ (Wells and Ravilious 2006). Ashournejad et al. (2019) estimated a mean economic value of 10 ecosystem services of mangrove forest to be US \$ 50, 349 ha^{-1} $year^{-1}$. Naturally, rich mangrove ecosystems provide greater value goods and services that upkeep human well-being, including food security, health services, income, poverty reduction, and social sustainability. Overall, mangrove ecosystems play an important role in coastal economies (Ahmed and Glaser 2016; Glaser 2003; Hamilton 2013; Walters et al. 2008).

In India, integrated mangrove fishery farming systems emerged as a part of the possible solution to at least conserve mangroves to some degree (Bosma et al. 2016). Over the last three decades, aquaculture has been the fastest growing food sector in the world, with an estimated annual growth rate of 8.6%. Globally, coastal aquaculture expanded rapidly. It is estimated that in Indonesia, aquaculture production will grow by 7% per annum between 2012 and 2030. The government has even set higher confidence in allocating an additional 26 million hectares of land for aquaculture expansion. The portion of this identified eligible land will include low-lying mangrove areas (Friess et al. 2019). In the Pacific Islands, aquaculture is currently of little commercial importance compared to fishing, with one important exception, black pearl farming, which is practically restricted to eastern Polynesia. Shrimp farming has been a focus of commercial development on several pacific islands with varying degrees of success (Adams et al. 2001).

6.2.1.2 Urban Development and Expansion

Shallow intertidal zones have often been used to convert reclaimed land for infrastructure and urban development in many regions. Urban development at the regional level may not be the biggest driver of the mangrove calamity but can be the predominant driver in certain places, such as the southeast coast of Brazil in the late twentieth century, Puerto Rico in the 1960s, and Douala, Cameroon, in the 1970s–2000s. Also in China, large mangrove areas and the associated mud flats have been a loss to urban growth (Friess et al. 2019). In Cambodia in the 1990s, large areas of mangroves were deforested for urbanization and resort development (Sharma et al. 2020). Similarly, Singapore's mangroves have decreased by nearly 91% since the 1950s due to industrial development and the damming of mangrove-fringe line estuaries to create a freshwater reservoir. It is further forecasted that 33% of the nations' remaining mangrove forest will be lost between 2011 and 2030, as current policies and frameworks favor persistent seaward expansion of urban land use to support economic and population growth (Friess et al. 2019).

The global population has reached almost 7.8 billion, of which almost 1.3 billion will incur pressure on the mangroves, peri-urban and urban areas, and it is estimated to expand by approximately1.2 million km^2 by 2030 to accommodate the increasing population (Beveridge et al. 2013). Goldberg et al. (2020) highlighted that conversion of mangrove forests for human settlement contributed the least to global losses, with only 3% (96 ± 15 km^2) of these damages, and the maximum is concentrated in Southeast Asia (Goldberg et al. 2020). Furthermore, downline from added impacts of urban development and expansion, the discharge (pollutants, chemicals, nutrients), and mining continue to have detrimental impacts on neighboring mangrove ecosystems. Several mangrove areas and other coastal ecosystems are threatened by industrial pollution, such as in New Caledonia, or by domestic/residential waste and solid waste, such as in Fiji, Kiribati, and Tuvalu (Worthington and Spalding 2018). In most regions, the clearing of mangroves for urban expansion and the development of coastal infrastructure, including bridges, ports, priers, and roads, has contributed to the losses, especially in places where the coastal population is rapidly growing (Worthington and Spalding 2018).

6.2.1.3 Agriculture

Mangrove forests have been cut down primarily in Africa, Asia, and Latin America to produce agricultural products such as coconut, palm oil, and rice (Richards and Friess 2016; Sharma et al. 2020). In Madagascar, rice production was responsible for the approximately 35% loss of mangroves between 1975 and 2005. Within the Caribbean and South American coastal countries, mangrove flower nectar, particularly *Avicennia* spp., is exploited in the apiculture industries, where beehives are transported to mangrove forests during the species' flowering seasons to produce honey and wax (FAO 2007). In southern China, commercial rice production was accountable for 48% (>210 km^2) of mangrove loss between 1950s and 2010. The

Ayeyarwady Delta in Myanmar experienced a 44% (~940 km^2) loss of mangroves forests between 1989 and 2000, attributable solely to rice fields to ensure food security in response to national strategies (Friess et al. 2019). In the coast of NSW, Australia comprises mangroves fringing the river and salt marsh where the majority of the land is used for agriculture and dairy farming; cattle grazing has caused mangrove degradation and impacted the structure of the vegetation (Minchinton et al. 2019). In Benin, West Africa, ruminants grazing triggered pressure on the surrounding meadows and mangroves. Mangroves modules (leaves, bark, flowers, and propagules) are also harvested for animal fodder, even sold and preserved for the dry season (Ahouangan et al. 2021).

The coastal environments are one of the most widely used and fragile natural systems associated with human well-being. In PICs, these ecosystems broadly support food security, reduce vulnerability, strengthen resilience, and mitigate natural disasters (UNDP/IUCN 2006). For example, traditional or subsistence farming and fishing practices in Fiji resulted in a decline in mangrove cover (Agrawala et al. 2003). Predominately, conversion to agricultural farms has accounted for the greatest loss of Fiji's mangroves. This decline intensifies during the beginning of commercial agriculture and housing settlements in the past centuries, particularly in the Western Viti Levu of Fiji Islands. The previous loss of 4313 ha of mangrove between 1896 and 1986 was predominately driven by the conversion to sugar cane plantations, as sugar was listed as the highest export commodity (Lal 1990). Since the early 1960s, the growth and development of towns and resorts have augmented their share of consumption of mangrove land proportional to agriculture (Agrawala et al. 2003; Nunn 2013; Singh et al. 2021).

6.2.1.4 Wood Products and Building Material

The overexploitation of the provisioning ecosystem services such as wood/timber and fuelwood also lead to large-scale changes in land cover. Mangroves are highly preferred for firewood and charcoal due to their high heating capacity of the wood. In South America, Eastern and Western Africa, and in many parts of Asia, large-scale mangrove deforestation is due to fuelwood and charcoal production (Friess et al. 2019). For instance, 16% of Madagascar's mangrove cover loss between 1975 and 2005 was due to log harvesting and converting to timber (Giri and Muhlhausen 2008). In the Caribbean (Colombia, Costa Rica, Ecuador, and Panama), mangrove forests have been exploited for tannin production for almost 30 years, from the 1940s to the 1970s, because they were one of the greatest commercial commodities (López-Angarita et al. 2016) to dye leather and fabricate fishing nets.

In Sundarbans, mangrove palms (*Nypa fruticans* and *Phoenix paludosa*) and ferns (*Acrosti chumaureum*) are used for thatching material for light construction, roofing for boats, and plaiting cottage walls (Islam et al. 2018). A very rich traditional history of mangrove harvesting for fuelwood, tannin, and timber is also found in the PICs (Allen et al. 2001; Friess et al. 2019). In coastal rural areas of PICs, mangrove timber has its traditional significance, typically for construction and firewood. Customarily, native people in the coastal areas of the PICs use mangrove bark tannin to mark, print, and dye masi (tapa cloth), and their knowledge is passed down like a legacy from generation to generation. Masi plays an important role in PIC culture, highly valued for decorative and ceremonial uses. They are important signifiers of Fiji's native people, signifying their place and identity, as well as a source of pride (Ewins 2004). Harvesting of selected tree species for construction and fuelwood continued by local communities and has resulted in degraded mangrove forests in many parts of Fiji. *Bruguiera gymnorrhiza* is one of the preferred species for construction due to its durability. Both *Bruguiera gymnorrhiza* and *Rhizophora* spp. are preferred for dye production among the pacific people (Dayal et al. 2022).

6.2.1.5 Other Drivers of Mangrove Deforestation and Degradation

Additional drivers of mangrove degradation and loss are pollution such as oil, solid waste, mining, and petroleum. In the Niger Delta of Africa, petroleum extraction alone represented 20 km^2 of mangrove area losses (Goldberg et al. 2020). According to Friess et al. (2019), an estimated amount of 100,000 tons per decade impacted the mangroves in the Niger Delta. In Aaliyah, Iran, pollution from oil and gas infrastructure and refineries has been identified as destructive factors for the region's mangroves, solely affecting the morphological structure and resulting in degradation (Ashournejad et al. 2019). In Papua, Indonesia, protruding resource extraction in the region accounted for 5 km^2 of mangrove loss from the Grasberg mine tailings (Goldberg et al. 2020).

There are several other interrelated causes of mangrove degradation and deforestation beyond those described. These include mangrove areas transformed into salt ponds in Asia and Africa, created for salt deposits through evaporation. In South America and West Africa, as well as in the Mahakam Delta and West Papua in Indonesia, there are large oil deposits under mangroves, which cause mangrove losses when drilling and developing infrastructure for the production of oil and gas. The additional threat in these locations exacerbates extensive oil spills from ships wells/tanks and pipeline infrastructure within and near the mangroves (Friess et al. 2019). Oil spills damage mangroves by coating roots and restricting the oxygen transport to underground roots (Islam et al. 2018). Dreading activities cause a further threat to mangroves when the aerial roots become flooded, resulting in the root system being unable to uptake oxygen, which eventually leads to the deaths of mangrove trees. Added terrible damage to mangroves are herbicide and sewage, which causes water pollution resulting in plant mortality. Mangroves are very vulnerable to herbicides, as confirmed by the US military in South Vietnam by defoliation and destruction of over 1012 km^2 of mangroves (Hay 2011). In Fiji, mangrove degradation in the urban area is pollution from industries, and in peri-urban areas mangroves are threatened for the purpose of housing and squattering, which leads to illegal waste disposal and sewage leaching into mangroves harming mangrove health and marine life.

In Oceania, mangrove loss ranges from 0 to 1.2% in the twenty-first century, 77 ha in New Zealand (Hamilton and Casey 2016), 1763 ha in Papua New Guinea, and 1030 ha in Australia (Hamilton and Casey 2016; Worthington and Spalding 2018). The estimated average rate of mangrove loss in Fiji for the period 1991–2007 was approximately 217 ha/year, occurring mainly between Suva and Rewa Delta regions. According to Cameron et al. (2020), Fiji's mangroves covered 65,243 hectares with a loss of 1135 hectares between 2001 and 2018. The second largest cause of the loss of coverage is the conversion of mangroves for tourism development and coastal reclamation, followed by the disposal of dredging soil in river deltas. Other oceanic island atolls account zero to very less percent loss. Papua New Guinea, Solomon Islands, and Fiji have, in some of the regions, vast and most pristine mangrove forests, but they also have had the biggest loss over the past decades both from natural and anthropogenic causes (Bhattarai and Giri 2011).

6.2.2 Mangrove Degradation Due to Climate Change

Climate change is the most important arguable environmental issue currently affecting mangrove ecosystems and the livelihood of the people downstream at the community level. The documented effects of climate change include the cumulative number of warmer days and nights in a year, change in precipitation patterns and volume, lengthier summer seasons in many regions, rise in sea level, storms, oceanic circulation, and increasing frequency and intensity of droughts and floods (Rasyid et al. 2016). Aggregated impacts of these factors have a further distinct influence on the soil moisture content, salinity, pH, and nutrient cycle and availability.

Sea level rise (SLR) has been a major impending threat from climate change to the mangrove biological systems. As mangroves are very sensitive to changes in the duration and frequency of water inundation as well as to salinity levels that exceed tolerance limits, which may lead to death (Ball 1998; Friess 2016). An intensification of the duration of flooding leads to plant mortality on the seaward margins (He et al. 2007) or shifts in species composition inland. Mangroves located on the seaward fridges and micro-tidal are at greater risk from SLR than those that are situated inland due to lower elevation (Lovelock et al. 2017). SLR may also cause mangroves to invade or migrate inland, with a possibility of mangrove species loss and fragmentation (Nitto et al. 2014). In the northern Gulf of Papua New Guinea, deforestation and intense logging have caused soil erosion, further contributing to the loss of mangrove cover attributed to rising sea levels (Shearman 2010). In Samoa, mangroves are migrating landwards and many more islands in Micronesia and Melanesia where sea level spells extinction of local mangroves (Alongi 2015; Ellison 2008; Gilman et al. 2008).

A similar statement by Lata and Nunn (2012) predicted that mangrove fringes in the future will retreat or shift inland in the Rewa Delta areas in Fiji between the years 2030 and 2100. Mangrove fringes take approximately 25 years or longer for full development and establishment to perform their ecological functions (Nunn 2009). Pest and disease are an added threat ascribed by climate change and climate variability. Studies in South Africa on species *Avicennia marina* showed symptoms of disease in stem and branches, unhealthy stands, wood-boring insects, and leaf galls. Some mangrove-associated species such as *Hibiscus tiliaceus* showed signs of herbivory leaf beetles and *Barringtonia racemosa* showed signs of leaf and fruit disease (Osorio et al. 2017). A previous report by Osorio et al. (2015) found that the fungal pathogen *Pseudocercospora mapelanenesis* affects mangroves in South Africa that causes fruit and leaf disease of the mangrove-associated species (Osorio et al. 2015). Invasive plants could be a possible threat to mangroves decreasing their richness, biomass, diversity, and functional groups (Biswas et al. 2007). Numerous rapid global climate change factors combined with robust anthropogenic disturbance would greatly exacerbate the invasiveness of some plants and ecosystem invisibility (Chen 2019). *Spatina alteriflora* is one of the top 16 most problematic invasive plants in China, now aggressively invading stands of native mangrove in China over the last 10 years. The species is directly causing millions of dollars of economic loss per year by even invading fish ponds and young mangrove swamps (An et al. 2007; Zhang et al. 2012).

Alarming threats to today's sea-level rise are leading to mangrove cover loss and soil degradation and erosion (Padhy et al. 2020). The consequence of global climate change such as sea level rise and change in precipitation regime results in variations in salinity gradient. Less precipitation and hotter summer may cause more evaporation in the soil leading to high salinity levels harmful to plants. Additionally, seawater intruding inland causing soil to be hyper-saline is an added threat to the mangrove species to survive, resulting in defoliation, mortality, and degraded wetland swamps. Pacific island atoll nations such as Tuvalu (~2–4.6 m), Kiribati (~0.5–1.8 m), and Marshall Islands (~2–4 m) are considered to be the most vulnerable due to being just a few meters above sea level. These atolls have a low percentage of mangrove cover and a rise in sea level may result in degraded forests or complete loss affecting livelihoods. The Intergovernmental Panel on Climate Change (IPCC) projected that about 13% of mangroves could potentially disappear in these 16 pacific countries (Bhattarai and Giri 2011) in the next few decades, with the projection of a global mean rise in sea level by 1 m between 1990 and 2100.

6.2.3 Mangrove Degradation Through Natural Disasters

Storm surges, hurricanes, tsunamis, pests and diseases, floods, and thunderstorms plus lighting are specific natural phenomena that have caused damage and deterioration of mangrove ecosystems in the tropics and subtropics. Mangrove soil erosion is a major problem with river bank flooding and when combined with sea level rise. In Myanmar and the Sundarbans regions in the Bay of Bengal, an increase in flood events and cyclones has led to massive sediment erosion resulting in the loss of mangroves (Agrawala et al. 2003; Auerbach et al. 2015; Giri and Muhlhausen 2008). In addition, disease outbreaks in Sundarbans forest such as Agamora (top-dying disease) result in tree mortality leading to mangrove decline (Islam and Bhuiyan 2018). Prolonged flooding may also cause mangrove aerial/silt roots to be under threat when roots are covered for a longer period of time by soil erosion, sedimentation, and water, causing the mangroves to die off due to the need for oxygen in their plant tissues (Naidoo 1983; Srikanth et al. 2016; Lovelock et al. 2017). In 2014, the coastal areas of Asia (Bangladesh, India, Indonesia, Malaysia, Myanmar, Sri Lanka, and Thailand) were relentlessly devastated by the Indian Ocean tsunami as mangroves were uprooted and debris washed inland (Giri and Muhlhausen 2008). The conservation and restoration effort in these states have been enhanced after earthquakes and tsunamis; however, removing the mangrove in some areas is still taking place (Sreelekshmi et al. 2020).

In 2007, most of the mangrove forests in the Solomon Islands were damaged by earthquakes and tsunamis, resulting in a decrease in fishery resources (Warren-Rhodes et al. 2011). In PNG, deltaic mangrove loss and gain have occurred due to geomorphological processes such as tectonic movement (Shearman 2010; Shearman et al. 2013). In 2016, severe Cyclone Winston in Fiji caused damage to mangroves, and local people reported damages and losses to fishery resources, especially the mud crabs (Thomas et al. 2018, 2019). Globally, tropical cyclones have caused the largest degradation and loss of mangrove areas. About 45% of the reported global mangrove mortality is from events that occurred over the past six decades. The recent large mortality event associated with climatic extreme was in Australia, which accounts for 22% of all reported historical forest loss (Sippo et al. 2018). Shoreline erosion represented the second highest contributor of global losses at 27% (912 ± 41 km^2), and extreme weather events contributed 11% of the losses (361 ± 31 km^2) in the present decade (Sharma et al. 2020).

6.3 Implication on Environment and Livelihoods/Treats and Environmental Impacts

The implication of mangrove deforestation and degradation may lead to devastating environmental impacts and threaten livelihoods. These combined and interlinked threats to mangroves are rising, and at the same time, the dependence on mangrove goods and service is increasing. Coastal erosion/shoreline erosion, change in the hydrological regime, forest fragmentation and loss, and reduction in carbon storage/stock and food security are possible related impacts.

Mangrove loss due to shoreline erosion occurred substantially in Bangladesh, almost 80% of national loss, where the loss was along the seaward margins of the Sundarbans, affecting overall well-being (Jahfer et al. 2017; Islam et al. 2018). In the eastern coast of Brazil, nearly 130 km^2 of coastal erosion occurred as a result of the Amazon River discharge (Jahfer et al. 2017). The coast of southern Vietnam situated in an extensive flat alluvial and neighboring tidal river fringed by wide mangrove swamps has been eroding continuously by approximately 50 m/year since the early twentieth century (Mazda et al. 2002). In South Sulawesi, it was noted that coastal erosion had caused a decline in fish capture and also a reduction in juvenile shrimps and milkfish with an outbreak of shrimp disease (Malik et al. 2017). Globally, over 100 million people live within 10 km proximity to mangrove areas, and this number is estimated to increase by 2030, and the pressure on the mangrove ecosystem ultimately is going to increase (FAO 2007).

In Pacific islands like Fiji, the industries are responsible for mangrove clearance and coastal degradation. These activities aggravate problems such as coastline erosion, the decline in fisheries stock, pollution, poor water quality, biodiversity loss, and adverse effect on adjacent coastal habitats (Mumby et al. 2004; Singh et al. 2021). Historically, heavy mangrove exploitation has left behind many habitats severely damaged beyond the loss of the trees themselves. Mangroves serve as nursery grounds for many marine lives, and damages to these have a direct effect on fishery resources and the livelihood of those who depend on them for subsistence and income generation. In some places, the loss of mangroves might also result in reduced tourism revenue (Wells and Ravilious 2006) as mangroves are used as recreational sites and mangrove parks attract people. Furthermore, degradation of one coastal habitat may result in reduced health of adjacent coastal habitat (seaweed meadow and coral reefs) and reduces subsequent ecological functions (Gilman et al. 2006; Mumby et al. 2004). Traditionally, the Pacific Island diet consists of fish, seafood, and crops. With the rising risks such as sea level rise, saltwater inundation into agricultural land, frequency of cyclones, and other climate change variability, the resource on which almost 70% of the pacific population depends is under immense threat and will be one of the causes of malnutrition and chronic hunger in the region (Kumar et al. 2018; WFP, SPC 2018).

Mangrove loss can potentially reduce global carbon storage. The impact of deforestation on carbon (C) stock is relatively spontaneous or unplanned and may result in a significant decrease in C stocks. It remains unclear how degradation from selective harvesting of trees affects C stock as it depends on the intensity of tree extraction (Sharma et al. 2020). However, Rasquinha and Mishra (2021) analyzed small-scale disturbances in harvesting mangrove forests for fuelwood and stated that vegetative biomass and soil carbon levels were lower in the harvested forest than in untouched forests. According to Donato et al. (2011), mangroves store between 4 and 20 million tons of blue carbon globally. More than 80% of the mangrove's blue carbon is stored in the soil. Globally, mangrove soils contain approximately five million tons of carbon within 1-m soil depth (Jardine and Siikamäki 2014). There is an estimated 13.76 m ha of mangrove forests worldwide (Bunting et al. 2018; Zeng et al. 2021). Losing mangroves would drastically lose carbon stored in mangroves and add to greenhouse gas (GHG) emissions, which means having a huge implication on climate change mitigation and adaption and moreover livelihoods.

Forest fragmentation is also a primary driver of ecosystem degradation leading to the shrinking of the capacity of habitat to provide vital ecosystem services. In Southern Asia, forest fragmentation due to aquaculture and rice plantation lead to a nonfunctional ecosystem. Fragmented forests have a reduced capacity to ameliorate waves and have a higher through-flow of tidal waters leading to greater sediment erosion (Ahmed and Glaser 2016; Bryan-Brown et al. 2020). Sediment erosion affects the ability of mangroves to keep pace with the rise in sea level; hence, mortality can be a possibility in many cases. Furthermore, mangrove fragmentation may lead to more accessibility by humans, potentially leading to an increase in deforestation and exploitation of marine species that use mangroves as their habitat. Additionally, the capacity of mangroves to provide for many faunas may be jeopardized by fragmentation (Bryan-Brown et al. 2020). Finally, affecting the food chain threatens food security. Fragmentation also causes difficulty to cross-pollinate among species resulting in less genetic diversity. Moreover, an increase in wind, lower humidity, higher daytime temperatures, an increase in invasive plants, pests, and pathogens, and a reduction in water quality are added consequences of fragmentation. Bryan-Brown et al. (2020), from a high spatial resolution dataset from 2020 to 2021, compared rates of mangrove fragmentation and deforestation on a global scale. They observed that the highest rate of mangrove loss and fragmentation was in Indonesia, Malaysia, Myanmar, the Philippines, Thailand, and the United States.

Fragmentation metrics for the mean patch size may change, either increase or decrease when mangroves are lost. The consequences of mangrove degradation and deforestation will reduce mangrove cover and decline in vegetation health, leading to a threat in food security. This will further risk human safety, resulting in widespread unemployment, poverty, and induced migration or relocation. IUCN (2010) stated that 11 out of the 70 mangrove species are now extinct, and 2 are in the critically endangered category (IUCN 2010; Polidoro et al. 2010). In 26 out of 120 countries, mangroves are critically endangered and approaching extinction (Duke et al. 2007).

For instance, in Cameroon, mangroves have experienced dieback of up to 3 m in 30 years on the seaward edge, while almost 89% of one offshore mangrove island is now underwater (Ellison and Zouh 2012). Projections indicate that increasing sea levels in Cameroon may lead to the relocation of approximately 580,000 people, with the destruction of 39,000 houses. These displacement activities may cost several million dollars of losses to the industrial sector, as well as an unemployment deficit of more than $1 billion (Gabche et al. 2000). Coastal fisheries are also expected to be severely affected by temperature increases due to mangrove loss, which could lead to shifts in the centers of fish production. Biological changes such as species loss, habitat, and process alterations in West Africa are evident as a result of mangrove loss attributed to climate change. The other environmental effects of mangrove loss would be an alternation of species composition, zonation pattern, and structural complexity of mangrove stand and hence impair the functioning and regeneration dynamics (Maina 2014). While harvesting has taken place for almost 6–7 centuries, in some parts of the world it is no longer sustainable, threatening the future of the forests.

6.4 Conclusion

Livelihood dependence on the mangroves is vastly high, with communities extracting firewood, food, medicine, charcoal, construction material, tannin, and dyes from the mangrove forests. Deforestation for the cultivation of commodities, such as a combination of rice, shrimp, and oil palm, serves as the primary global driver of mangrove loss for decades. Forests converted to aquaculture or rice plantations and so on strongly correlate to fragmentation and deforestation. The hotspot of deforestation and degradation in the mangrove ecosystem is Southeast Asia followed by North and Central America and the Caribbean. In the Pacific, mangrove deforestation is high in the urban centers and low or sustainable in remote islands. Agriculture and urban colonization are the main elements of mangrove forest deforestation and degradation. Climate change events may have a slow occurring and lesser impact on mangroves in the future, whereas the immediate threat comes from uncontrolled deforestation and exploitation due to human interference is more evident. A common approach to mangrove conservation and its ecosystems involves establishing protected areas that reduce the anthropogenic pressures, as is practiced in many regions and countries. Another possible approach may be integrated mangrove-aquaculture system, which will be a potential solution to blue carbon emission, sustainable mangroves, and socioeconomic benefits.

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Assessing Land Degradation Using SDG 15.3.1 Indicators: Case Study from Climate-Vulnerable Assam State of India

7

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Abstract

Indiscriminate human activities are inducing adverse changes in the properties of terrestrial land. Our actions are responsible for affecting nearly 70% of the total land surface in the last 50 years. Avoiding, reducing, and reversing land degradation is the only possible way around. In particular, the SDG indicator 15.3.1 talks about the "proportion of land that is degraded over the total land area." It requires countries to monitor and inform about land degradation status regularly. In accordance with this matter, this chapter aims to analyze land degradation possibility for India's highly vulnerable Assam state by using Trends.Earth application and Earth observation data. All the computed results provide convincing evidence in favor of possible land degradation cases. Overall, the study shows that the Assam state experienced either stable or improvement in land degradation from 2000 to 2015.

Keywords

Earth observations · land degradation · SDG 15.3.1 · Earth

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7.1 Introduction

It has been estimated that globally 25% of the land area is either highly degraded or undergoing high degradation rates (Anon 2014). Land degradation is threatening the livelihoods of 1 billion people in over 100 countries, and each year 12 million hectares of arable land are lost to drought. It is estimated that approximately 24 billion tons of fertile soil are lost every year (Anon 2020). Unsustainable agriculture practices are attributed to be the main reason behind it (Anon 2018a). Unscientific usage of fertilizers causes severe damage to the soil microbiological health. Expansion in agriculture driven by clearing forests and woodlands also contributes to this problem. Several other factors, such as over-cultivation, overgrazing, forest conversion, and rapid urbanization, also play a crucial role (Cowie et al. 2018). Persisting with this trend would degrade 95% of the Earth's land areas by 2050 (Anon 2014). Early signs of temperature rise, drop in crop yield, and variable rainfall patterns indicate this effect.

United Nations Sustainable Development Goals (SDGs) has recommended that respective countries come up and provide support in assessments/mapping of their degraded lands to avoid or reduce land degradation through sustainable land management practices (Orr et al. 2017; Cowie et al. 2018). Target 15.3 of the Sustainable Development Goals aims to achieve Land Degradation Neutrality (LDN) worldwide by 2030. As part of the "2030 Agenda for Sustainable Development," SDG 15 is to "*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*" (Anon 2018b). SDG has various targets, and target 15.3 aims to, "*By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world*" (Anon 2018b). Similar to targets, SDG also maintains some indicators to assess the progress toward a land degradation neutral world. Specifically, SDG 15.3.1 is used to assess the "*proportion of land that is degraded over the total land area*" (Anon 2018b).

Satellite imagery or Earth Observation (EO) data has remained a valuable source of information for Land Degradation analysis (Dubovyk 2017). The main advantage of EO data is that they provide spatially continuous and reliable information on the dynamics of the environment cost-effectively. Time series atmospheric data are one such example that is commonly used to analyze time-varying changes experienced by different climatic variables. Similar datasets can also be used to monitor and assess the magnitude of land degradation and determine its contributory factors.

Conventionally, soil degradation has been conceived in terms of soil erosion only. Revised Universal Soil Loss Equation (RUSLE) is one such model that utilizes rainfall, soil type, topography, cropping system, and land management practice information to predict average annual soil loss caused by erosion (Prasannakumar et al. 2012). However, the main disadvantage of RUSLE is that it does not apply to large watersheds (Ganasri and Ramesh 2016). There are some other soil erosion models also available such as EUROSEM (European Soil Erosion Model)/MIKE SHE (Systeme Hydrologique European or European Hydrological System), ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation), and CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems). However, as mentioned, all these models characterize land degradation in terms of soil erosion factor alone. This is perhaps entirely not correct as there are various other parameters also involved. Moreover, the majority of the existing modeling techniques are resource-intensive. These applications require a considerable amount of technical expertise and are often limited by computational capabilities.

With technological advancements, this limitation is easing up to a great extent. For instance, Google earth engine (GEE) can be used for data acquisition and analysis purposes. Another application known as Trends.Earth (formerly the Land Degradation Monitoring Toolbox) also utilizes EO data and leverages an innovative desktop and cloud-based collaboration system. Trends.Earth is an open platform from Conservation International for monitoring land change. The application runs on a local system but harnesses the computational power of the GEE platform in the back end. This way, the application cleverly overcomes the requirement of resource-intensive platforms without compromising the quality of output.

In this chapter, we aim to explore Trends.Earth for monitoring and assessing land degradation in compliance with the SDG indicator 15.3.1 UN guidance. We have considered the state of Assam, one of the north-eastern provinces of India, for the analysis purpose. We have chosen Assam as it is experiencing an ever-increasing threat of flood, deforestation, and rapid urbanization from all fronts. This exercise would be beneficial in formulating land degradation conservation plans. The organization of this chapter is arranged into five sections. Section 7.2 provides a brief introduction to the study site. Section 7.3 discusses the datasets and methodology used, and Sect. 7.4 presents the results obtained and the rationale behind them. Finally, Sect. 7.5 provides the concluding remarks.

7.2 Study Site

Assam is one of India's eight northeastern states, situated at an elevation of 45–1960 m above sea level (Fig. 7.1).

It is located at the foothills of the eastern Himalayas and lies in the middle reach of rivers Brahmaputra and Barak. The total geographical area of Assam is approximately 78,438 sq. km. This is about 2.4% of the country's total geographical area and provides shelter to 2.6% population of the country (DES 2016). The state's total forest area is around 1,852,676 hectares, including 51 major forest types. Bamboo and timber are regarded as the prime forest products of Assam. It witnesses an average rainfall of 2077.8 mm per year, and the maximum temperature is recorded between 35 and 39 degrees. However, as per Assam State Action Plan on Climate Change, 2012–2017, the region has experienced an increase in the annual mean maximum temperatures, increasing at the rate of +0.11 °C per decade and annual mean temperatures at a rate of 0.04 °C per decade in the region. The state of Assam falls under the high vulnerability category in Vulnerability Indices of states, their

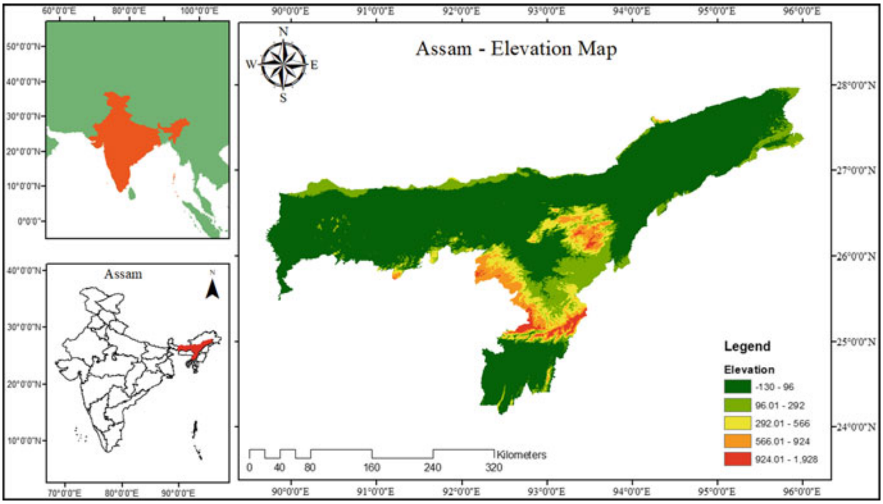

Fig. 7.1 Study area map

ranking, and categorization of the government of India (GoI 2020). Since eastern Himalaya's region falls under an active seismic zone, Assam is highly vulnerable to landslides, floods, and riverbank erosion.

7.3 Materials and Methods

7.3.1 About Data

Trends.Earth provides two options for the integration of data into the model. Users can choose to use either the default dataset provided by Conservation International Foundation or other datasets if there is a need. In this chapter, we have used the default dataset for analysis work. These data sources are made available by various organizations and individuals under separate terms and conditions. Details about these input datasets are given in Table 7.1.

7.3.2 Methodology

Land degradation assessment was carried out using the methods described in the Good Practice Guidance (GPG) document for Sustainable Development Goal. SDG 15.3 specifically intends to tackle desertification and restoration of land degradation to achieve a land degradation neutral world by 2030. More specifically, SDG 15.3.1 is an agreed-upon indicator used to assess the progress to this goal. It uses three sub-indicators to assess the progress toward this goal: (i) change in land productivity,

Table 7.1 Input dataset details[a]

Variable	Sensor/dataset	Temporal	Spatial	Extent	Units/description
NDVI	AVHRR/ GIMMS	1982–2015	8 km	Global	Mean annual NDVI[a] 10000
	MOD13Q1-coll6	2001–2016	250 m	Global	Mean annual NDVI[a] 10000
Land cover	ESA CCI	1992–2015	300 m	Global	Land cover classes
Soil taxonomic units	SoilGrids—USDA	Static	250 m	Global	Soil units

[a] Conservation International (Trends.Earth, 2018)

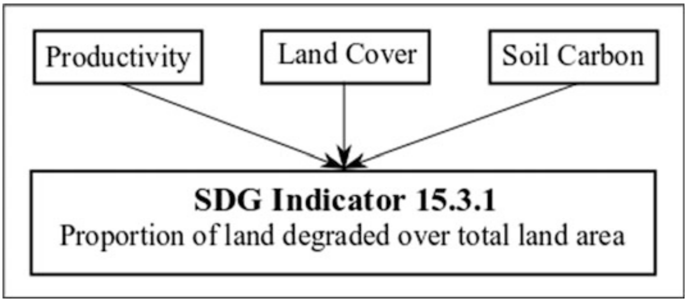

Fig. 7.2 SDG 15.3.1 and sub-indicators

(ii) change in land cover, and (iii) change in soil organic carbon. This relationship is shown in Fig. 7.2.

7.3.2.1 Workflow

Each of these sub-indicators was computed separately, and after that the SDG indicator 15.3.1 tool was executed to output the final result. A brief description of these processes is given below.

Productivity: It helps to measure the trajectory, performance, and state of primary productivity. Land productivity rate is an indicator of its natural productive capacity. Generally, net primary productivity (NPP) measures land productivity, but its estimation is time-consuming and costly. Another commonly used alternative to NPP is the Normalized Difference Vegetation Index (NDVI). NDVI value was calculated using MODIS and AVHRR images using the following equation (Rouse et al. 1973):

$$\mathrm{NDVI} = (\rho\mathrm{NIR} - \rho\mathrm{R})/(\rho\mathrm{NI} + \rho\mathrm{R}) \tag{7.1}$$

where ρNIR and ρR are surface reflectance centered at near-infrared and visible portions of the electromagnetic spectrum. This NDVI value was then used to compute different productivity indicators, as explained in Fig. 7.3.

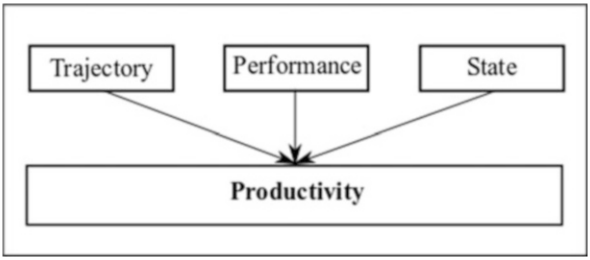

Fig. 7.3 SDG 15.3.1 and sub-indicators

Table 7.2 Aggregation of productivity sub-indicators

Trajectory	State	Performance	class
Improvement	Improvement	Stable	Improvement
Improvement	Improvement	Degradation	Improvement
Improvement	Stable	Stable	Improvement
Improvement	Stable	Degradation	Improvement
Improvement	Degradation	Stable	Improvement
Improvement	Degradation	Degradation	Degradation
Stable	Improvement	Stable	Stable
Stable	Improvement	Degradation	Stable
Stable	Stable	Stable	Stable
Stable	Stable	Degradation	Degradation
Stable	Degradation	Stable	Degradation
Stable	Degradation	Degradation	Degradation
Degradation	Improvement	Stable	Degradation
Degradation	Improvement	Degradation	Degradation
Degradation	Stable	Stable	Degradation
Degradation	Stable	Degradation	Degradation
Degradation	Degradation	Stable	Degradation
Degradation	Degradation	Degradation	Degradation

Trajectory represents the rate of change in primary productivity as a function of time. Trends.Earth uses linear regression to identify areas experiencing changes in primary productivity for the duration considered for analysis. Then, a Mann–Kendall test is applied by considering only significant changes with a *p*-value of >0.05. Positive significant trends in NDVI correspond to potential land condition improvement, and significant negative trends would mean otherwise. The second indicator, i.e., productivity state, helps detect recent changes in primary productivity compared to a given baseline period. Similarly, the productivity performance indicator measures the local productivity to similar vegetation types in similar bioclimatic regions throughout the study area. Trends.Earth uses soil type and land cover classes to define the area of analysis.

Finally, these three sub-indicators are interpreted in a matrix form to generate the inference. The classification process is shown in Table 7.2.

Land cover: It helps to calculate land cover change based on a baseline period. Here, the primary focus is on classifying any changes into degradation, stability, or

Table 7.3 Land cover calculation matrix

Land uses	Forest	Grassland	Cropland	Wetland	Artificial area	Bare land	Water body
Forest	0	-	-	-	-	-	0
Grassland	+	0	+	-	-	-	0
Cropland	+	-	0	-	-	-	0
Wetland	-	-	-	0	-	-	0
Artificial area	+	+	+	+	0	+	0
Bare land	+	+	+	+	-	0	0
Water body	0	0	0	0	0	0	0

Degradation Stable Improvement

improvement classes. Trends.Earth uses ESA CCI land cover maps as the default dataset for this purpose. However, the provision of using other datasets is also available. The process starts with reclassifying input land cover maps into seven classes (forest, grassland, cropland, wetland, artificial area, bare land, and water) in compliance with UNCCD guidelines. Then, potential changes between baseline and target year were computed for each pixel in the map. In the end, Table 7.3 is used to generate the final output.

Soil carbon: It is used to compute changes in soil organic carbon as a consequence of changes in land cover and agricultural practices. It is a proxy used for representing soil health. SOC changes are difficult to assess because of the high spatial variability of soil properties, the time required, and the cost. To overcome these limitations, Trends.Earth uses a combined land cover/SOC method to assess SOC change and identify potential degraded areas. SOC values were extracted from SoilGrids 250 m carbon stock map. Values up to 0–30 cm depth were used as the reference values.

Similarly, the land cover map is input and reclassified into seven major classes as it was done in the previous step. Finally, to estimate the changes in C stocks, C conversion coefficients for changes in land use, management, and inputs were used. These coefficient values were computed by UNCCD after a thorough literature review process and are presented in Table 7.4.

SDG 13.5.1: The GPG performs the identification of land degradation by aggregating all three sub-indicators using a one-out-all-out (1OAO) approach. In this approach, an area is identified as degraded if one or more sub-indicators show degradation. It essentially means that if land cover, productivity, or SOC stocks show degradation, the output is classified as potential degradation. The aggregation process is presented in Table 7.5.

Table 7.4 Carbon conversion coefficients

LU coefficients	Forest	Grassland	Cropland	Wetland	Artificial area	Bare land	Water body
Forest	1	1	f*	1	0.1	0.1	1
Grassland	1	1	f*	1	0.1	0.1	0.1
Cropland	1/f*	1/f*	1	1/0.71	0.1	0.1	1
Wetland	1	1	0.71	1	0.1	0.1	1
Artificial area	2	2	2	2	1	1	1
Bare land	2	2	2	2	1	1	1
Water body	1	1	1	1	1	1	1

*IF Temperate Dry (f = 0.80), Temperate Moist (f = 0.69), Tropical Dry (f = 0.58), Tropical Moist (f = 0.48), and Tropical Montane (f = 0.64)

Table 7.5 Aggregation of SDG 15.3.1 sub-indicators

Productivity	Land cover	SOC	SDG 15.3.1
Improvement	Improvement	Improvement	Improvement
Improvement	Improvement	Stable	Improvement
Improvement	Improvement	Degradation	Degradation
Improvement	Stable	Improvement	Improvement
Improvement	Stable	Stable	Improvement
Improvement	Stable	Degradation	Degradation
Improvement	Degradation	Improvement	Degradation
Improvement	Degradation	Stable	Degradation
Improvement	Degradation	Degradation	Degradation
Stable	Improvement	Improvement	Improvement
Stable	Improvement	Stable	Improvement
Stable	Improvement	Degradation	Degradation
Stable	Stable	Improvement	Improvement
Stable	Stable	Stable	Stable
Stable	Stable	Degradation	Degradation
Stable	Degradation	Improvement	Degradation
Stable	Degradation	Stable	Degradation
Stable	Degradation	Degradation	Degradation
Degradation	Improvement	Improvement	Degradation
Degradation	Improvement	Stable	Degradation
Degradation	Improvement	Degradation	Degradation
Degradation	Stable	Improvement	Degradation
Degradation	Stable	Stable	Degradation
Degradation	Stable	Degradation	Degradation
Degradation	Degradation	Improvement	Degradation
Degradation	Degradation	Stable	Degradation
Degradation	Degradation	Degradation	Degradation

7.4 Results and Discussion

Land degradation analysis using all three sub-indicators, i.e., land productivity, land cover, and SOC, is shown in Fig. 7.4a, b, and c, respectively. The analysis has been performed to assess land degradation changes from 2000 to 2015. The target year of 2015 is chosen as the UNCCD dataset provides NDVI and land cover maps until 2015 only. Although the local dataset of the latest data could have been used, this part will be considered in future endeavors.

About 7% of the geographical area in Assam experienced land area with degraded productivity. Similarly, the land area with degraded land cover and degraded SOC represented 0.6 and 0.8% of the state's total geographical area, respectively (Tables 7.6 and 7.7).

We were unable to compare our findings with those in the literature due to differences in (i) monitoring periods, (ii) indicators used in the methodology, and (iii) data source and image resolution. However, we believe this study has advanced land degradation assessment in Assam by assessing three components of land degradation according to the SDG 15.3.1 indicator. Assam state, mainly the plain region, is less susceptible to water erosion, and therefore the land area degraded with SOC was meager. Additionally, in conjunction with various national policies that aim to conserve natural resources, the government of Assam enacted "Assam Forest Policy of 2004," which aims to recognize local people's participation in forest management. The policy emphasizes improving the quality of forests through the involvement of people. It aims at combining the traditional knowledge of local people alongside the use of efficient modern technology. The northeastern region of India, including Assam, is characterized by fragmented landholding and small farm sizes. This restricts the economical use of large-sized farm machinery. The majority of small farmers are poor and are not able to purchase costly machinery like tractors, combine harvesters, etc. To a large extent, the region's agricultural practices are extensive and use small inputs of labor, fertilizers, and capital. Such agricultural and forest management governance might have conserved the agricultural landscape and natural forests while reducing land area with degraded land cover and degraded SOC.

The default inputs maps are pretty large and hence require enormous time to analyze. Therefore, as a part of preprocessing step, maps are clipped to the closest bounding rectangle covering the study area. Once the calculation of each sub-indicator is over, the final computation is conducted. The output of the SDG15.3.1 module is shown in Fig. 7.5.

It can be seen from Fig. 7.5 that the state of Assam is primarily experiencing either stability or improvement in terms of land degradation from 2000 to 2015. The possible reason could be that there have been no or very few industrial developments in that period. Moreover, population growth, which is an essential factor, was also very nominal. During this period, the net population change was 1.17%, which was far less than other comparable states (Staticstime 2020). However, there is a clear indication of land degradation along the bank of the Brahmaputra River. This is significant as the phenomenon is consistent throughout the river length. Land

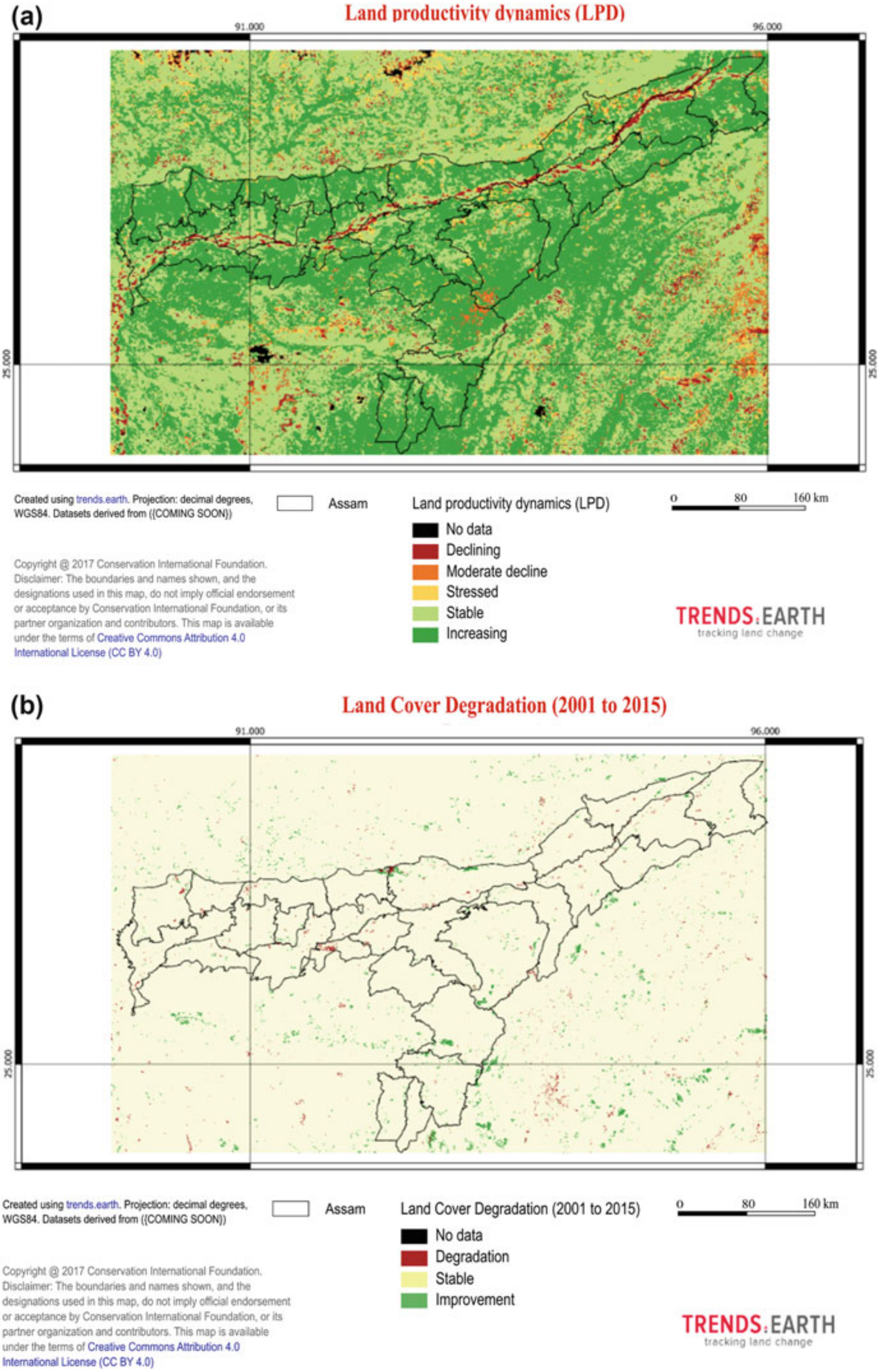

Fig. 7.4 Input map of (**a**) land productivity, (**b**) land cover, and (**c**) SOC

(c)

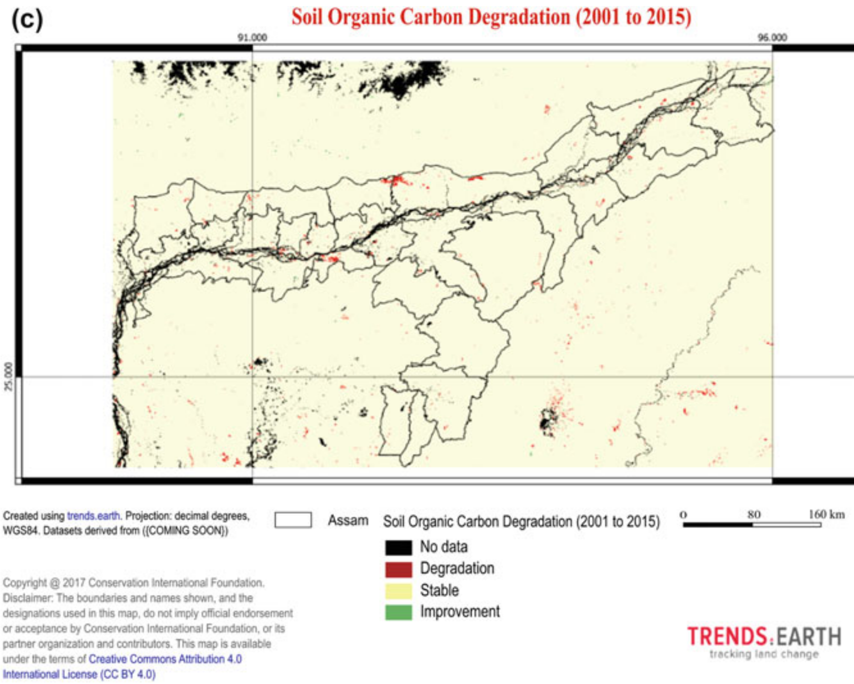

Fig. 7.4 (continued)

Table 7.6 Summary of changes in terms of different SDG indicators for Assam

Indicators	Area (km^2)	Percentage of total land area
Summary of change in productivity		
Total land area	76,511.3	100.00%
Land area with improved productivity	51,461.9	67.26%
Land area with stable productivity	19,455.2	25.43%
Land area with degraded productivity	5564.8	7.27%
Land area with no data for productivity	29.4	0.04%
Summary of change in land cover		
Land area with improved land cover	900.0	1.18%
Land area with stable land cover	75,126.0	98.19%
Land area with degraded land cover	485.3	0.63%
Land area with no data for land cover	0.0	0.00%
Summary of change in soil		
Land area with improved SOC	28.3	0.04%
Land area with stable SOC	75,316.4	98.44%
Land area with degraded SOC	620.7	0.81%
Land area with no data for SOC	545.8	0.71%

Table 7.7 Summary of SDG 15.3.1 indicator for Assam

Parameters	Area (sq km)	Percentage of total land area
Total land area	76,511.3	100.00%
Land area improved	51,185.8	66.90%
Land area stable	18,791.8	24.56%
Land area degraded	5966.7	7.80%
Land area with no data	566.9	0.74%

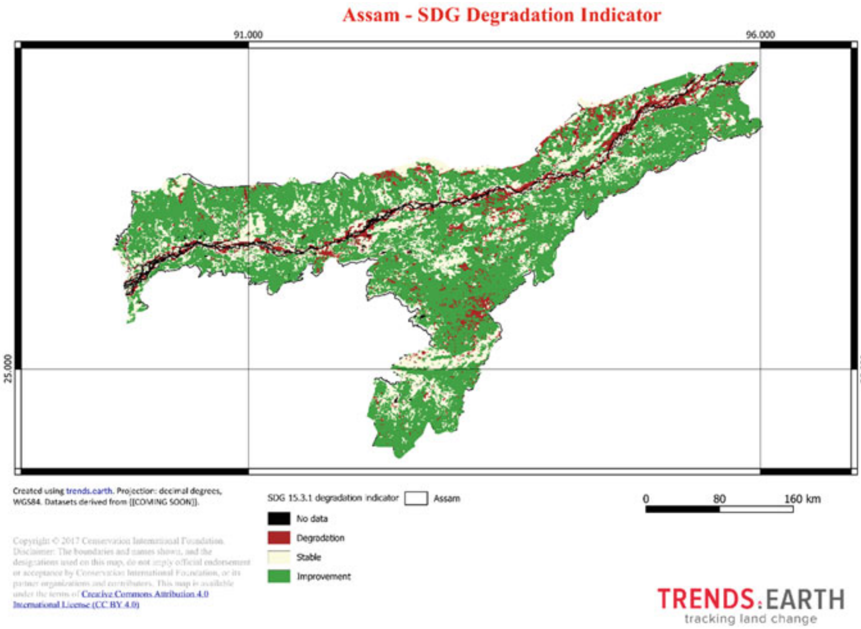

Fig. 7.5 Land degradation indicator of Assam

degradation in terms of erosion in the Brahmaputra riverbank is a severe concern, and it is reported from time to time (Kotoky et al. 2005; Stewartet al. 2008). Apart from this, hilly regions of Karbi Anglong districts and some places of upper Assam are also experiencing similar degradation changes.

7.5 Conclusion

The present study offers advancement of state-level assessments of land degradation in heterogeneous landscapes. The present study also demonstrates the potential of earth observation techniques for land degradation monitoring. Overall, the state of Assam is experiencing a stable state in terms of land degradation. However, further research should conduct field validation of LD assessments. We argue future research to cover the biologically diverse Indian Himalayan region with high-resolution images to obtain land degradation status using the SDG 15.3.1 indicators.

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Benefit and Risk Analysis of a Novel Nomadic Practice in Northeast China

8

Yanbo Yang, Chentao Liang, Xiting Zhang, and Wenjie Wang

Abstract

Wise utilization of crop straw wastes, control of autumn–winter haze pollution, and degraded soil improvement for agriculture security have been receiving increasing attention in China. Here, we report a novel nomadism from grassland to the agricultural areas in northeast China, likely to solve the above-mentioned issues. A total of 48 novel nomadic families were field-surveyed and questionnaire-interviewed to testify the hypothesis that nomadism is of much more benefits than increasing herdsmen's incomes and multiple benefits can be maximized by proper risk controls. Our data manifested that this nomadism was of cows and sheep transportation from grassland to agricultural areas in the winter–spring season and self-initiated by herdsmen with features of drought-driven and cost-effectiveness. There were 3.2-fold higher social benefits and 2.5-fold higher ecological–environmental benefits than the direct income for herdsmen and farmers. Moreover, >74% of the variations could be explained by the livestock amount, showing that more livestock will maximize the benefits. This practice is a feasible way for straw-waste utilization, air pollution, and land degradation control in China. Our findings highlight that future ecological and environmental governance should be strategically designed in a large-scale region

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across current administrative divisions for a cost-effective national ecological security construction.

Keywords

Novel nomadism · Autumn haze · Straw utilization · Soil degradation · Benefit analysis

8.1 Introduction

With the growth of population and rapid industrialization, the world grain output is constantly increasing, and crop straw residues are also increasing sharply (Hong et al. 2016). Straws are used in many ways, such as straw substrate, straw fertilizer, and straw energy. However, utilization of these straws, requiring a large amount of manpower or material resources, is usually not cost-effective (restricting their widespread application) (Li et al. 2020). Thus, most of the straws are field-fired, especially in high-latitude cold regions, where decomposition of the returned straws is too slow to farm the land next year. The fast economic development in China has resulted in serious environment-ecological problems, and the government has put great efforts into environmental rehabilitation (Bryan et al. 2018). In NE China, several ecological–environmental problems have received much attention from residents and governments.

First, an urgent challenge is how to provide enough grassland husbandry meat through less productive grassland under the scenarios of global warming and frequent drought (Bodner and Robles 2017; Su et al. 2017). Grassland is the main place for grazing, and its productivity is mainly affected by grazing intensity and climate change (Liang et al. 2018; Zhou et al. 2019). Grassland productivity directly determines the development of animal husbandry and the social supply of beef and mutton (Chen 2005). In the past two decades, per capita meat consumption in China has increased 2–3 times (Briske et al. 2015). Husbandry meat from Inner Mongolia grassland has been recognized as the best one in China (Han et al. 2017), and animal husbandry is a kind of seasonal grazing together with captive feeding (Chen 2005). Winter hay amounts strongly limit animal husbandry, especially in a warming and drought year. Previous research studies have reported different methods for solving the challenge, such as agricultural hay provision and transportation to grazing regions (Peng et al. 2001), and new winter silage centers in alternative regions (Guo et al. 2016). However, owing to benefit–cost imbalances, the sustainable development of grassland husbandry in NE China is still a tough issue (Qu et al. 2019; Wudabala et al. 2017).

Second, autumn–winter farmland straw field fires have a serious impact on environmental quality and human health (Li et al. 2019), resulting in air pollution (Ren et al. 2019). Economic development has changed local farmer lifestyle, and most importantly, cornstalk fuel for cooking and room heating in cold winter has been altered to natural gas or coal today. This change has resulted in field fire of straw waste in a very concentrated way (late autumn), with the production of too heavy haze pollution, in which abundant SO_2, NO_x, and PM2.5 exist in the atmosphere (Ma et al. 2017a, b; Wang and Zhang 2008). Wise utilization of crop straw with a cost-saving method is an urgent need for controlling air pollution, easing farmers' following-year practices on non-decomposed straw returned in the previous year (Hao et al. 2013; Zou et al. 2016), and making degraded farmland and grassland long-term improvements (Zhao 2018).

Third, serious soil degradation-induced farmland productivity decline has got more and more concerns in China (Zhou et al. 2019), especially NE China, owing to the fact that one-fifth of whole China's commercial grains come from this black soil region. On average, 0.3–1.0-cm-thick black soil surface layer is lost every year in NE China, with a total of 30–50% SOC losses after 50-year land reclamation (Liu et al. 2010a; Wang et al. 2011). Direct straw returning to soils, a generally used method to improve soils in hot climatic regions, has found difficulties owing to low decomposition in very cold climates (Hao et al. 2013), although some revision, such as deep soil returning, has been encouraged by the government as returned-straw-to-soil policy in this region (Zou et al. 2016).

Furthermore, modern ecological and environmental governance practices have faced great challenges owing to multi-stakeholders in different administrative divisions and regions (Yu et al. 2021), and how to design a policy for solving ecological problems needs wisdom and intelligence from nature and history. In history, nomadism has been used by herdsmen to make a life with transportation of livestock according to grassland forage availability. This herdsmen's wisdom has favored society development, such as high land livestock cultivation, old Asia's Silk Road development, and even the appearance of agriculture in middle Asia (Frachetti et al. 2017). In recent years, local herders in Inner Mongolia grassland have initiated a novel nomadic practice between Inner Mongolia grassland and the northeast agricultural region.

At the moment, no holistic evaluation of this novel nomadic practice and possible risks has been reported to date. Here, we hypothesized that this nomadic practice is a possible solution for straw-waste disposal, control of haze air pollution, and soil degradation in farmland and grassland, rather than only for herdsmen's income increases. The field survey, questionnaire interview, and statistical analysis were used to testify this hypothesis, and the following questions were tested. (1) What are the characteristics of the novel nomadic practice, different from the regular one in Mongolia grassland? (2) What are the social–economic–environmental benefits and risks of the novel nomadism? (3) How to improve the benefits and control the risks of the novel nomadism? Hopefully, the data will help widespread old nomadism wisdom for solving ecological–environmental puzzles today.

8.2 Study Site Description, Data Acquisition, and Interviewing Methods

8.2.1 Study Site Description

The starting place of the novel nomadism is in the southwest of Hulunbuir grassland (118°48′ E–121°09′ E, 47°32′ N–49°15′ N) (Fig. 8.1a, b). This region belongs to the temperate semi-arid continental monsoon climate, with a mean annual temperature (MAT) of 1.5 °C and a mean annual precipitation (MAP) of about 344 mm (Wang et al. 2017a). The destinations of the nomadic practices are in agricultural regions in NE China plain (Fig. 8.2b). The northeast agricultural region is the largest commercial grain-producing area for the whole of China. The climate is temperate continental monsoon climate, temperate monsoon climate, and temperate semi-arid continental monsoon climate, with a MAT of 2–5.6 °C and a MAP of 360–450 mm (Hou et al. 2012).

8.2.2 Questionnaire Survey and In-Depth Interview Data

In November 2017, we conducted a 4-week field study of the novel nomadic practice in Da'an city, Jilin Province. The questionnaire interviews by phone were carried out at Hulunbuir grassland by asking for the following information about novel nomadism (times, history, distance, destination place, initial place, costs during novel nomadism processes, difficulties for nomadic herdsmen, needed support from government policies, etc.). For improving data accuracy, in May 2019, another investigation was done in five towns in Hulunbuir grassland face by face, the main initiating region of this novel nomadic practice. The survey focused on herders with at least one nomadic experience. Questionnaires and semi-structured interviews were carried out in the survey, and interviews were also recorded by a voice recorder for later analysis. Finally, a total of 48 nomadic families were interviewed and their data were used in the paper analysis. This kind of interview method is similar to previous publications (Tunn et al. 2019). Questionnaires and semi-structured interviews included nomadistic times, destination place, nomadic distance, nomadic reasons, number of workforces involved in the nomadic practice, type of straw field in the destinations, cost of novel nomadism, etc. We also enquired of the difficulties of herdsmen in the nomadic region, governmental policies in farmer straw disposal, nomadic land-related problems, etc. These data were used to calculate the ecological–environmental benefits, economic benefits, and social benefits, and also possible risk analysis.

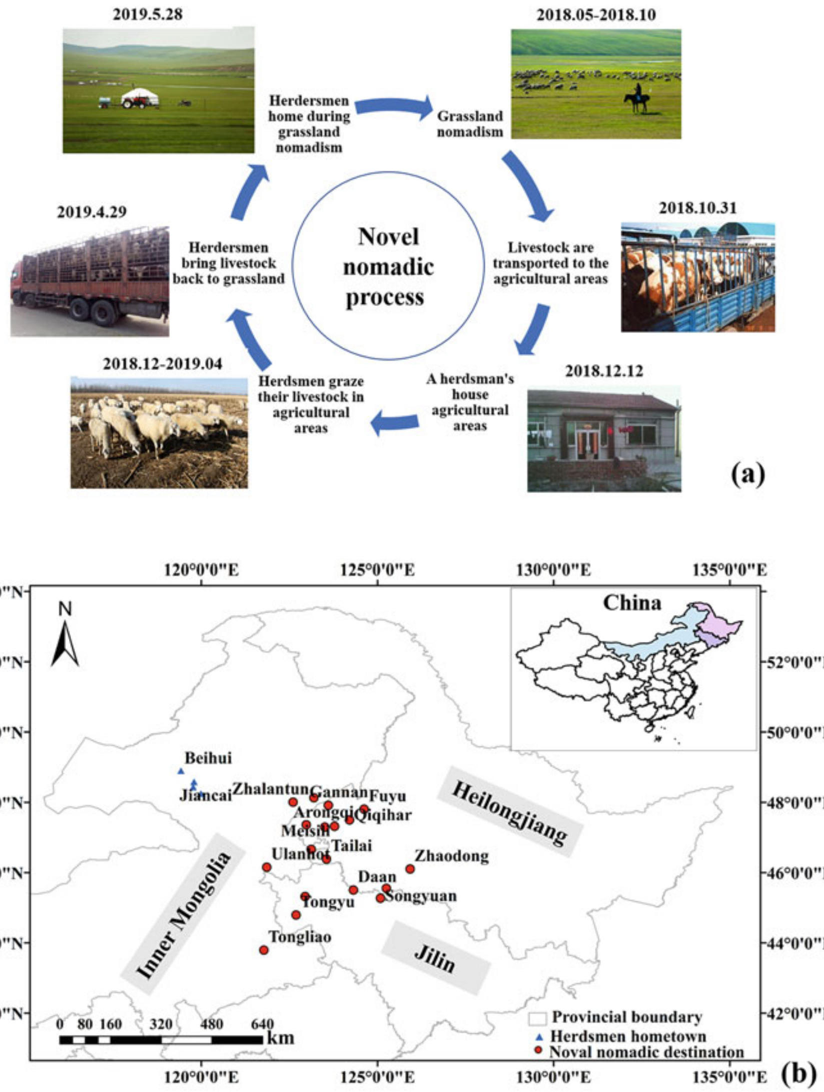


Fig. 8.1 The novel nomadic process (**a**) and schematic diagram of novel nomadic sites (**b**). **Notes:** The blue points in **b** represent the starting sites of the novel nomadic practice, and the red triangle represents the novel nomadic place. 350-km and 1000-km dashed-line circles were also marked to identify the minimum and maximum nomadic distances. The novel nomadic destinations included Arongqi, Tongliao, and Ulanhot in the Inner Mongolia region, Qiqihar, Zhaodong, and Zhaoyuan in the Heilongjiang province, and Da'an, Tongyu, and Taonan in the Jilin province (Fig. 8.2b). The nomadic herders were from several towns (mainly Honghuaerji, Beihui, Yongfeng, etc.) in the Hulunbuir city (Fig. 8.2b). Moreover, this nomadism was grassland-to-agricultural region nomadism across different provinces, sharply different from the regular nomadism within the same administrative province (Fig. 8.2b). Moreover, the nomadic distances are generally longer than the regular one

8.2.3 Estimation of Economic, Social, and Ecological–Environmental Benefits

We divided the benefits of the novel nomadism into three groups: ecological–environmental benefits, economic benefits, and social benefits (Fig.8.2a, b). All benefits were ultimately quantified as money of RMB (Renminbi, Chinese dollar; 1US \$ = 6.7RMB).

The ecological–environmental benefits (Eq. 8.1) were calculated as a sum of economic plus from the transformation of straw wastes into livestock foods (Eq. 8.2), increasing soil fertility by the manures (Eq. 8.3), and reducing haze pollution by less straw field burning (Eq. 8.4).

$$\text{Ecological and environmnetal benefits} = \frac{746.27}{10800} \times S + 0.1 \times F + 36.95 \times H \tag{8.1}$$

The transformation economic plus of straw is a reduction of straw treatment fees by farmers, i.e., the production of economic plus coefficient and average straw consumption (S); the economic plus coefficient is the ratio of the disposal fee (746.27 RMB/ha) (Li 2019; Su et al. 2021) and crown straw production (ca. 10,800 kg ha^{-1}) (Ma et al. 2017a, b). F is the average manure yield per family, and 0.1RMB is the price of the manure per kg (the data were obtained from interviews with herdsmen). The reduction of air pollution was quantified as the product of smog cleaning fee \$5.35 (36.95 RMB/kg) (Nowak et al. 2006) and the total haze amounts (H). S, F, H, H_SO_2, H_NO_x, and $H\_PM2.5$ were, respectively, calculated from the following Eqs. (8.2, 8.3, 8.4, 8.5, 8.6, and 8.7).

$$S = \sum\nolimits_{i=1}^{n} \left(s_{\text{cow}} \times a_{\text{icow}} + s_{\text{sheep} \times} a_{\text{isheep}} \right) \times d/n \tag{8.2}$$

$$F = \sum\nolimits_{i=1}^{n} \left(f_{\text{cow}} \times a_{\text{icow}} + f_{\text{sheep}} \times a_{\text{isheep}} \right) \times d/n \tag{8.3}$$

$$H = 24.2 \times S \times P/1000 \tag{8.4}$$

$$H\_SO_2 = 0.56 \times S \times P/1000 \tag{8.5}$$

$$H\_NO_x = 3.37 \times S \times P/1000 \tag{8.6}$$

$$H\_PM2.5 = 20.27 \times S \times P/1000 \tag{8.7}$$

where S_{cow} and S_{sheep} (kg/day) are straw consumption per cow and per sheep per day; a_{icow} and a_{isheep} are the cows and sheep amount in the no. i nomadic family; f_{cow} and f_{sheep} (kg/day) are fecal yields per cow and sheep per day; d is the nomadic period for each family (d = 90 days, on average); n is the number of nomadic

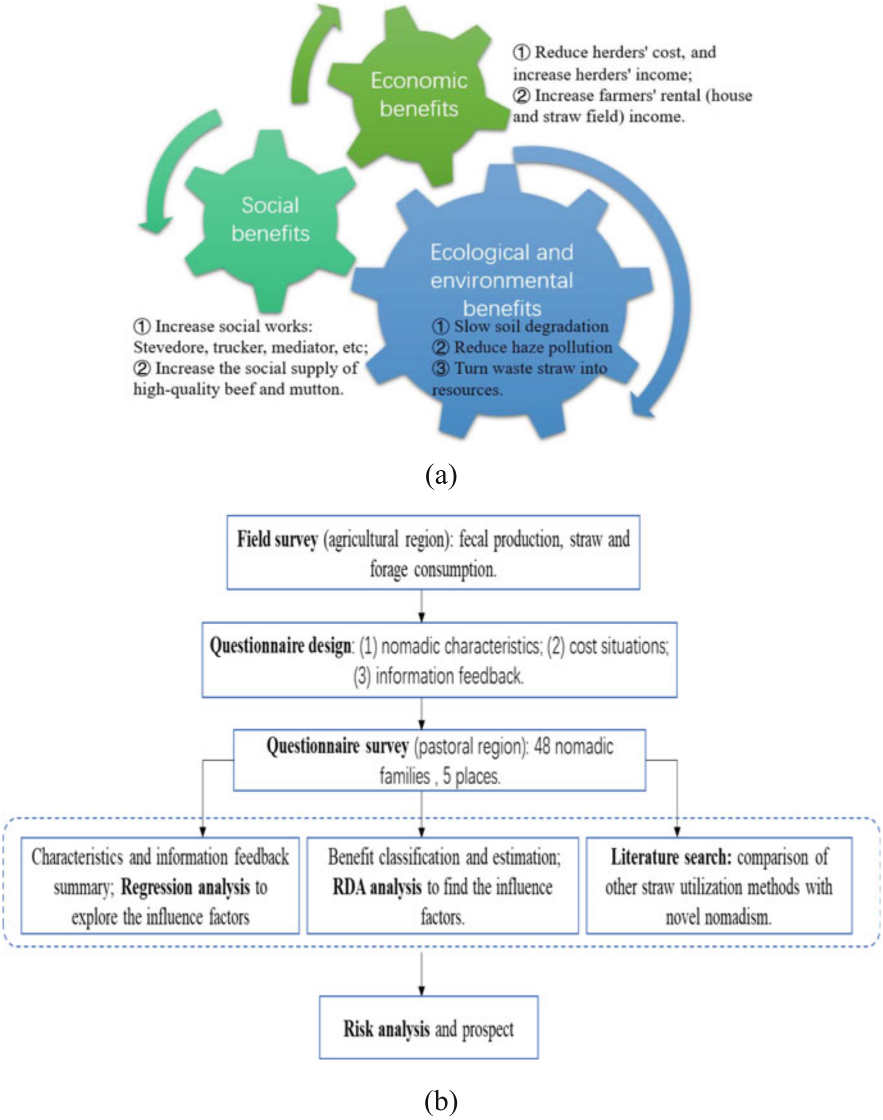


Fig. 8.2 Hypothesis for all possible benefits from the novel nomadic benefits (**a**) and the routine experimental design for testifying for it in this study (**b**)

families; *H* (kg) is the emission reduction of haze pollutants from straw utilization for each nomadic family during the nomadic period; the pollutant content per kilogram of straw combustion is 24.2 g (Wang and Zhang 2008); H_SO_2 is the reduction of SO_2 emissions; H_NO_x is the reduction of I_2 emissions; $H\_PM2.5$ is the reduction of $PM2.5$ emissions; and *P* is the combustion efficiency of straw. Here, the average burning efficiency of crop straw is used as a reference (Wang and Zhang 2008; Zárate et al. 2000). Factors of 0.56, 3.37, and 20.27 in Eqs. 8.5, 8.6, and 8.7 are the SO_2, NO_x, and PM2.5 production from burning 1 kg straw, respectively, and / 1000 is a transformation factor from grams to kg.

As shown in Fig. 8.1a, the economic benefits are the sum of the reduction of cost and the income increase for farmers and herdsmen (Eq. 8.8).

$$\begin{aligned}\text{Economic benefits} &= \text{Farmer}_{\text{income}} + \text{Herdsmen}_{\text{income}} \\ &= (C_5 + C_6) \\ &\quad + (m \times G - C_1 - C_2 - C_3 - C_4 - C_5 - C_6)\end{aligned} \tag{8.8}$$

where G (kg) is the amount of hay consumed by cows and sheep per season per family; m (RMB/kg) is the price of hay; C_1 is the transportation cost for cows and sheep; C_2 is the loading and unloading charge for livestock; C_3 is the intermediary fee to agents or contacting a person for negotiating destination location; C_4 is the fuel fee; C_5 is the house rental fee; and C_6 is the renting cost of straw fields. G is calculated as Eq. 8.9.

$$G = \sum\nolimits_{i=1}^{n} \left(g_{\text{cow}} \times a_{\text{icow}} + g_{\text{sheep}} \times a_{\text{isheep}}\right) \times \mathrm{d/n} \tag{8.9}$$

where g_{cow} and g_{sheep} are hay consumption by cows and sheep per day.

As shown in Fig. 8.1a, the social benefits are assumed as the new addition of social jobs (stevedores, truck drivers, mediator, etc.) and increased high-quality beef and mutton, and they are calculated as Eq. 8.10.

$$\begin{aligned}\text{Social benefits} &= p \times \left(w_{\text{cow}} \times a_{\text{cow}} + w_{\text{sheep}} \times a_{\text{sheep}}\right) \\ &\quad + (C_1 + C_2 + C_3 + C_4)\end{aligned} \tag{8.10}$$

where p is the average price of beef and mutton (both as 60 RMB/kg for herdsmen sale); w_{cow} is the average beef production from a cow; w_{sheep} is the average mutton production from a sheep; a_{cow} is the total number of cows per family on average; and a_{sheep} is the total number of sheep per family on average. $C_{j\,=\,1,2,3,4}$ is the indirect social benefit, including the transportation costs for cows and sheep, loading and unloading, intermediary fee, and fuel used in the transportation.

Above-mentioned three aspects of the benefits were also scaled-up from a family level to a regional level based on 80% utilization of the total straw production in NE China. According to reference data, total straw production in NE China averaged at 121.41 million tons per year in Heilongjiang province and Jilin province from 2013 to 2015 (Wang et al. 2017b).

8.2.4 Advantage of Novel Nomadism Compared With Other Straw Utilization Methods

The characteristics of other five straw utilization methods of energy, manure, forage, raw materials, and new substrates were cited from references (Wang et al. 2017b; Zhao et al. 2014) to make a comparison with the method in this paper.

8.2.5 Data Analysis

To find the associations between climatic changes and nomadic practices, the data of mean summer temperature and rainfall (June to August) from 2013 to 2018 in this grassland region were also collected from the China weather network (http://www.tianqi.com/). Regression analysis was performed between climatic data, grassland productivity, forage price, and nomadic times, and the stronger associations indicate their stronger impact on the nomadic practices.

For decoupling the association between different benefits and characteristics of the novel nomadic practice, redundancy (RDA) ordination and variation partitioning were performed to identify the most significant factors responsible for the interfamily variations. This identification will favor the maximization of benefits through key-factor regulations of the nomadic practice. The analysis was performed by Cannoco 5.

The possible risks of the novel nomadism were derived from the average of the questionnaire data; then, possible countermeasures and prospects were also proposed. All data statistics and calculations were performed in SPSS 22.0.

8.3 Results

8.3.1 Characteristics of Novel Nomadism

As shown in Fig. 8.2a, the autumn harvest-induced crop straw waste in NE China could be used as food resources for the cows and sheep from the Hulunbuir grassland. The novel nomadism normally began at the end of October. Herders transported livestock by big trucks, and then livestock could eat up the straw waste. The nomadic families usually lived in rural spare houses, prefabricated apartments, or Mongolian yurts close to the straw fields, and the livestock was kept in a simple sheepfold. Herdsmen transported their livestock back to Inner Mongolia grasslands in next April or May.

8.3.2 Nomadic Data Statistics from Interviews

As shown in Fig. 8.3, over 94% of the novel nomadism was induced by the herbage shortage and the related high cost in winter. Moreover, this nomadism was a

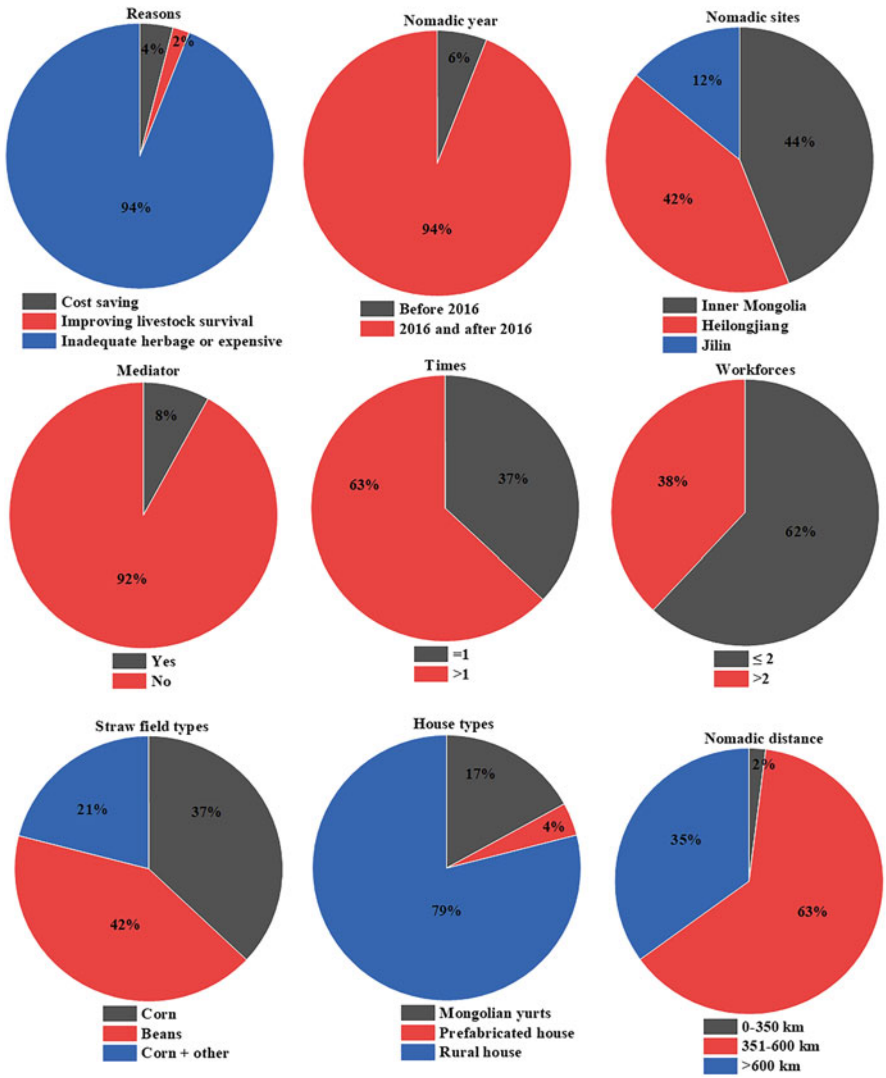


Fig. 8.3 The pie chart of basic information of the novel nomadism in nomadic reason, initial year, sites, mediator agent, nomadic times, working force involved, farmland types, accommodation conditions, and nomadic distance from questionnaire data

recent-3 year's phenomenon, firstly initiated around 2016, and before 2016, there were 6% of total interviewees. Also, 63% of families had more than one nomadic practices, and over 60% of the nomadic practices had inclusion of two labors into nomadism. Most nomadic distances ranged from 350 km to 1000 km.

Each nomadic family had 44 cows and 661 sheep on average. The destinations were mainly on the east edge of the Inner Mongolia autonomous region (44%) and

Heilongjiang province (42%). The selection of destinations was a herder-self-served contacting via his relatives or friends (92% of the total) and <10% through agents (Fig. 8.3).

Corn was the main farming crop in the nomadic sites, and corn straw alone took about 42%. A combination of corn straws and bean straws took another 37%, and corn straws and other types of straw combinations took 21%. Three types of herdsmen's dwellings included rural spare houses (79%), followed by Mongolian yurts (17%) and prefabricated apartments (4%) (Fig. 8.3).

8.3.3 Temporal Changes of Nomadic Practices and Associations With Climates and Pasture Productivity

As shown in Fig. 8.4, from 2013 to 2018, the number of nomadic families linearly increased with a rate of 15% in the summer (June to August).

Moreover, summer temperature is exponentially associated with the nomadic percentage ($p < 0.05$), with an increasing exponent of 1.1265. Furthermore, a negative correlation was also found between the nomadic number and grassland productivity ($p < 0.05$), showing that grassland productivity decline is a direct reason for nomadic practices. Importantly, this nomadism in recent years has become a common mode for herdsmen in Hulunbuir grassland, especially when facing the decline of grassland productivity and the shortage of forage caused by drought.

8.3.4 Novel Nomadic Benefits: Economic, Social, and Environmental–Ecological Distribution

Economic benefits were a sum of herdsmen's income and farmers' income. Compared with purchasing hay to feed cows and sheep in the Hulunbuir grassland in winter, the novel nomadism in the northeast agricultural region could save 139, 216 RMB/family. Moreover, the farmers were paid 7008 RMB/family. The total economic benefits at the family level were 146,224 RMB/family (Fig. 8.5a, b).

Social benefits were a money sum of social works and the beef and mutton for society provided by the nomadic practice. As shown in Fig. 8.5a, the benefits of beef and mutton provided to the society in the novel nomadic process were the highest, accounting for 43.85% of the total benefits, about 421, 010 RMB/family. In addition, the benefit of social work provided in this process accounted for 3.84% of the total benefit, about 40,040 RMB/family. The social benefits of the new nomads accounted for 48% of the total benefits, about 461,050 RMB/family.

Environmental and ecological benefits of the nomadic practices were a sum of air pollution removal, degraded soil rehabilitation, and turning straw residues into resources. The above three accounted for 32.5% (312,037 RMB/family), 1.44% (13,826 RMB/family), and 3.14% (32,492 RMB/family) of the total benefits,

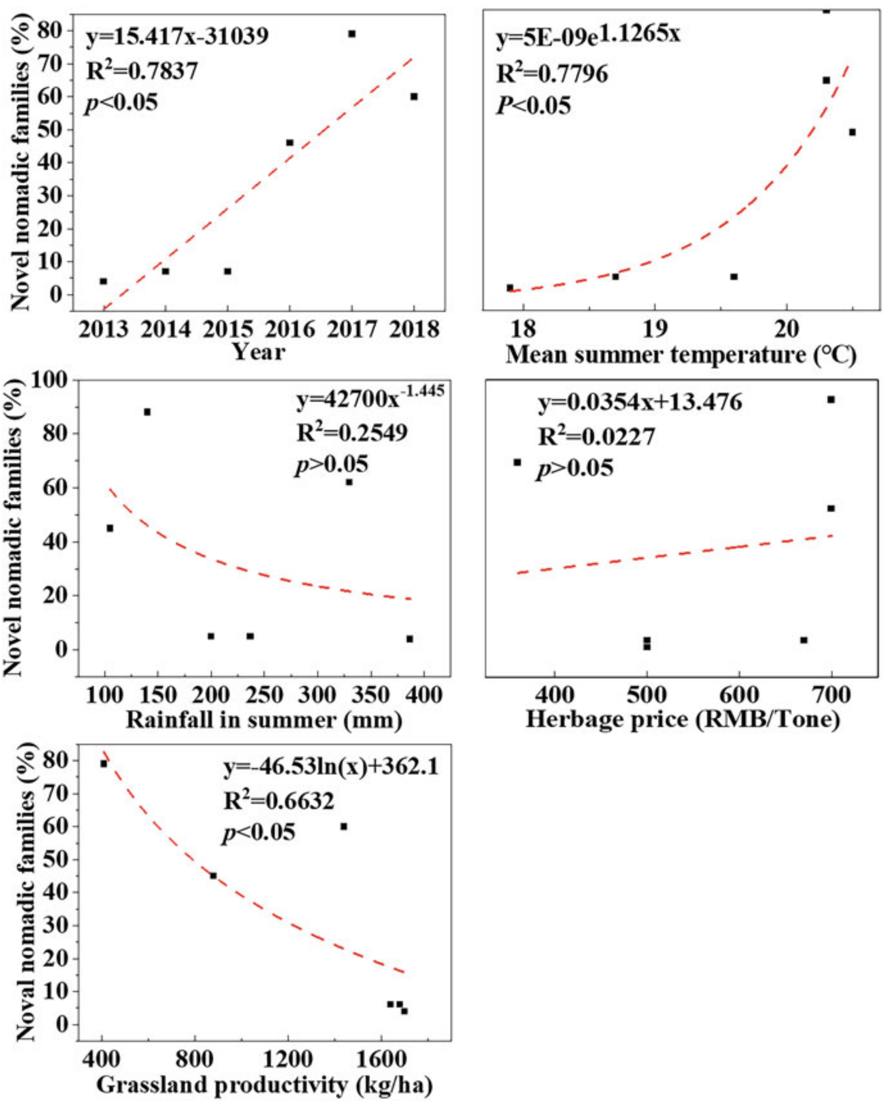


Fig. 8.4 The relationship between the novel nomadic family percentage and initial year, annual mean temperature, rainfall in summer, grassland productivity, and forge price

respectively. Environmental and ecological benefits accounted for 37% of the total benefits, about 358,355 RMB.

The benefit distribution showed that benefits for herdsmen and farmer only took 16% of the total benefits (Fig. 8.5a). The environmental and ecological benefits were twofold higher than the economic benefit, while the social benefits were over

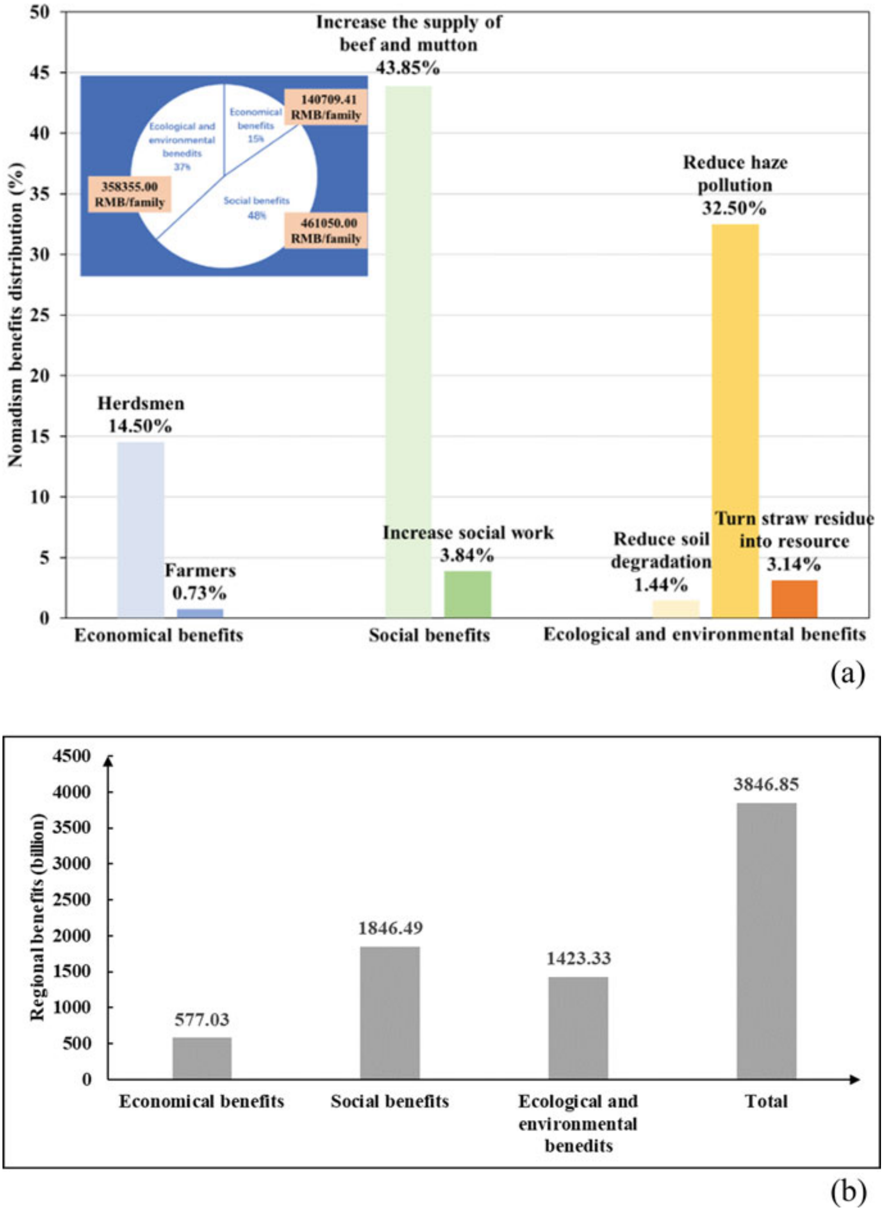


Fig. 8.5 Benefits of the novel nomadic practice at the family level (**a**) and regional level of straw utilization of northeast agricultural area (**b**)

threefold higher than the economic benefits (Fig. 8.5a). Furthermore, herdsmen's benefits (14.50%) were about 20 times that of farmers (0.73%). Among the social benefits, the benefit of increasing the supply of high-quality beef and mutton (44%)

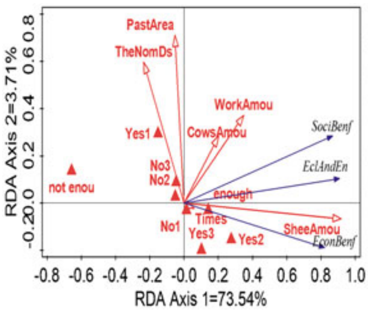
was 11 times higher than the increase of social works. Among the ecological–environmental benefits, the benefit of reducing haze pollution (32%) was about 11 times higher than that of turning waste straw into resources (3%) and 22 times higher than the soil degradation rehabilitation (Fig. 8.5a).

At the regional level (Fig.8.5b), if the 80% annual straw production of Heilongjiang and Jilin provinces (121.41 million tons) was used in the novel nomadic, the economic benefits would be 577.03 billion RMB, social benefits 1846.49 billion RMB, ecological and environmental benefits 1423.33 billion RMB, and total benefits 3846.85 billion RMB.

8.3.5 RDA Ordination: Factors Responsible for Interfamily Variations

As shown in Fig. 8.6, with the increase in economic benefits to farmers and herdsmen, the social and ecological–environmental benefits also increased.

Moreover, the more sheep and cows, the more workforces involved, and the less travel distance, together with enough straw-nomadic area and governmental supports (subsidiary fund and mediator agent), were aligned with the higher benefits at three aspects. Under simple term effects, sheep amounts, cow amounts, and traveling distances could explain 63.6%, 10.3%, and 6.8% of interfamily benefit variations ($p < 0.05$). When the collinear effects were excluded (conditional term effects), sheep amounts (62.5%) and cow amounts (11.9%) showed significant contribution for the variations ($p < 0.05$). In all, sheep and cow amounts were the key factor for the benefit variations, followed by workforce involved, nomadic distance, pasture, and straw field size.



Simple Term Effects				Conditional Term Effects			
Name	Explains %	pseudo-F	P	Name	Explains %	pseudo-F	P
SheeAmou	**62.5**	**73.3**	**0.002**	**SheeAmou**	**62.5**	**73.3**	**0.002**
WorkAmou	**10.3**	**5**	**0.024**	**CowAmou**	**11.9**	**20.1**	**0.002**
TheNomDs	**6.8**	**3.2**	**0.05**	**Past Area**	**2**	**3.6**	**0.058**
CowsAmou	6.6	3.1	0.072	TheNomDs	1.4	2.6	0.068
enough	5.9	2.8	0.094	No2	1.4	2.7	0.102
not enou	5.5	2.8	0.094	Yes2	1.4	2.7	unknown
Past Area	1.9	0.8	0.368	WorkAmou	0.4	0.8	0.406
No2	1.3	0.6	0.498	No1	0.3	0.5	0.482
Yes2	1.3	0.6	0.466	Yes1	0.3	0.5	unknown
No3	0.8	0.3	0.65	enough	0.2	0.3	0.698
Yes3	0.8	0.3	0.636	not enou	0.2	0.3	unknown
Times	0.6	0.3	0.704	No3	<0.1	<0.1	0.982
No1	0.3	0.1	0.828	Yes3	<0.1	<0.1	unknown
Yes1	0.3	0.1	0.86	Times	<0.1	<0.1	0.994

Fig. 8.6 RDA ordination between the novel nomadic basic features and various benefits. Abbreviations: *EclAndEn* ecological and environmental benefits, *SociBenf* social benefits, *EconBenf* economic benefits, *CosAmou* cow amounts, *SheeAmou* sheep amounts, *TheNomDs* the nomadic distance, *Past area* pasture area, *Times* the novel nomadic times, *WorkAmou* workforce amounts, *enough* straw field area was enough, *not enough* straw field area was not enough, *Yes1* nomadic destination site via mediator, *No1* nomadic destination site via individual contacts, *Yes2* percentage of herders who got subsidies, *No2* percentage of herders who did not get subsidies, *Yes3* livestock with health problems, *No3* livestock without health problems

8.3.6 Risk and Difficulties for Herdsmen Nomadism

We summarized the risks and difficulties into five types: personal risk, social risk, livestock health risk, crop yield risk, and environmental pollution risk. Herdsmen's personal risks and difficulties include family property, personal safety, traffic risks, etc. Of the entire reviewer, there was no theft or hijacking, but 8.33% of families worried about theft incidents, and 2.08% of families worried about the hijack. Furthermore, about 29% of herdsmen reported life difficulties and environmental problems (Fig. 8.7).

The social risks mainly referred to the communication and negotiation difficulties between herders, farmers, and the government. Over one-fifth of herdsmen had conflicts with local farmers (Fig. 8.7). Governmental regulations also greatly shaped the nomadic practice, such as the inspection of livestock quarantine certificates by the two-side governments is too complicated, and two-side approval of the same certificate will greatly encourage the widespread of this novel nomadism.

Livestock health was an often-observed problem. Over 31% of the data reported health problems in agricultural areas, which was 3 times higher than in pasture regions (Fig. 8.7). Serious death diseases included foot-mouth disease, sheep pox, and other infectious diseases. The availability of grazing straw fields was another problem for livestock health, and 17% of the novel nomadic families reported too

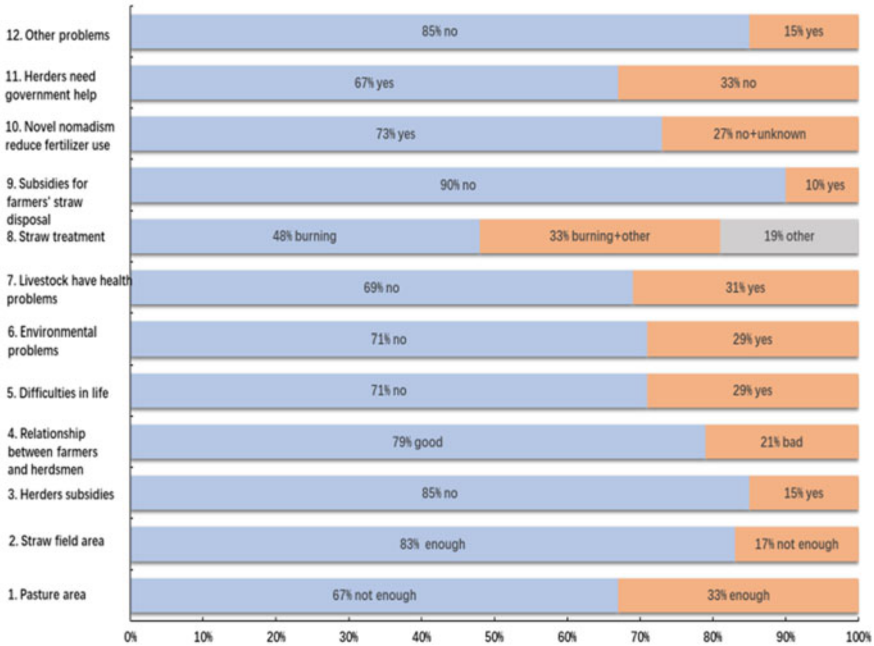


Fig. 8.7 Risks and difficulties reported by interviews and questionnaires on nomadic herdsmen families

small grazing field in the agricultural region (Fig. 8.7). At the same time, law-inhibited field fire of the crop straw was reported in 80% of rural areas reported by the interviews (Fig. 8.7). There was a big gap between farmer straw waste disposal (e.g., anti-law treatment) and nomadic straw utilization (no enough straw fields for their livestock).

Environmental pollution risks were also reported from the interview data. Usually, the grazing field should be arranged close to the river for providing water for the livestock, and this increased the risks of river pollution from veterinary drugs, livestock carcasses, etc. Over 70% of herdsmen reported that cow and sheep manure was too small in amounts for reducing chemical fertilizer utilization in the farmland, and this untreated manure (no fermentation before returning to the farmland) could induce unknown diseases and pests in the field in the coming year and possible crop yield risks, too (Fig. 8.7). Of course, their risks for these pests were much lower than the direct returning of straw to soils.

Other difficulties faced by herdsmen and farmers were also found. For example, 67% of the herdsmen did not have their own pasture in their native grassland (Fig. 8.7). In dry years, only 15% of the herders received subsidies from the local government for livestock or pasture, and the rest 85% never received it. In the case of the agricultural region, 10% of the farmers received straw treatment subsidies (Fig. 8.7). For this kind of novel nomadic practice, 67% of herders wanted help from the pasture regional governments, mainly on free toll fees for the livestock transportation by "green passage" privilege (Fig. 8.7). This kind of privilege is a common case during transportation of mutton or beef.

8.4 Discussion

8.4.1 Novel Nomadism: A More Efficient, Down-to-Top Volunteered Way for Straw Waste Utilization

In history, straw has been widely used as a cooking and heating biofuel in winter (Chen and Liu 2015). However, natural gas and coal utilization in the rural farming region has sharply declined straw-fuel-used amounts (Ren and Li 2013). This resulted in a huge amount of straw waste in farmland, and straw waste wildfires become the most convenient way, with the heaviest air pollution potential in the autumn–winter season (Du et al. 2018; Guan et al. 2019). The wildfire treatment of straw wastes has been strictly prohibited by local regulations (law) for air pollution control (Bian 2021). Some other treatment methods, such as bio-energy utilization as charcoal, and liquefaction–gasification as natural gas (Cui et al. 2008), are still in the laboratory and not good enough into the market in large scales (Table 8.1).

For relief of air pollution from autumn to the winter season, different utilization methods have been proposed by scientists, and most of these methods have been implemented by strong top-to-down support from central and local governments. For example, Heilongjiang province has subsidized the farmer for returning straw into soils by 40 RMB/mu (667m^2) (Su et al. 2021). The farmland in NE China usually

Table 8.1 Advantage and disadvantage comparison between the grassland-farmland novel-nomadism-related cornstalk utilization and other cornstalk utilization methods

Straw utilization method	Advantage	Disadvantage	Reference
Novel nomadism	The method is simple, direct, and of low cost, which can promote the development of animal husbandry and improve the soil fertility of farmland	May cause river pollution and spread of disease; it is not convenient to clean the residue of straw after cows and sheep eat; lack of uniform standards	This study
Energy utilization	Direct wildfire straw burning most convenient for farmers; alcohol can be produced indirectly	The former is easy to cause pollution; the latter cost is high; the craft is complex and has not yet been marketized	Cui et al. (2008), http://www.china-nengyuan.com/tech/107083.html
Manure utilization	Direct return to the field: Supplement nutrients, improve aggregate structure, and improve water conservation. Indirect green manure: Green manure produced by fermentation	In the former, winters are cold and long in NE China, and straw cannot be decomposed; in the latter, the cost of green manure is too high and cannot be fermented in winter	Wang et al. (2017b), Zhao et al. (2014)
Forage utilization	After the straw was treated by physical, chemical, or biological methods, the feed reached the balance of various nutrients and improved palatability. Special species at young stage are more common, rather than the harvested straw waste	Domestic research is still in the primary stage, it lacks process methods, processing equipment is not perfect, and the cost is too high	Cui et al. (2006), Wang et al. (2017b), Yan et al. (2019)
Raw material utilization	Straw can become the raw material for agricultural production facilities, industrial materials, and daily supplies, such as fiberboard, composite board, and tableware manufacturing. Realizing the high efficiency utilization and industrialization development of straw.	Due to economic costs and other factors, the development in Northeast China is limited	http://www.china-nengyuan.com/tech/107083.html
Substrate utilization	Straw-based macro fungus cultivation material: Special process treatment, increase the raw material source of edible fungus production, reduce the production cost	The technology and process of straw base material production are not standardized and lack unified scientific standards. The cost is too high and marketization is difficult	http://www.cnki.com.cn/Article/CJFDTotal-GZZZ200601019.htm

suffers about 6-month frozen season, and such low temperature has resulted in difficulties for following year crop farming from non-decomposed straw in the soil (Table 8.1). To date, the widespread of returning straw directly to farmland is still on the way in NE China (Table 8.1) (Cui et al. 2006; Yan et al. 2019), although scientists have reported its advantage (Hao et al. 2013); deep soil returning is also encouraged (Zou et al. 2016). Moreover, positive relations were found in different diseases and returning straw amounts (Liu et al. 2010a, b).

Presently, straw utilization as forage has got more and more concerns, while most of them still focus on straw transportation to pasture regions (Wang et al. 2019). There is much more difficulty when compared with livestock transportation, owing to the huge volume of straw. Some high techniques also used straw as a new substrate for the production of new medicine fibers (Peng et al. 2014) or paper, fiberboard, composite board, and other daily used materials (Li et al. 2017). However, their less cost-effective reliability in the market and limited treatment capacity are not good enough for 121.41Mt/year of straw production in NE China (Peng et al. 2014). Compared with straw bioenergy and new-material utilization, the novel nomadism is simple with no complicated techniques, and affordable with very low cost. In particular, this method was initiated by herdsmen themselves and was well accepted by local farmers right now. This made the widespread of this practice could be much easier, especially with some governmental support (Table 8.1).

8.4.2 Driven by Drought Climates With More Than Sixfold Higher Total Benefits Than Herdsmen's Incomes

Traditional nomadic practices are driven by grassland productivity, and the benefits are herdsmen's incomes (Adeoye 2019), and they are also featured as foot-dependent transportation within the grassland region (Miller 2002). Except income increases by herdsmen (AREnHe 2018), other benefits are seldom reported. The reason of our reported nomadic practice was analyzed, and we found that it was driven by drought climate and shortage of grass and was initially invented by herdsmen for a better income. The number of novel nomadic practices in 2016–2018 took 94% of the total surveyed families (Fig. 8.3), mainly due to the serious drought in the Hulunbuir grassland in 2016–2017, the 60-year lowest precipitation in this region (Jiang et al. 2017). In 2017, hot weather together with drought has decreased grassland productivity by 60–70% (Li and Zhao 2017).

Besides direct increases in the income of herdsmen, the social and ecological–environmental benefits of the novel nomadism are much greater, >6 times higher than the incomes of herdsmen (Fig. 8.5a). An approximate scaling-up showed that 80% of total straw production utilization in this practice would result in 209 billion RMB total benefits. In 2019, gross national product (GPP) in Heilongjiang and Jilin Provinces was 2534 billion RMB. Thus, the wise utilization of straw waste will increase by 8.2% of total GPP. The benefits of the novel nomadism could comprehensively solve the important cross-regional development problems such as livestock crisis in pastoral areas, straw residues in agricultural areas, and haze pollution.

A total of 17 Sustainable Development Goals from United Nations have been accelerated by China's large-scale ecological projects (Bryan et al. 2018), and a widespread of this nomadic practice will give new support for the sustainable development of the grassland–agricultural region with heavy ecological vulnerability (Wang et al. 2016).

8.4.3 Risk Control Suggestions

Traditional nomadism has various challenges and is well reported in livestock disease, farmer–herder conflict, and cultural exchanges among different civilizations (Paolo et al. 2018; Oyama 2014). Similar risks are also reported in our data, and a new mode for consultation and communication between agricultural and pastoral governments, farmers, and herdsmen could minimize the risks and maximize the benefits (Fig. 8.8). First, for herdsmen's personal risk, the two-side governments should jointly negotiate for providing supportive policies. For example, the destination government can make some regulations on theft or hijack, or extort bribes of herdsmen (Fig. 8.8). For the social risks, the local government should support the novel nomadism by some regulations or law construction, which will let the novel nomadism implemented in an orderly way. This requires government involvement in solving conflicts and safeguarding the interests of herders and farmers (Fig. 8.8).

Second, diseases can cause a decline in livestock numbers and production capacity (Godde et al. 2019). At the moment, infectious diseases like foot-mouth

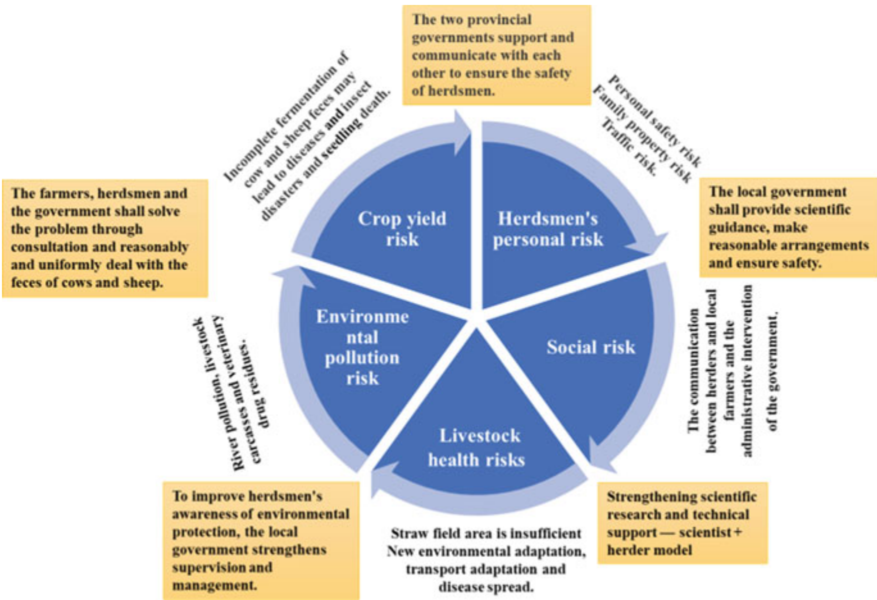


Fig. 8.8 Risks and countermeasures of the novel nomadism

disease, sheep pox, and brucellosis have been reported worldwide (Mocellin and Foggin 2008; Schley et al. 2009), and some have been found in this practice. A combination of scientific studies, technological advances, and herdsmen–farmer's experience could possibly give a good solution to the livestock health risks (Fig. 8.8). Third, environmental pollution caused by novel nomadism, especially possible water pollution, should be controlled with suitable methods. The government could also specify disposal sites for drug residues and animal carcasses, while herdsmen should also strengthen environmental protection awareness (Zhang et al. 2007). In this process, new regulations from local governments are welcomed (Fig. 8.8). Fourth, crop yield risks are another necessity to overcome owing to its commercial grain base status for the whole China. Without the fermentation process, untreated excrements could induce plant diseases and insect pests and also hinder next year's farming processes. The future widespread of novel nomadism should strengthen the knowledge and training of related pesticides to reduce the possible risk (Fig. 8.8).

8.4.4 Implications

Grassland and farmland ecosystem degradation, air pollution, and health-safety of the social system under global environmental change are complex issues. The solutions to these ecosystem problems mostly start from the interests of a certain level of a single ecosystem but rarely start from the integrity and systematization of the ecosystem and ignore the balance of benefits between different ecosystems. Therefore, it may be a scientific approach to realize the optimization of the complex ecosystem of nature–economy–society and the synergistic improvement of benefits through the macro-ecosystem management approach (Yu et al. 2021). The novel nomadism has realized the synergistic enhancement of grassland–agriculture–social ecosystem benefits, which may be of some theoretical reference to similar regions in the world. For example, Australia, Russia, the United States, Argentina, and other countries, which have developed agriculture and animal husbandry (Xiao et al. 2013), may face the same problems as NE China.

Furthermore, nomadic practices have various functions, such as long-term evolution of the ancient "Silk Roads" across Asia closely related to the long-established mobility patterns of nomadic herders in the mountains of inner Asia (Frachetti et al. 2017). Ecological knowledge of Mongolian nomadic pastoralists and their role in rangeland management has been well reported in pasture privatization, as well as herding practices (Fernandez-Gimenez 2000). Our paper highlighted that some old wisdom in nomadism could solve today's social–environmental problem, and we need to learn a lot from herdsmen's wisdom even under modern conditions nowadays.

8.5 Conclusion

The novel nomadism was initiated by the Inner Mongolia herdsmen, characterized as long-distance, pasture-agricultural traveling, and social–environmental and economic co-enhancing nomadic practice. This novel nomadism effectively alleviated the shortage of pasture in grassland in winter, slowed down soil degradation, and reduced the field fire of straw-related haze air pollution. The social benefits and ecological–environmental benefits were several-fold higher than the income benefits of herders and farmers, and the benefits could be increased with increasing livestock amounts and more workforce involvement and less nomadic distance. By constructing the cooperative mode of "government–farmer–herder," most risks would be controllable. Our finding highlights that the novel nomadism could solve the current hot ecological–environment–social challenging issues, but also provides a perspective for other regions to solve difficult problems through the utilization of the old wisdom of multi-benefit coordinated improvement of the ecosystem.

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9 Soil Degradation: Causes, Consequences, and Analytical Tools

U. A. D. Prasanthi Gunawardena

Abstract

When the soil is under increasing pressure from anthropogenic activities, the ability of soil to maintain its optimal functional status is impaired. This chapter aims to describe first the status of the resource and the resource dynamics in response to factors of degradation by adopting the circular economy approach. Second, it elaborates on a variety of analytical techniques suited for analyzing degradation and the available options for reversing land degradation along with global interventions. Within the circular economy model, soil serves dual functions: a resource for various economic activities and a receiving medium for waste. Violation of circular economy principles leads to soil degradation. From a resource usage point of view, allowing soil erosion beyond the soil regeneration rate leads to the ultimate depletion of the resource. Continuous addition of chemical fertilizers and agrochemicals into the soil and direct dumping of waste from domestic and industrial activities may lead to complete degradation of the biological or the renewable component of the soil. There are a variety of approaches including micro and macroeconomic techniques, multicriteria approaches, and environmental management tools available to analyze the degradation itself and the viability of sustainable options. These tools combine biological, social, and economic information and could be applied at the plot level, project level, program level, and sectoral and national level. Understanding the technicalities and applicability of such tools facilitated with necessary incentives for their adoption guided by traditional knowledge, national

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policies, and global agreements related to land degradation would pave the way toward land degradation reversal and ultimate sustainability of the land resource.

Keywords

Soil resource · Erosion · Degradation · Pollution

9.1 Introduction

The proper functionality of soil is important to ensure the continuous flow of ecological services of soil that will form the basis of food and many other needs of humans. When the soil is under increasing pressure from anthropogenic activities such as intensive farming, urbanization, mining, and various infrastructure developments, the ability of soil to maintain its optimal functional status is impaired. Soil degradation starts with this. There are many viewpoints from which land degradation topic is approached. This chapter takes the circular economy approach in describing first the status of the resource and the resource dynamics in response to factors of degradation. Second, it focuses on the role of economic and other analytical techniques in analyzing options available for reversing degradation. Finally, traditional approaches and global agreements are discussed, focusing on their distinct role in land degradation reversal.

9.2 Soil as a Resource: Conceptualization Under the Circular Economy Principles

Soil consists of several components. Soil minerals form the nonrenewable component. It has taken a long time to bring the soil into its present form. The renewable component of soil is the biological component, which consists of macro and microorganisms that provide the necessary functional role in circulating nutrients and maintaining dynamic linkages with the nonrenewable component. The renewability could be affected if the nonrenewable components on which they live become contaminated with either pollutants or excessive levels of nutrients. If the level of contamination is extensive or persistent, the ability of the soil system to come back to the original full functional level will be impaired and this implies nonrenewability of the renewable component or degradation. Ensuring the circularity of the resource requires in-depth understanding of such dynamics.

9.3 Soil in the Context of Circular Economy

Soil acts as a resource for various economic activities and also as a receiving medium for waste. Therefore, within the circular economy model, soil serves dual functions: providing resource inputs and providing waste assimilative function. A closer examination will enable us to understand the dynamics of this dual function. When the soil or the land becomes an input to a production system, it has to be considered under both of renewable and nonrenewable resource pathways.

An eco-friendly farming operation can be considered to illustrate this further. Eco-friendly farming helps the healthy functioning of the renewable part of the soil by encouraging natural processes such as nutrient cycling, supporting the functionalities of the microorganisms, etc. The minerals, the nonrenewable part of the soil, are “used up” or “mined” gradually from the system with harvesting activities. However, when the crop residues are returned back to the farmland, the circle is completed and the circularity of the nonrenewable component is ensured. In addition, the continuous flow of mineral inputs from deeper layers of soil to the soil surface is ensured with the deep-rooted trees that are usually accommodated in the same farmland.

There is an interesting functional relationship between the renewable component and the nonrenewable component of the soil. They are mutually reinforcing each other. Availability of an optimal soil mineral nutrient level means that the conditions required for the renewable part of the soil—the biological organisms—are at the optimal level, which ensures delivering the necessary services for the relevant ecosystem, such as nutrient circulation. Means and mechanisms that facilitate this balance are a sustainable use of land and those that disturb this balance are unsustainable use of land.

When the system is burdened with, for example, excessive nutrients as in the case of commercial agriculture, the soil organisms may not be able to tolerate such conditions. The organisms may be damaged, malfunctioned, or may be dead. They may undergo mutations and allow invasive species to arrive and so on. All of which lead to the suboptimal or nonfunctional status of the resource, implying that the renewability is now impaired. The renewable resource now enters into a status of nonrenewability. Perhaps the correct term would be a “dead” or a “mined” resource because classifying it as a “nonrenewable resource” means that there is some use of it. Repeated conversion of living renewable resources to dead resources is land degradation.

9.3.1 Factors of Degradation: Conceptualization under the Circular Economy Principles

Land degradation occurs with water and/or wind erosion and with physical and chemical degradation. It is estimated that 5- to 10-million ha are being degraded annually (Stavi and Lal 2015), and 75 billion tons of soil is lost globally (Ashton 2012). Salinization is one form of chemical degradation and is caused by the use of groundwater that is saline in nature or due to the saline seepage in dry areas. Loss of soil organic carbon due to soil erosion can also lead to loss of productive capacity of soil. The lost carbon from soil can be emitted into the atmosphere adding to the global warming problem and may be deposited in water bodies (Lal and Pimentel

2008). Land degradation is also defined more broadly in terms of the loss of ecosystem services (MEA 2005).

9.3.1.1 Soil Chemical Pollution and Impacts on Soil Organisms

Soil pollution is mainly caused by chemical residues resulting from application of fungicides, herbicides, and insecticides under commercial agriculture. Solid waste, effluents, and emissions resulting mainly from industries also cause soil contamination. This may result in contamination of groundwater and may lead to bioaccumulation in the case of persistent organic pollutants such as dioxin and furan. Soil can also be contaminated with oil and diesel (Dudai et al. 2018). When pollution from agrochemicals is considered, most often, agricultural lands are contaminated with mixtures of insecticides and herbicides. These mixtures along with heavy metals can bring significant synergistic ecotoxicological effects to the earthworms (Wang et al. 2015). Heavy metal pollution of soil and the resultant impact on soil organisms will have a variety of negative consequences on the entire ecosystem. Heavy metal concentrations in earthworms have been demonstrated by Morgan and Morgan (1992). Cadmium can cause demographic and reproductive abnormalities in earthworms (Fourie et al. 2007).

9.3.1.2 Impacts of Microplastics

Microplastics entering soil may get incorporated into the bodies of soil organisms. Experimental evidence suggests that microplastics generated from polyethylene have a negative effect on the reproduction of earthworms. Earthworms generate nanoplastics from disintegrating microplastics.

9.3.1.3 Impacts of Mining Operations

Mining operations also degrade land, especially in mountainous areas. The amount of material that needs to be mined gradually increases since the rich ores have already been exploited. Therefore, higher waste quantities are produced per unit of useful product and are finally being disposed into tailing dumps (Slipenchuk et al. 2019). Such mining operations and haphazard disposal of mining waste lead to heavy pollution and degradation of the natural environment. Such deformed natural and anthropogenic systems may in turn lead to unpredictable hazardous consequences such as the development of little-known diseases among humans.

9.3.2 Understanding Dynamics of Land Degradation Due to Chemicals

Although the full-scale dynamics of land degradation due to chemicals is not available in the literature, a systems perspective could be applied to describe the sequence of events. When an outside material has entered into the soil system, there will be a series of reactions initiated with spending system energy. The system may tend to compete with it, incorporate it, or tend to assimilate, or the system may get attacked by it and may finally succumb. Permanent changes or mutations may occur within the biological organisms, and the system faces a new level of equilibrium and may not come back to the original state again. This state can be described as "renewability at a depleted/suboptimal level." Several cycles of this type of depletion imply that the new system is very much different from the original 'natural' state and also imply a reduced or suboptimal level of the functions. In this case, a new level of equilibrium may be defined. Recurrence of such new equilibria may result in ultimate depletion—a zero level of biological activity.

Continuous addition of harmful chemicals and materials into the soil may lead to complete degradation of the biological or the renewable component of the soil. Then, the nonrenewable component of soil has some use as just a medium of growth, which can only support the growth of crops or plants with a high cost of artificial inputs. This is the status of most agricultural land in the world now. This is reflected in the fact that higher levels of artificial fertilizers are needed to be supplied every year in order to maintain the same yield. The consequences of this pollution to the rest of the economy is obvious. The product made from polluted soil is now containing harmful pollutants that enter into the human body and create various diseases among humans. This may need new treatment technologies, thus increasing spending on health care resources.

9.3.3 Analytical Tools for Land Degradation Assessment

Analysis of land degradation can be approached from a biological, chemical, economic, and social point of view. Although biological and chemical approaches are mostly used in analyzing causes of land degradation, economic and social viewpoints are equally useful and can bring additional policy perspectives as well. Assessment of effectiveness or viability of various remediation measures mostly requires economic and financial viability in addition to technical viability. As such, combining multiple dimensions, multiple tools, and multiple criteria in decision-making contexts of land degradation assessment is extremely important.

9.4 Cost–Benefit Analysis

Cost–benefit analysis (CBA) intends to guide decision-making by assessing project programs and activities from an economic efficiency point of view. Application of cost–benefit analysis within land degradation context requires several steps. First, it is required to identify all relevant costs and benefits from social, economic, and environmental viewpoints. The next step is estimating economic values for each cost and benefit. Several approaches are available for this. If market prices are available, their corresponding economic values can be derived by using economic conversion factors. There are varieties of other adjustments needed for the price distortions in the market. For social and environmental costs and benefits, environmental valuation methods could be adopted to derive values. The activity can be considered economically efficient if the total benefits are outweighing the total costs when all future occurrences of costs and benefits are taken into account. CBA outcomes are biased against future generations. This is an inevitable result of applying positive discount rates in calculating present values. Under higher discount rates, activities leading to land degradation in a future period are easily justified, and land rehabilitation activities that yield long-term benefits are not supported. It has been recommended to use low discount rates and declining discount rates to overcome this issue (Gunawardena 2013; Hurst 2019).

There are additional challenges in applying CBA in the decision-making context. There can be effects that are experienced by the low-income groups alone. Certain impacts may be irreversible, and uncertainties and risks can flow along a variety of temporal and spatial scales. There have been several adjustments proposed in order to overcome the drawbacks associated with the CBA. The CBA is initially based on the idea that different segments of society are receiving costs and benefits, and the activity is justified if the benefits outweigh costs when the entire society is concerned. However, there may exist groups of people, especially those from low-income segments who are the losers of the projects. This inequity issue could be addressed by applying distributional weights considering different income groups who are affected by the proposed project activities. Land-related projects may illustrate a wide range of costs and benefits that are not usually captured by markets. Varieties of valuation methods are available to evaluate these costs and benefits. Table 9.1 elaborates the details on how the CBA has been applied in evaluating different soil conservation and remediation efforts.

CBA has been applied in a variety of land degradation contexts. Many of the studies illustrate the economic feasibility of adopting soil and water conservation measures and soil remediation measures. Illustration of this information will provide useful inputs toward the actual implementation of such measures. It is also important to understand long-term dynamics of the interventions with a view to identifying costs and benefits that flow into the future. When analyzing long time frames, it is important to be aware of the caveats associated with the use of high discount rates. In addition, proper attention needs to be paid toward the long-term risks and uncertainties and their spatial dimensions associated with land and soil degradation contexts. Higher risks associated with large scale changes may require adopting a composite tool that could address multiple issues. Cost–benefit analysis can often guide the adoption of new policy instruments such as payments for ecosystem services as well (Udayakumara and Gunawardena 2018, 2021).

9.5 Multicriteria Analysis

The limitations of single-criteria decision-making methods have led to the development of multicriteria approaches. Multicriteria analysis (MCA) is capable of accommodating a range of criteria, including environmental, social, economic, and financial and technical. They are capable of incorporating the views of stakeholders, a feature that is not facilitated under many other decision-making tools. These methods have a wide variety of applications within the land degradation context.

Table 9.1 Application of cost–benefit analysis in different land degradation contexts

Study and the location	Focus of the cost–benefit analysis	Data and analysis
	Soil and water conservation measures	
Mishra and Rai (2014) Sikkim Himalaya, India	Indigenous soil and water conservation measures	Costs and benefits from field data and household data CBA with sensitivity analysis
Sun et al. (2013) Erlongshan reservoir catchment, China	Ecological compensation estimation of soil and water conservation	Remote sensing and geographic information systems with CBA
Teshome et al. (2013) Northwestern Ethiopian highlands	Different types of soil and water conservation technologies (soil bunds, stone bunds, etc.)	Farm surveys, field data CBA to measure profitability
	Soil remediation	
Söderqvist et al. (2015) Sweden	Evaluating options for polluted land	CBA as a part of excel-based MCA tool to evaluate options available
Wan et al. (2016) China	Assessment on phytoremediation technology for soil contaminated with arsenic, cadmium, and lead	Costs and benefits of a two-year phytoremediation program
Lavee et al. (2012) Israel	Assessment of soil remediation in industrial zones	Direct and indirect benefits from soil remediation
van Wezel et al. (2008) The Netherlands	Assessment of soil remediation under four alternatives for future investments	Health benefits (exposure to heavy metals and carcinogens), water supply, and shelter
Dudai et al. (2018) Israel	Assessment of vetiver grass for phytoremediation of diesel-polluted soils	Field trials, chemical analysis of soils, economic data

Table 9.2 illustrates examples of multicriteria approaches available around the world under subthemes of land degradation, soil pollution, and soil erosion. Geographical information systems (GIS) are being often used in combinations with MCA methods.

Table 9.2 shows multiplicity of issues that span across a wide geographical area. MCA is proven to be a promising methodology for analyzing land degradation-related decision-making contexts.

Table 9.2 Application of multicriteria analysis in land degradation-related decision-making contexts

Study	Location	Application of MCA	Remarks
Land degradation			
Ewunetu et al. (2021)	Upper Blue Nile River	Spatial multicriteria evaluation technique GIS and remote sensing integrated with MCA	Land degradation status analyzed using spatial analysis; biological, physical, and chemical land degradation indicators
Shareef et al. (2019)	Kirkuk city, Iraq	Integrating of GIS and fuzzy analytic hierarchy process (FAHP)	Land degradation due to urban growth; integration of Landsat data using GIS and FAHP
Imbrenda et al. (2021)	Greece	Integration of land-use maps and environmental indicators	Land degradation linkages with metropolitan expansion
Soil pollution			
Nikolić et al. (2011)	Serbia	Critical zones of polluted soil ranked by MCA method PROMETHEE/ GAIA	Soil pollution by heavy metals due to copper smelting plant
Bagdanavičiūtė and Valiūnas (2013)	Lithuania	GIS-based land suitability analysis using AHP	Combining GIS-based land suitability with MCA 16 factors concerning the geological and socioeconomic factors
Hokkanen et al. (2000)	Helsinki, Finland	Stochastic multicriteria acceptability analysis, group decision-making tool	Evaluating proposals for cleaning the polluted soil using five criteria defined by eight experts
Assessment of soil erosion/soil quality			
Altaf et al. (2014)	Western Himalaya	Satellite-based remote sensing data combined with field data in an MCA framework	Parameters on drainage and land cover as the indicators of erosion susceptibility Prioritizing the watersheds based on susceptibility to soil erosion
Pal (2016)	West Bengal, India	Weighted linear combination method (raster based)	Identification of soil erosion vulnerable areas with six parameters for soil erosion
Arabameri et al. (2018)	Iran	Remote sensing and GIS with four MCDM models	Soil erosion vulnerability assessed with morphometry and land use/land cover factors
Aslam et al. (2021)	District Chitral, Pakistan	Spatial analyst tool in conjunction with AHP	Eleven different factors used to identify areas with a risk of severe erosion
Andualem et al. (2020)	Ethiopia	ArcGIS and multicriteria decision analysis (MCDA)	Five different soil erosion contributing factors

(continued)

Table 9.2 (continued)

Study	Location	Application of MCA	Remarks
		technique using thematic layers pairwise comparison tool	identified erosion of hotspot areas
Chitsaz and Malekian (2016)	Arangeh watershed, Iran	IOWA model (induced ordered weighted averaging)	Thirteen soil erosion criteria applied at the sub-watershed level
Haidara et al. (2019)		Fuzzy AHP and GIS	Six criteria were used to assess soil erosion vulnerability
Vulević, and Dragović, (2017)	Topciderska river watershed	Multicriteria decision analysis using the PROMETHEE method	Sub-watersheds ranking according to soil erosion
Impacts on soil organisms			
Cisneros et al. (2011)	Pampas, Argentina	Goal programming (weighted and lexicographic), compromise programming	Thirteen decision factors were used in the optimization trials

9.6 Land Degradation and Environmental Economic Accounting

The widespread land degradation issues resulting from various sectors of the economy justify the need for a central framework to assess the relative costs and benefits incurred from each activity and the intersectoral links with the land sector. There may be benefits associated with allowing land to degrade; for example, chemically intensive agriculture may generate large output immediately while it may pollute the water sources, impact human health, and affect soil health and agricultural productivity in the long run. The central framework of the System of Environmental Economic Accounting (SEEA) provides information on all resources of the economy, including ecosystems and the resulting pollutants and waste with a common metric. This is done in agreement with the concepts of the System of National Accounts, and therefore environmental information can be easily incorporated within the economic information.

The SEEA provides the relationship of the economy and the environment. It brings together statistical data on both the economy and environment, which is capable of measuring the status of the environment, how the environment is supporting the economy, and how the economic activity impacts the environment. In order to facilitate this, a set of accounting rules is proposed that are capable of producing internationally comparable statistics (UN 2014). The central framework provides first guidance on measurement of on environmental flows, especially how the natural inputs and the residuals take their paths in the economy both in physical and monetary terms. Second, it provides a stock of environmental assets and their relative changes during an accounting period both as physical and monetary units. Third, it estimates the monetary flows associated with expenditure toward the protection of the environment.

Applying SEEA principles for land will be useful in understanding the use of land and soil resources as inputs in the economic system, as well as how the resource is affected by the waste resulting from a variety of economic operations such as agriculture and industry. Collating this information into one account will provide useful information to the decision-makers on how the land and soil are being used in the economy and how they are being degraded from the other economic sectors. This will allow one to think about applying resource transfers between sectors in order to compensate for the damages. For example, upland farming activity may generate sediment that will be deposited in the downstream reservoir affecting power generation (within the energy sector) and the water sector (since sediment affects the water quality and will result in added costs on water purification). The chemicals that are added to the farmland will be washed with the water and cause health problems to the people downstream. Explicit identification and quantification of such impacts will help in understanding the linkages between the land sector with the energy sector, water sector, and health sector. Such externalities could be internalized through interagency mechanisms with a view to enhancing the positive resource flows and organizing compensation schemes for the losers.

Application of the SEEA framework to soil and land resources involves preparing accounts for the different components of the soil, including its inorganic parts, organic parts, and biological components both as stocks and flows. Robinson et al. (2017) have prepared a framework for the assessment of soil natural capital in Europe with the aim of assessing the state and the changes. Similarly, Yang et al. (2018) elaborate on the interrelation of different functions of the ecosystems, for example, how the soil pollutants could be purified by the forest ecosystems. How the hydrological ecosystem service could be integrated within the ecosystem accounting framework has been assessed by Duku et al. (2015). The essential linkages between water and the soil could provide useful information for the decision-makers. The need for the correct level of information is very critical in the green accounting scheme. Turner et al. (2016) reviewed the available data and the other inputs that could be used in the assessment of changes in values of ecosystem services due to land degradation. There is a large potential for the application of ecosystem accounting in the land sector.

9.7 Environmental Valuation and Land Degradation

Environmental valuation methods are capable of estimating the values of environmental costs and benefits. This is essential since markets do not provide direct information about the valuation of changes in the provision of environmental goods and services except for a few provisional services. These values provide the foundation upon which the other analytical tools, such as CBA and SEEA frameworks, are built. Degraded land results in lowering the value of the land. There are several environmental valuation methods that could be used in the estimation of the value of lands. This section provides a brief account of the valuation methods and their applications in the land sector. The polluted landscapes may generate negative impacts on human health and may endanger other living resources. Thus, a polluted landscape may result in lowering of the prices of the surrounding houses. The hedonic price model analysis is one of the popular methods adopted to estimate the value of land with polluted surroundings. A study by Li et al. (2015) found that the value of real estate is reduced by more than 10% due to the presence of soil and groundwater pollution. Similarly, pollution remediation will bring improvement in environmental quality and result in enhancement of the land value. A study by Lavee et al. (2012) illustrates the direct economic benefits of an increase in land values with remediation of contaminated industrial sites in Israel.

It is also important to understand the range of impacts, spatial, temporal, and sectoral aspects. For example, nutrient depletion of land has a wider spatial impact that goes beyond the farm level. Its impacts can be extended to regional and national scales spanning into environmental, economic, and social sectors. There will be reduction of above ground and below ground biodiversity. The reduced yield implies income losses and impairment of food security. Onsite costs may result from mechanisms to overcome the losses, for example, additional inputs to compensate for nutrition (Drechsel and Gyiele 1999). Offsite costs may result from eroded soil, sedimentation of reservoirs and associated cost of cleaning water and reservoir dredging costs, reduced hydropower capacity and increased thermal generation (Udayakumara and Gunawardena 2021), and associated global costs. Nutrient depletion may also result in reduced outputs leading to food security issues and employment issues. Udayakumara and Gunawardena (2018) elaborate on the land degradation resulting from a large-scale single-purpose hydropower reservoir development project. Estimation was made on how crop yields were reduced due to the diversion of water.

9.8 Environment Management Tools and Other Models for Land Degradation Analysis

There has been a development of a large number of environmental management tools, including life cycle assessment (LCA), footprint analysis, and environmental management accounting tools over the past decade that are capable of analyzing the environmental impacts of products, processes, and activities. LCA, for example, uses physical information to analyze impacts on a wider geographical scale which is a useful tool in the assessment of land use impacts. Variation of soil qualities can be measured by single indicators such as soil organic matter, salinization, and soil organic carbon or multiple indicators such as the land use indicator value calculation (LANCA®) model. This model intends to focus on several soil functions including biotic production, groundwater recharge, erosion resistance, and how they are affected by different land use interventions (De Laurentiis et al. 2019).

9.9 Other Approaches to Reduce Land Degradation: Operating Within Biophysical Realities

9.9.1 Indigenous Approaches

Many countries have inherited traditional land, soil, and water management practices (Koul et al. 2012) that are based on the principles of circular economy and operated within ecological boundaries. Traditional societies had adhered to certain basic principles that were deemed not to be violated. The first principle was to use renewable resources in such a way that the rate of use was not greater than the natural regeneration rate, and the second was to keep waste flows to the environment at or below the assimilative capacity of the environment. By observing these principles, the ancient planners knew that the stock of renewable resources and the stock of assimilative capacity would not fall and therefore would be available in any future period. Nature acts as an ultimate limit for resource use, but resource exploiters consider the nature from an instrumental perspective as an unlimited source of inputs into the production system as well as an unlimited sink for waste. Modern resource management mechanisms have ultimately transferred the resource exploitation and degradation rights to the rich and to the rich nations (De Zoysa et al. 2020), leading to large inequities.

9.9.2 Land Use Planning Within Biophysical Constraints

The following section provides an account on the traditional land use management practices that have been practiced in the Sri Lankan context. The ancient village model consisted of three systems of land use: paddy field, home garden, and chena. The traditional home gardens have adopted agroforestry systems, a self-sufficient system planned with a long time horizon. Proper land and water resource management was an essential component of the village model. This is clearly demonstrated in the land use zonation within the micro-catchment. The land use associated with tank cascade systems in Sri Lanka illustrates an excellent example of the perfection of resource management in a manmade ecosystem context. The tanks and the paddy fields occupied the valleys, where low humicGley soils with poor drainage had limited use other than for paddy cultivation. Ridge summits, with rock outcrops and inselbergs, were converted into works of art and places of worship and spiritual retreat (Dharmasena 2009).

This system lasted for a long period of time with inbuilt disaster tolerance and sustainable livelihood systems. The chena and paddy cultivation processes have followed the patterns of rain and have adopted drought averting practices such as dry sowing, shared cultivation, and tank bed cultivation. Such practices have a significant influence on mitigating climate change impacts as well (Subba et al. 2018). The traditional varieties of crops, such as vegetables and fruits, were grown under complete organic conditions. The varietal diversity of the indigenous paddy and other crops was much suited for the local land and soil conditions. If the soil is water logged, there were varieties capable of surviving. There were varieties suitable for drought-stricken areas and salinity-affected areas as well. The varieties have diverse nutritional qualities that are suited for the diverse nutrient needs of the society, for example, children, pregnant women, elderly, and clergy. The incorporation of biophysical constraints into the current land use planning implies understanding the minimum requirements of the communities for their "sufficiency economy" and rearranging the resource and waste flows in harmony with nature's principles. This may involve radical transformations to the current systems and finding innovative mechanisms to comprehend and achieve it. The practicalities of such transformations may be worth exploring further.

9.10 Global Frameworks and Applications

Globally, countries have agreed upon certain protocols and multilateral environmental agreements (MEAs) to protect shared and global resources. There are several land degradation-related MEAs. United Nations Convention to Combat Desertification (1994/1996) (UNCCD) is aiming at combating desertification and addressing the effects of drought in developing countries with a focus on sub-Saharan Africa. Prevention of adding hazardous material to soil is governed by several other MEAs, which are mainly dealing with hazardous impacts of wastes and chemical pollution. Stockholm Convention on Persistent Organic Pollutants (POPs) is applicable for certain organic pesticides that cannot be degraded under natural conditions and remain in the environment for long period of time. Such chemicals can pose significant human health risks (Li 2018). Perfluorooctanoic acid, which is a persistent organic pollutant, can lead to soil ecotoxicity.

Rotterdam Convention, the Convention on the Control of Transboundary Movements of Hazardous Wastes, aims to control the international trade of certain hazardous chemicals to safeguard human health and the environment. Individual country responsibilities toward such MEAs have a significant impact on land health. There are several targets under the Sustainable Development Goals 2030 that focus on land and soil health. Sustainable cultivation practices could reduce water pollution (SDG 6), reduce greenhouse gases (SDG 13), provide necessary inputs for good health and well-being (SDG 3), and enhance ecosystem services and biodiversity (SDG 14, 15). Furthermore, the United Nations declared 2021–2030 as the "Decade on Ecosystem Restoration," which could be harnessed toward addressing land degradation.

9.11 Conclusions

Land degradation can be explained as a consequence of the violation of the principles of circular economy. From a resource usage point of view, soil is often not being used in a sustainable way to ensure its renewable capacity. Allowing soil erosion beyond the soil regeneration rate leads to the ultimate depletion of the resource. Soil is also being used as a dumping ground for waste. In addition to direct dumping of waste from domestic and industrial sources, soil is often contaminated with chemical fertilizers and agrochemicals used in the commercial agriculture. Proper understanding of the dual role of soil as a resource input and as a waste receiver is important for the planning of the sustainable use of the resource. Violation of circular economy principles leads to depletion of dual roles of soil, leading to soil degradation. There are multiple tools available to analyze the degradation as well as sustainable land use options. These include economic tools (both micro and macro), multicriteria tools, and more recent environmental management tools, along with best practice examples from traditional knowledge systems. The tools have different levels of applications, for example, plot level, project level, program level, and sectoral and national level. Some tools are even applicable at the global level. Understanding the technicalities and potential of such tools with necessary incentives for their application guided by national policies and global agreements would pave the way toward land degradation reversal and ensuring ultimate sustainability of the land resource.

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Accountability of Woody Plants for Restoring Degraded Forest Landscapes and Provision for Ecosystem Services: An Overview

10

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Abstract

The woody plants in the forest ecosystem play an important role in delivering various ecosystem functions and services beneficial for the ecosystem and human well-being. Undoubtedly, these multifunctional features of woody plants keep declining due to the exploitation and degradation of forest landscapes for different causes and purposes. In order to re-establish ecosystem services of the restored forest ecosystem, ecological restoration approaches can be an effective tool through afforestation planning and management across the world. The ecosystem services multifunctionality concept has been used widely to evaluate the ecosystem services of various ecosystems and incorporate these values to meet sustainable development goals and conservation planning and management. Therefore, this chapter deals with forest ecosystem services' accountability and stresses the significance of woody plants for restoring degraded forest ecosystems. Furthermore, an accurate and adequate quantification of ecosystem services could provide a platform to discuss the restoration of degraded ecosystems in the light of ecosystem values for the well-being of biodiversity, including human beings. Similarly, the role of forest ecosystem services quantification in fulfilling sustainable developmental goals stands very high in recent advancements.

Keywords

Woody plants · Forest ecosystem · Ecosystem services · Restoration · Multifunctionality · Degradation

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10.1 Introduction

An ecosystem is a network of interconnected biotic and abiotic components, where the interrelationships of all organisms depend upon well-maintained ecological functions and processes. Thus, ecosystem functions are those life-supporting tools that include the interchange of energy between plants and animals required for life to exist (Ramachandra et al. 2007). These mandatory functions include oxygen regulation, climate regulation, and nutrient cycling. The forests are the treasure of biodiversity and probably contain half of the world's biodiversity. Biodiversity is a term that refers to the variety of organisms vital to humankind in terms of meeting its needs by providing food (80,000 species), medication (20,000 species), raw materials (8000 species), medication formulations (8000 species), and materials for industries (90% from forests) (TEEB 2010).

With the rapid rise in population and economic growth, needs and demands have abruptly increased, resulting in serious ecological degradation and biodiversity loss (MEA 2005; Rapport et al. 1998). These effects trigger the changes in ecosystem functioning, which in turn affects the overall accessibility of forest ecosystem goods and services and, as a result, has an adverse impact on human livelihood (Liebhold et al. 2017; Wagner et al. 2014). The direct and indirect benefits that people get from the ecosystem are referred to as ecosystem services (MEA 2005). The forest ecosystem provides many important ecosystem services vital for human well-being. These include food, freshwater, and timber, local and global climate regulation, pollutant removal, enhancing soil regulation and preventing soil erosion, hydrological services, and improved landscape aesthetics (De Groot and van der Meer 2010; De Groot et al. 2010a, b). So, improving the sustainability of multiple forest ecosystem services has become a key challenge in the current scenario of a growing population. Therefore, restoration of forest functionality has become important from a socioeconomic and environmental perspective. Planting woody plants in forests indeed plays an essential role in forest landscape restoration. If planted trees are used to improve local people's access and use rights to natural resources, they can provide significant social benefits. Jackson et al. (1998) attribute the substantial increase in the forest cover by the local people to provide a careful conservation and management of new plantations. There are currently 12,000 forest user organizations in Nepal, controlling around 850,000 hectares of forest. Over a million communities have far greater control over the management of their forest resources (Maginnis and Jackson 2003).

Landscape restoration, which tries to restore damaged ecosystems, has been significant in reducing human pressure on natural ecosystems, restoring ecosystem services, reversing biodiversity losses, and increasing agricultural productivity and food security (Holl et al. 2003; Doren et al. 2009; Bullock et al. 2011). Restoration of degraded forest landscapes can yield both private and public benefits and hence may represent a potentially major approach to overcoming poverty, food insecurity, and environmental issues in a "win–win" manner (Scherr et al. 2012). Conservation and management of degraded forest landscapes can be possible by a proper valuation of goods and services. Valuation of the ecosystem also enhances the ability of policymakers and stakeholders to evaluate ecosystem management regimes and multiple services provided by the ecosystem.

Additionally, the value of forest ecosystem services should be incorporated into national development policies. For example, Green Growth Plans, Low-Carbon Development Plans, and Sustainable Development Plans are becoming reasonably widespread long-term planning frameworks for many countries. They are often compatible with the Sustainable Development Goals (SDGs) in many developing countries. With substantial exports in agricultural commodities, fish, timber, and high reliance on tourism, developing countries' economies are highly dependent on natural resources and thus ecosystem services for their income. So, ecosystem services are important, especially for rural poor people in developing countries. Hence, the forest ecosystem not only is conserved but must also be restored (Lambin and Meyfroidt 2011). This is why forest restoration awareness is gaining popularity around the world. This chapter briefly discusses (1) global forest cover and ecosystem services provided by woody plants from forest landscapes, (2) valuation of ecosystem services for restoring degraded forest landscapes, (3) accounting of forest ecosystem services in sustainable development goals (SDGs), and (4) ecosystem service multifunctionality of forests for conservation and management.

10.2 Global Forest Cover and Ecosystem Services Provided by Woody Plants from Forest Landscapes

10.2.1 Status and Recent Trends in Forest Area

Forest ecosystems are more biodiverse than other ecosystems, making them an important part of the biodiversity; therefore, one of the indicators of SDGs 15: "Life on Land" is the area covered by the forests. According to the Global Forest Resource Assessment (FRA) and UN Food and Agriculture Organization, 30.8% of the worldwide land area is currently occupied by forests (FAO 2020) that correspond to 4.06 billion hectares or about 0.5 hectares per person. Nevertheless, they are not evenly dispersed worldwide except in five countries (Russia, Brazil, Canada, the United States, and China) that constitute more than half of the world's forests. Only ten countries encompass 66% of forests (Fig.10.1). Besides, Fig. 10.2 displays the share of total land area covered by forest (country-by-country). In forests and other ecosystems dominated by woody plants, trees constitute the primary unit for land restoration. The fact that we don't know enough about their ecology, genetics, and physiology of most of the world's 60,000 tree species may explain some of the current problems with restoration efficacy on a global and local scale. According to the Global Tree Search database (BGCI 2019), there are 60,082 tree species, including palms and agricultural trees that are generally absent in forests.

Among these, 45% are members of just ten families. Fabaceae, Myrtaceae, and Rubiaceae are the three top-most tree-rich families. *Syzygium* (1069 sps.), *Eugenia* (884 sps.), and *Eucalyptus* (747 sps.) are the most varied tree genera in the Myrtaceae family (Fig.10.3). The fourth, fifth, and sixth largest genera are *Ficus*

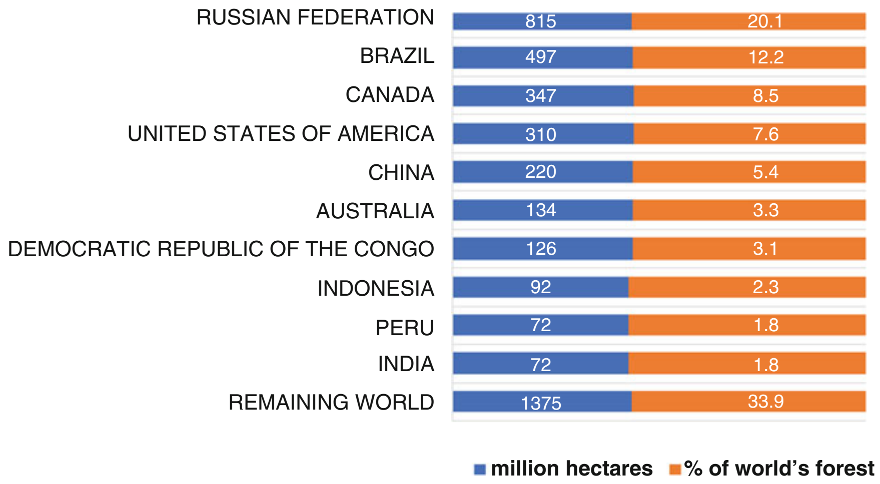

Fig. 10.1 Global distribution of forest with most significant forest area, 2020. (Source: FAO 2020)

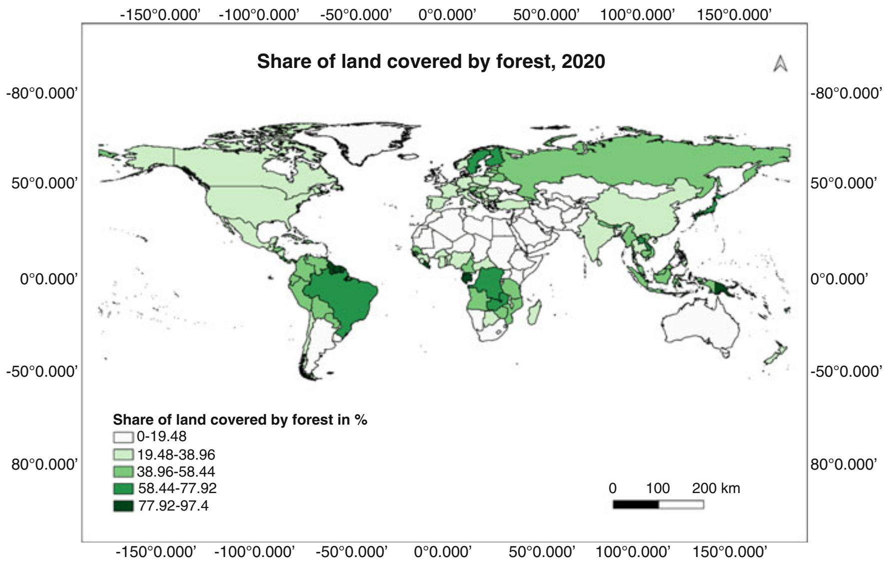

Fig. 10.2 Share of total land area covered by the forest ecosystems across the world. (Source: FAO 2020; https://fra-data.fao.org/WO/assessment/fra2020)

(Moraceae), *Diospyros* (Ebenaceae), and *Psychotria* (Rubiaceae), sequentially (Beech et al. 2017). The countries having the most tree species include Brazil, Colombia, and Indonesia.

Crowther et al. (2015) have mapped global tree density in a study published in the prestigious journal "Nature" (Fig.10.4). To accomplish this, they used 429,775

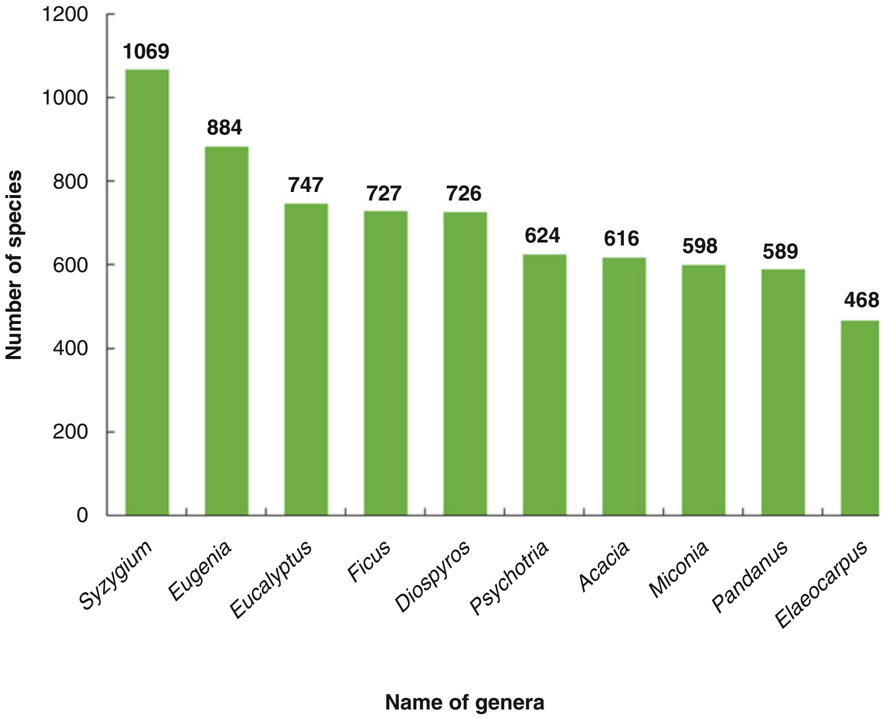

Fig. 10.3 The top ten genera have the most significant number of tree species

ground-based tree density data from each continent to create a worldwide forest's tree map. A tree is defined as a plant with woody stems greater than 10 cm in diameter at breast height (DBH). They estimated that the world's tree population was around 3.04 trillion. According to the authors, approximately 15 billion trees are chopped down every year; therefore, the worldwide tree population has decreased by nearly half (46%) since the dawn of civilization.

Deforestation and the degradation of the world's forests have resulted in ecologically, economically, and culturally degraded landscapes. So, a proper understanding of ecosystem services has become important to restore and rehabilitate degraded forests. The top two international conservation organizations, IUCN and WWF, have been working with other leading organizations since 1999 to promote a proposal called "Forest Landscape Restoration." They aim to boost ecological integrity and enhance human well-being by producing goods and services by simply planting trees. Forest's ecosystem services such as climate change regulation, agricultural productivity, hydrological services, reduced soil erosion, availability of forest products like wood, and increased wildlife habitat have been receiving acknowledgment and consideration from industries, governments, the media, and NGOs since the publication of the Millennium Ecosystem Assessment (MEA 2005; Ciccarese et al. 2012). These services are grouped under four main classes, i.e.,

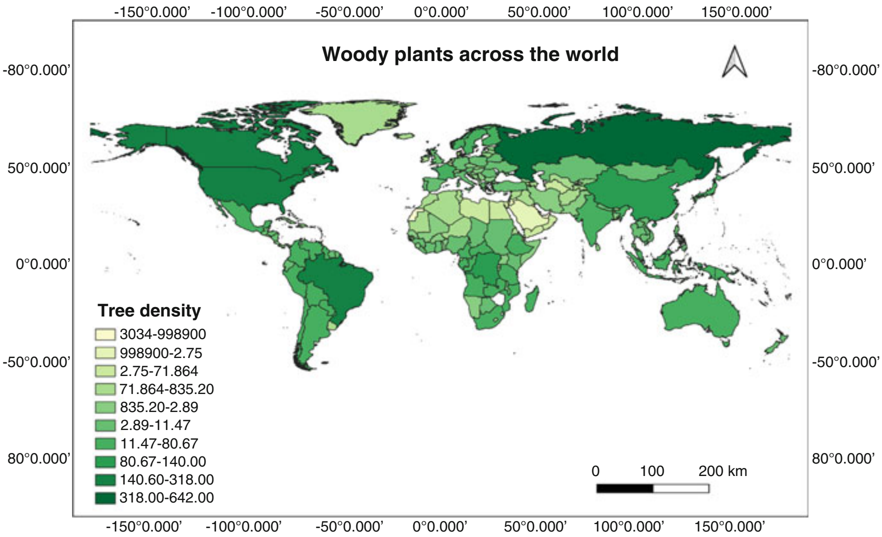

Fig. 10.4 Distribution of trees worldwide (values between 2.75 and 835.20 are in millions and between 2.89 and 642.00 are in billions). (Source: FAO 2020; https://www.nature.com/articles/nature14967)

provisioning, regulating, cultural, and supporting services (Fig. 10.5). Timber is one of the most critical resources obtained from the forest ecosystem and provides considerable direct economic benefits (Fischer et al. 2006; Brandt et al. 2014).

Forests contribute to climate change extenuation by sequestering atmospheric CO_2 and accumulating in various biomass pools (Powers et al. 2013). Forests are also regarded for the numerous recreational opportunities they provide, including wildlife and birding, hunting, rafting, fishing, and hiking that come under cultural services (Ninan and Kontoleon 2016). The most difficult challenge in managing forests is to withstand timber output, biodiversity, carbon stock regulation, and recreational services all at the same time (De Groot et al. 2010a). Several studies have looked into the possible associations between ecosystem services and the effects of forest administration on their availability (Bradford and D'Amato 2012; Brandt et al. 2014).

10.2.2 Status and Current Trends of Forest Degradation

A literature survey has revealed that land degradation is discussed in a variety of ways, with greater emphasis on biodiversity and ecosystem functioning and services. Olsson et al. (2019) describe land degradation as the steady decline in land condition caused by direct or indirect natural and anthropogenic factors and climate change is blamed for a long-term decline or loss of biological production, ecological integrity, or human value. This concept applies to both forest and nonforest land. Philip Curtis

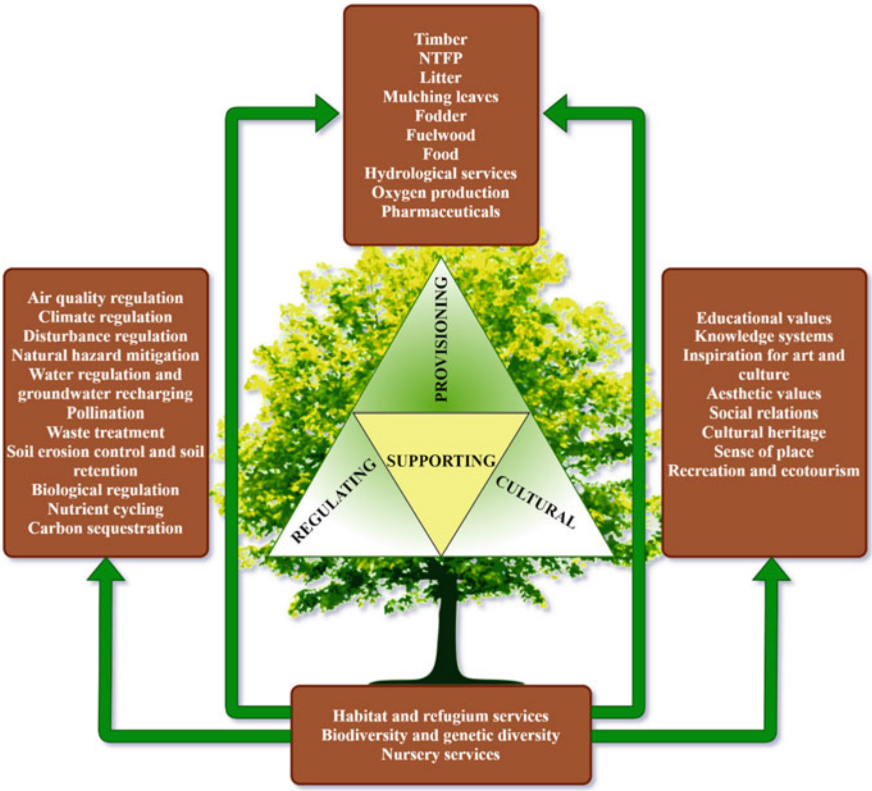

Fig. 10.5 Provision of ecosystem goods and services in a typical forest ecosystem (MEA 2005)

and his colleagues used satellite images to analyze global forest loss between 2001 and 2015. Forest loss is the combination of deforestation and forest degradation. Deforestation is responsible for 27% of global forest loss. The remaining 73% resulted from three forest degradation drivers: shifting agriculture (24%), forestry products (26%), and wildfires (23%) (Curtis et al. 2018) (Fig.10.6).

In tropical regions (Latin America, Southeast Asia, and Africa), forest loss constitutes 95% of global deforestation and 34% of forest degradation. Likewise, in the temperate region (North America, Russia, China, South Asia, Europe, Oceania), forest loss constitutes 66% of forest degradation and 5% of global deforestation. It indicates that deforestation driver dominates in tropical and degradation dominates in temperate regions.

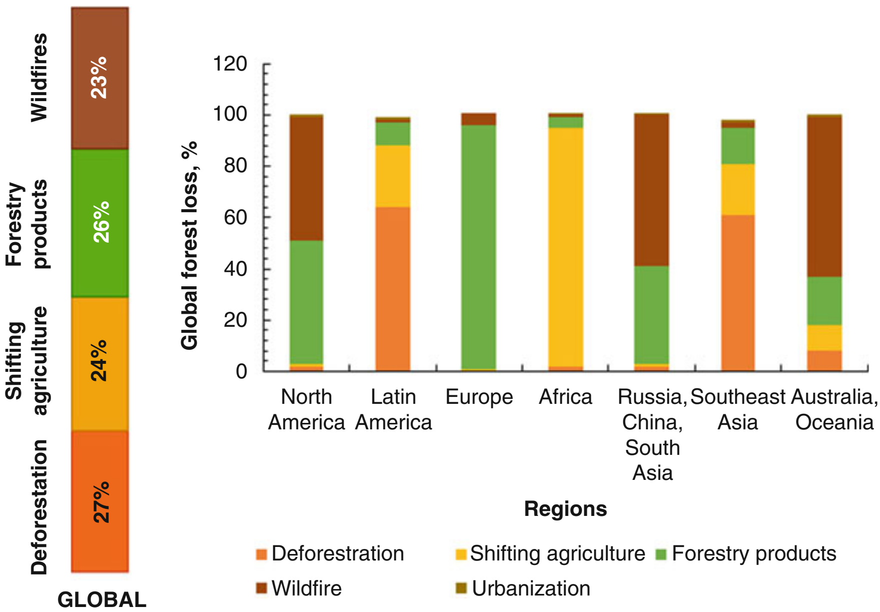

Fig. 10.6 Global forest loss by several drivers for the period 2001–2015. (Modified: Curtis et al. 2018)

10.3 Valuation of Forest Ecosystem Services: A Paradigm for Restoring Degraded Forest Landscape

The ecosystem's health, integrity, and resilience are all important factors in providing sustainable ecosystem services. The failure to recognize the ecosystem's value is the primary cause of ecosystem mismanagement. The forest ecosystem services value should not be taken for granted because life would not be possible without these services. Hence, an appropriate valuation of ecosystem goods and services is necessary for the restoration of a particular forest ecosystem. Costanza et al. (1997) evaluated the annual value of forest ecosystem products and services to be $4.7 trillion and the total yearly value of global tropical and temperate/ boreal forests to be US $ 3813 and US $ 894 billion, respectively (Fig. 10.7). According to Pimentel et al. (1997), an annual value of $63.6 billion is estimated to be produced by the 520 million acres of temperate/boreal forests in the United States.

10.3.1 Methods for the Quantification of Forest Ecosystem Goods and Services

Despite the importance of ecosystem functions and the implications of their degradation, society undervalues ecosystem services, mainly because of a lack of

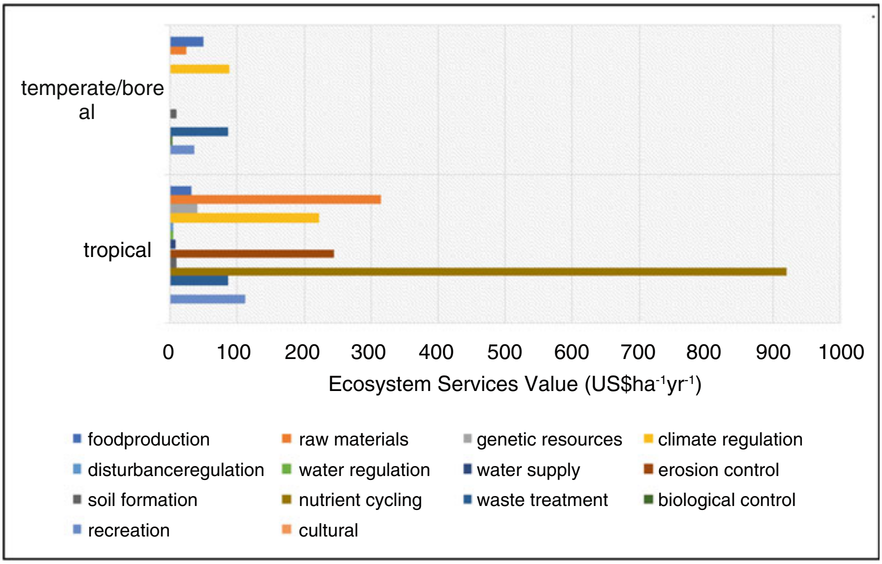

Fig. 10.7 Ecosystem services value of global tropical and boreal forest ecosystems. (Source: Costanza et al. 1997)

understanding of the link between natural ecosystems and the functioning of human support systems. Different disciplines, cultural ideas, and philosophical viewpoints interpret and convey the significance or "value" of ecosystems and their services in diverse ways (Goulder and Kennedy 1997). The valuation of ecosystem services can provide scientific information for decisions and policymakers (Turner et al. 2010). This includes international and national, regional, and subregional policy decisions, plannings, and projects. In recent times, the valuation of ecosystem services has provided new insights into restoring degraded forest landscapes. A range of management approaches can reclaim even a highly degraded ecosystem. Reclamation, rehabilitation, and reforestation will increase the ecosystem services supply, which will ultimately increase total economic value (TEV) (Fig. 10.8).

Controlling subsequent pressure on forests caused by fires, invasive species, and unsustainable harvesting by using strategies to speed up forest regeneration, such as planting or attracting seed dispersers, can help restore forests. The scientific literature on ecosystem services valuation and assessment is divided into two main categories. The first is the ecological valuation method, which aims to evaluate the significance of biological phenomena without primarily focusing on consumer preferences. The second is the economic valuation method, which focuses on the market and nonmarket value of ecosystem services for people rather than on the structure and inner complexity of the ecosystem (Gómez-Baggethun et al. 2010; Liu et al. 2010).

In ecological evaluation methods, landscape indicators are useful to comprehend the supply of ecosystem services or the status of the ecosystem by utilizing a set of

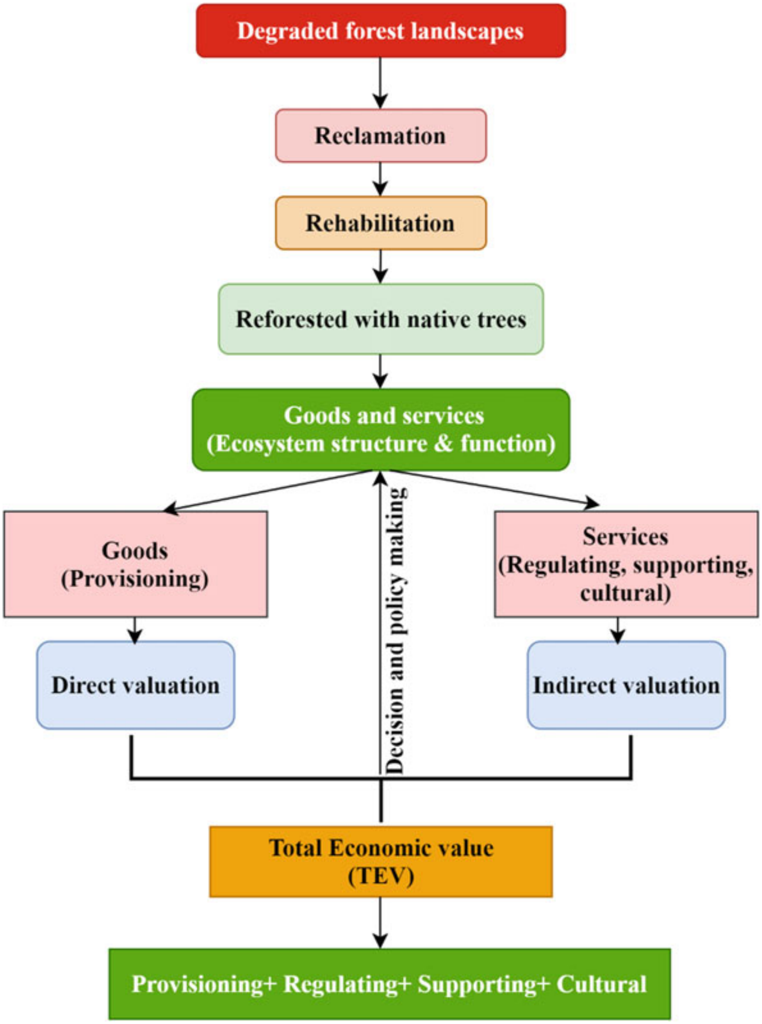

Fig. 10.8 Diagram showing linkages between ecological restoration, forest ecosystem services, evaluation, and policymaking

metrics. Ecological valuation is somehow complex because of the large number of features that might be measured, data availability concerns, and assessment complexity (Chan et al. 2006; De Groot et al. 2010a; Spangenberg and Settele 2010; Baveye et al. 2013). Evaluation methods used in landscape planning are the following:

- Diversity indices (Shannon–Wiener Diversity Index, Simpson's Index, Similarity indices, Berger–Parker Diversity Index).
- Landscape complexes.

- Landscape ecological planning (LANDEP).
- Functional efficiency evaluation of nonforest vegetation.

Economic evaluations are usually an effort to bring out individual preferences within the general public for changes in the delivery of services or the state of the environment in monetary and nonmonetary terms. These are built on the basic principles of welfare economics, which state that changes in an individual's well-being are reflected in their willingness to pay (WTP) or accept recompense (WTA) for changes in their degree of use of a particular service or set of services (Hanley et al. 2001). Department for Environment, Food and Rural Affairs (DEFRA 2007) states that there are two main economic valuation methods for estimating public preferences: the revealed preference approach and the stated preference approach in monetary terms. The revealed preference approach is based on actual behavior data. Some methods indirectly assume values from behavior in surrogate markets, which are expected to relate to ecosystem services directly. This includes the market price method, travel cost method, hedonic pricing, and benefit transfer method. In the stated preference approach, structured questionnaires are used to obtain individual preferences. These methods are based on hypothetical rather than actual data. This includes contingent valuation method, choice modeling, damage cost avoided, replacement cost, restoration cost, relocation cost, and averting behavior models.

In some cases, monetary valuation of ecosystem services is not possible due to the nature of ecosystem service, degree of environmental change, and the interest of stakeholders and policymakers. In such a situation, a variety of nonmonetary or qualitative methodologies can be undertaken. This can be done by interviews, questionnaires, observations, expert-based, scenario-simulation, social-media-based, focused-group, participatory mapping, and GIS. There are numerous examples of degraded forests being restored worldwide, including both local sites and large areas. Some case studies have resulted from conscious intervention; some have occurred naturally due to the abandonment of land uses. The following case studies emphasize vital insights that can be utilized to guide attempts to participate in more targeted, widespread, and large-scale restoration initiatives (Table 10.1).

10.4 Accounting Forest Ecosystem Services in Sustainable Development Goals (SDGs)

Continual forest loss severely impacts millions of people's lives and provides substantial sustainable development challenges, partly because forest ecosystem services are underestimated or ignored entirely. Fortunately, the international community appears to be approaching a turning point, with several recent activities aimed at a constructive direction of development, including some current pledges and agreements. This includes one of the most important milestones in the future of the forest ecosystem, "the 2030 Agenda for Sustainable Development and its SDGs." Therefore, there is an urgent need to integrate the evaluation of forest ecosystem services into the metrics of sustainable development goals, specifically

Table 10.1 Large-scale restoration commitment of different forest types across the world

Country	Forest type	Restoration area committed (ha)	Ecosystem service benefits	Restoration activities	Species planted
United States	Temperate broadleaf and mixed forests; temperate coniferous forest	15,000,000	Carbon, water, biodiversity, disaster risk reduction	Fuel reduction, watershed restoration	–
Uganda	Tropical/ subtropical moist broadleaf forest; savannah and dry grasslands	2,500,000	Carbon, food, fuel, fiber, water, biodiversity, erosion control	Agroforestry, protective forests, natural regeneration, silviculture	–
Guatemala	Tropical/ subtropical moist broadleaf forest; tropical/ subtropical coniferous forest	1,200,000	Carbon, tourism, biodiversity	Agroforestry	–
Colombia	Tropical/ subtropical moist broadleaf forest	1,000,000	Watershed functions, erosion control, biodiversity, control invasive species	Natural and assisted reforestation, avoided deforestation, agroforestry	–
Pakistan	Temperate coniferous forest; boreal/taiga forest	380,000	Carbon, water, fuelwood	Enrichment planting, afforestation, protective forests	–
Brazil's Atlantic Forest restoration pact	Mangrove; tropical/ subtropical moist broadleaf forest	1,000,000	Carbon, biodiversity, timber, water, pollination, pest control	Total planting, enrichment, natural regeneration, agroforestry	–
Canada	Temperate forest	–	–	Afforestation; management practices;	*Acer platanoides*, *Fraxinus*

(continued)

Table 10.1 (continued)

Country	Forest type	Restoration area committed (ha)	Ecosystem service benefits	Restoration activities	Species planted
				natural regeneration	*excelsior*, *Larix decidua*, *Piceaabies*, *Pinus nigra*, and *Tilia cordata*
Nepal	–	–	–	Natural regeneration; management practices involved community participation	–
Brazil mined land	Evergreen moist forest	100	–	Natural regeneration; commercial timber plantations	–
Australia	Tropical forest	–	–	Colonization	*Araucaria cunninghamii*, *Flindersia brayleyana*

Source: Christin et al. (2016), Lamb and Gilmour (2003)

those associated with "SDG 15: Life on Land." SDG 15 targets to "conserve, reinstate and encourage sustainable use of terrestrial ecosystems, sustainable manage of forests, combat desertification, and prevent and reverse land degradation and halt further biodiversity loss." There are 12 targets identified for fulfilling the goals of "SDG 15: Life on land." Fig. 10.9 demonstrates the targets that have been identified for forest ecosystem services. Target 15.1 identified the importance of conserving, restoring, and sustainably using forest ecosystem services. Target 15.9 is the closest for the economic valuation of forest ecosystem services (Jenkins and Schaap 2018). So, SDG 15 targets are a vital opportunity to integrate forest ecosystem services into the SDG measurement framework (Table 10.2).

10.5 Multifunctionality of Forest Ecosystems for Conservation and Management of Ecosystem Services

Various threats of climate and land-use change such as recurrent droughts, frequent fires, and loss of biodiversity in forests have placed a high focus on environment conservation while still supplying adequate food, fuel, and fiber to feed the world's growing population, which itself is a complex and challenging task (Garland et al.

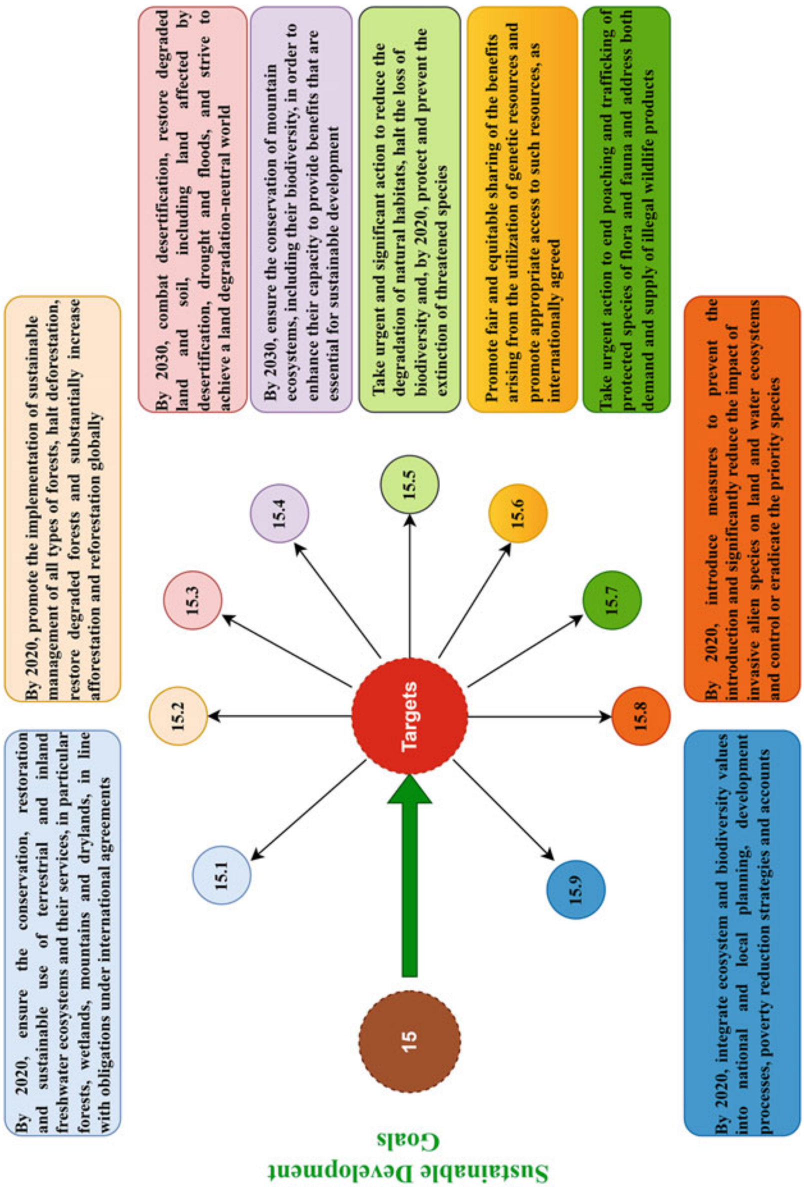

Fig. 10.9 Illustration of "SDG 15: Life on land" targets (source: Jenkins and Schaap 2018)

Table 10.2 Contribution of various forest ecosystem services to their SDG 15 targets

Forest ecosystem services	SDG 15 targets
Biodiversity conservation	15.1, 15.2, 15.4, 15.5, 15.7, 15.8, 15.9
Climate regulation	15.1, 15.2, 15.3, 15.9
Soil conservation	15.1, 15.2, 15.3, 15.9
Water conservation	15.1, 15.2, 15.3, 15.4, 15.9
Recreation	15.1, 15.2, 15.9
Disaster risk reduction	15.1, 15.2, 15.9

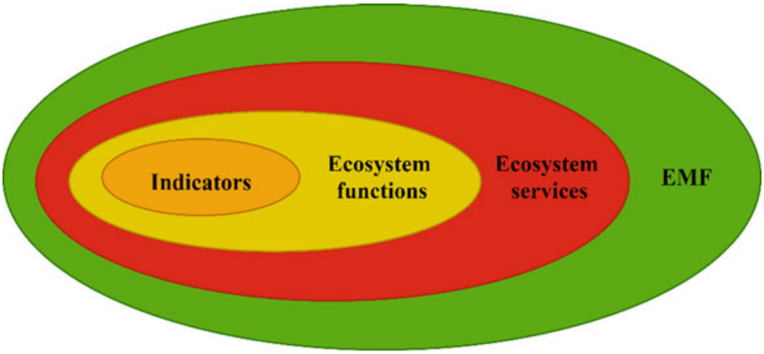

Fig. 10.10 A conceptual diagram showing the concept of ecosystem multifunctionality comprising ecosystem functions and services which can be quantified with the help of indicators (source: modified from Costanza et al. 1997)

2021). The well-known idea of ecosystem multifunctionality has been used by researchers and policymakers to attempt to accomplish this task (Costanza et al. 1997). Ecosystem multifunctionality (EMF) is the ability of an ecosystem to deliver multiple functions and services simultaneously (Manning et al. 2018).

Ecosystem functions are the sum of processes, biotic or abiotic, that occur within an ecosystem and can directly or indirectly contribute to ecosystem services (Fig. 10.10).

However, transforming the concept of EMF into conservation and restoration of the forest has been much more challenging. In fact, in recent years, the viability of the multifunctionality idea has been bitterly debated (Bradford et al. 2014a, b; Manning et al. 2018). Preventing forest degradation needs fundamental research to establish a relationship between biodiversity, ecosystem services, and the multifunctionality of the forest ecosystem (Teben'kova et al. 2020). A variety of experiments have been conducted to study the concept of ecosystem multifunctionality and project the relationship between biodiversity and multifunctionality. Earlier studies conducted on forest ecosystem functions and services have focused mainly on a single or a few services: outdoor recreation (Zandersen and Tol 2009), recreational value in an alpine valley (Grilli et al.

2014), and improving water quality (Ayenew and Tesfay 2015), whereas a few other studies have discussed forest ecosystems by considering multiple services (Zanchi and Brady 2019; Khai et al. 2021).

Although ecosystem service valuation has been recognized as an vital tool in ecosystem conservation and management assessment, they have rarely been included. Egoh et al. (2007) have reported that out of the 88 conservation assessments they reviewed, only 20 studies (23%) have integrated ecosystem services value as a part of the rationale for conserving biodiversity. However, only seven studies (8%) have mentioned ecosystem services crucial for the preservation and conservation of ecosystems. Moreover, the economic valuation approach simply conveys that proper valuation of environmental goods and services could lead to a healthier conservation outcome (Ninan and Inoue 2014). One of the leading causes behind the declination of ecosystem services in various regions of the world is the inadequate quantification of their physical and economic values. Hence, they lack a market price that would make them comparable to other goods (e.g., timber) (Lara et al. 2009). Therefore, ecosystem services have often been neglected or believed unnecessary in policymaking (Costanza et al. 1997; Nahuelhual et al. 2007). The notion of ecosystem services and their valuation offer a novel tool for studying conservation outcomes, including both the trade-offs and synergies to discourse the multiple interests and principles of biodiversity and ecosystem services (Daw et al. 2011). Furthermore, De Groot et al. (2010a) state that the ecosystem service approach and ecosystem service valuation efforts have changed the terms of discussion on nature conservation, natural resource management, and other areas of public policy. The forests and landscapes whose ecosystem services have been adequately quantified can sustainably be used for monitoring and managing conservation assessments. Most decisions in resource management are affected mainly by ecosystem services for which it is feasible to define a market value (Costanza et al. 2014). The monetary valuation of ecosystem services could assist in the allocation of decisions between preservation and conservation when the stocks of critical natural capital or flows of ecosystem services are vigorous and resilient (Limburg et al. 2002).

10.6 Conclusion

Forest ecosystems are arguably one of the most crucial parts of the biosphere that provide and fulfill the living system's numerous needs and demands. These forests supply clean water, air, and food, which are the most vital component of life and other services such as recreational, protection against natural hazards, regulation of climate, and many other services to people residing in or near the forest area. Similarly, the diverse existence of biological life forms in the forest ecosystem provides resilience and resistance against external destructive forces and maintains the ecological stability of the ecosystem. Unfortunately, these natural resources are degraded knowingly or unknowingly, causing significant effects on the ecosystem's environment and declining ecosystem services supply. In the case of the forest ecosystem, deforestation caused by various natural and anthropogenic activities has become the main dismantling factor that affects the overall functioning of the ecosystem. One of the primary causes of forest ecosystem destruction in earlier times was due to ignorance or little understanding of the values of the forest ecosystems for the welfare of the living system, including human beings. Moreover, the loss of forest cover can be clearly depicted from the share of forest cover (country-by-country) from time to time. Although several countries have acknowledged the importance of the forest ecosystem and tried to rebuild the same system through ecological restoration, their efficiency couldn't regain that of the original ecosystem. However, restoration would act in a sophisticated way to repay the loss and reach a much closer to the original system.

The concept of ecosystem multifunctionality has become a vital key to evaluating various ecosystems' overall functioning and integrating the values for policy management and conservation assessment. Different ecosystems and landscape types have been considered for ecosystem services evaluation globally. The values of the ecosystem could be evaluated through various means, of which economic and sociocultural approaches have been used frequently. After valuing the ecosystem services of a particular ecosystem, the decision-maker and policy framer can account for the loss of the ecosystem in terms of money and people preferences and may also incorporate the same value for framing developmental policy basis of values for the welfare of the living system. Those areas or ecosystems that have adequately quantified ecosystem services values could be explicitly and easily integrated to decide conservation and developmental management by the policy and assessment authorities.

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Ecological Restoration of Degraded Forests for Achieving Land Degradation Neutrality 11

Ajay Sharma, John Tracy, and Pankaj Panwar

Abstract

Land degradation neutrality (LDN) is an approach that counter balances the loss of productive land with degraded areas restoration. Forest represents 30% of the earth's land area and provides a variety of goods and services. Maintaining and improving the health and productivity of these landscapes is fundamental to putting the earth on a clear path toward sustainable development, which relates to LDN. Since global scale of forest loss is vast, so are the opportunities for rehabilitation and restoration across all the continents. Restored forest lands enhance provision of ecological and economic benefits, including improved livelihoods; enhanced biodiversity and habitats, supply of clean water, biomass fuel, and other forest products; reduced soil erosion; and recreational and educational opportunities. Restoring degraded forest lands requires a range of approaches according to the type, extent, and degree of degradation. Different forest management approaches like afforestation, reforestation, natural regeneration, and enrichment planting can be utilized both at local and landscape levels for ecorestoration of degraded forest for achieving LDN for ecological, social, and economic well-being.

Keywords

Land degradation neutrality · Forest · Restoration · Livelihood

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11.1 Introduction: Ecosystem and Land Degradation Causes and Consequences

Land degradation, meaning any reduction or loss in the biological or economic productive capacity of the land resource base, is a global problem (Stavi and Lal 2015; UNCCD 2016; Borrelli et al. 2017). Degradation is often the result of the poor or short-sighted management of our natural resources, including land, forests, and water resources. It takes many forms and works over long and short timescales. In farmland, intensive cultivation and grazing can leave soil depleted of nutrients and vulnerable to erosion, especially where tree cover has been removed (Celentano et al. 2017). Forests are being cleared and overexploited, often for short-term gain and to the detriment of local communities. Wetlands are being drained and freshwater resources rapidly depleted. Urban areas, infrastructure, and industry are expanding rapidly, often at the cost of our most productive farmland or natural landscapes. As a result, degraded ecosystems are losing their ability to provide basic services from the provision of food, water, and energy to the regulation of climate and diseases (Costanza et al. 2017; Jarrah et al. 2019; Toure et al. 2019). Global warming and rising human demands on earth's finite resources are making the dire situation worse. Increasing temperatures, altered rainfall patterns, soil erosion, biodiversity loss, and water scarcity and quality issues are undermining the ability of entire regions to sustain human populations. The poor are more affected by these issues and the associated land degradation as they depend most heavily on natural resources for their daily life (Barbier and Hochard 2018). Increasing competition and utilization for these resources along with increasing population increases risks of social, demographic, and political conflict by causing migration, conflict, and instability (Abel et al. 2019; Goldstone 2002; Raleigh and Urdal 2007; Raleigh 2011; Suhrke and Hazarika 1993).

The scale and severity of the degradation problem is not limited to a particular region but the entire world (Borrelli et al. 2017; UNCCD 2017). According to an estimate, more than 20% of the world's croplands, 30% of the woodlands, and 10% of the grasslands are in state of degeneration (Borrelli et al. 2017). Land degradation affects the lives of at least 3.2 billion on earth, most of which are smallholder farmers and rural communities (Scholes et al. 2018). Millions more are affected through food insecurity, higher food prices, effects of climate change, environmental hazards, and the loss of biodiversity and ecosystem services. These issues have raised concerns about a mass species extinction and the associated costs have been estimated to be more than 10% of global gross domestic product in lost ecosystem services. It is estimated, by 2050, that degradation and climate change could reduce crop yields by 10% globally and by as much as half in some regions (Scholes et al. 2018). An estimated 24 billion tons of fertile soil are lost each year due to unsustainable agricultural practices. If this trend continues, 95% of the Earth's land area could become degraded by 2050 (Scholes et al. 2018).

11.2 Land Degradation Neutrality and Forests

Land degradation neutrality (LDN) is an approach that counter balances the expected loss of productive land with the restoration of degraded areas (UNCCD 2016). The concept of LDN emerged from the UN Conference on Sustainable Development (Rio + 20) in 2012 (Leggett and Carter 2012). The Parties to the Convention defined LDN as a state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems. The purpose of the concept of LDN is to encourage implementation of an optimal mix of measures to "avoid, reduce, and/or reverse" land degradation to achieve a state of no net loss of healthy and productive land (UNCCD 2016). As such, LDN aims to balance anticipated losses in land-based natural capital and associated ecosystem functions and services with measures that produce alternative gains through approaches such as land restoration.

LDN may sound like a simple idea, but it is a powerful one. It aims to secure enough healthy and productive natural resources by avoiding degradation whenever possible and restoring land that has already been degraded. At its core are appropriate land management practices and land use planning that will improve economic, social, and ecological sustainability for present and future generations. According to an estimate, avoiding land degradation through sustainable land management can generate up to USD 1.4 trillion of economic benefits (Thomas et al. 2013; Scholes et al. 2018). Gradual implementation of sustainable management practices for land and forests on lands being degraded is a means to reduce degradation. Land restoration is another key approach to promote LDN, of which forest restoration is inarguably the major component due to the prominence of forests among the terrestrial ecosystems on earth.

Of more than 120 countries committed to LDN, more than 80 are reported to have completed baseline assessments of the degradation status of their lands and forests, identified key trends and drivers of degradation, and set clear targets as part of a strategy to achieve LDN by 2030 (UNCCD 2019). In the LDN country reports, deforestation—along with population pressure and poor agricultural practices—is the most frequently mentioned cause of degradation. As a result, virtually all countries pinpoint measures relating to forests in their response strategies. These include direct measures such as forest restoration and/or conservation as well as indirect measures like raising agricultural productivity to reduce pressures to convert more forest to farmland (UNCCD 2019).

Representing around 30% of the earth's land area, forests provide a variety of goods and services, such as timber, water, food, fodder, fuel, medicines, non-wood products, habitat for a variety of floral and faunal species, recreation, and shelter (FAO and UNEP 2020). In addition to providing a vital habitat for 80% of all terrestrial species, forests help mitigate many natural disasters such as floods, landslides, avalanches, droughts, and sand and dust storms (FAO and UNEP 2020). Perhaps most significant, and cutting across all these important objectives, is that protecting and restoring forests and trees in the landscape is critical to equitable development (Erbaugh et al. 2020; Osborne et al. 2021; Singh et al. 2021; Tiendrébéog et al. 2020). Forests and their goods and services are vital to the livelihoods of some of the world's poorest communities. They help generate income for estimated 1.6 billion people, particularly in developing countries where most of the population depends on non-wood forest products to meet economic, health, and nutritional needs (Zaibet 2016). Maintaining and improving the health and productivity of those landscapes is fundamental to putting the earth on a clear path toward sustainable development that leaves nobody behind. However, despite their ecological, social, and economic importance, forest ecosystems have experienced a steady decline in productivity and land cover over the last several decades, primarily due to unsustainable management, pressure caused by increasing human population, and climate change (FAO and UNEP 2020). To address this problem, it is vital to sustainably manage land and forest resources together—for example, by applying an integrated land-use approach that includes planting trees for multiple benefits at the landscape level. Many synergies and correlations exist between forest and land management, and integrated approaches can help maximize efficiency.

Protecting and restoring forests to achieve LDN can help bring many of the Sustainable Development Goals (SDGs) within reach. Forests and trees not only help achieve a balance between degradation and restoration but also power an overall improvement in the stock and productivity of a country's natural resources. Forest restoration can help boost livelihoods, secure food and water supplies, store vast amounts of carbon, and conserve biodiversity while helping meet many other SDGs. Poor rural communities in developing countries are expected to gain the most from forest restoration efforts (UNCCD 2019).

11.3 Forest Restoration for Achieving LDN

Forest restoration is one of the actions in LDN's response hierarchy of "avoid>reduce>reverse" (UNCCD 2017). Under this hierarchical approach, the top priority is to avoid the degradation of lands and ecosystems at the first place. Second-level actions are targeted at reducing the impacts of degrading land use, which could be achieved by adopting sustainable land and forest management practices. Restoration is the third action in the hierarchy. Ideally, restoration and rehabilitation will offset unavoidable degradation so that the net balance is neutral or even positive (UNCCD 2019). According to UNCCD (2019), forest restoration and rehabilitation would involve reversing the overexploitation or clearance of naturally forested landscapes and re-establishing their original productivity. Restoration aims for the full return of a forest's biodiversity, while rehabilitation targets the return of at least part of the natural array of species.

Just as the global scale of the forest loss is vast, so are the opportunities for rehabilitation and restoration across all the continents, with Africa offering the most land followed by South America and Asia (Minnemeyer et al. 2011). According to a global assessment, more than two billion hectares of land worldwide are potential candidates for restoration activities (Minnemeyer et al. 2011). The majority of more than two-billion-hectare land is suitable for "mosaic" restoration, meaning that forests and trees can be integrated with other land uses, such as small-scale agriculture. Another half-billion hectares are deemed suitable for large-scale restoration of closed forests. Additionally, planting more trees in cities and intensively farmed areas will also be beneficial. Therefore, a restored landscape can be a complex mosaic of diverse land uses consisting of protected forests, intensively managed plantations (pure or mixed), naturally regenerated forests, ecological corridors, and agroforests.

Restored forest lands enhance provision of ecological and economic benefits, including improved livelihoods, enhanced biodiversity and habitats, supply of clean water, biomass fuel and other forest products, reduced soil erosion, and recreational and educational opportunities. The addition of trees in agricultural landscapes can diversify production, reduce risk, improve soil fertility, conserve soil moisture and diversity, and increase farm production. Restoration of forests and agricultural landscapes will also help mitigate climate change by sequestering carbon from the atmosphere and can help communities adapt to global warming by maintaining or enhancing ecosystem functions and services and moderating the impacts of catastrophic events, such as wind storms and insect-pest attacks, in addition to droughts.

11.4 Approaches to Restoring Degraded Forests

Restoring degraded forest lands requires a range of approaches according to the type, extent, and degree of degradation. Natural regeneration may often be the most cost-effective approach; however, more intensive interventions may be required in other cases, for example, while restoring diverse forests on lands that had been converted from forest to agricultural lands or other land uses or areas where hydrology needs to be restored. Since many ecosystems are part of larger landscapes that need be managed productively (e.g., wetlands within a broader landscape of rangelands) and have been significantly modified by that management, the term "landscape restoration" is increasingly used to imply restoration of ecosystem functions to a level that sustains human activity. Forest landscape restoration (FLR), for example, has been described by IUCN as a process to regain ecological integrity and enhance human well-being in deforested or degraded forest landscapes.

Successful forest restoration projects typically build on many of the elements described in the LDN target setting process, including wide stakeholder participation and the application of safeguards to ensure, for instance, that vulnerable forest communities are not displaced from lands earmarked for restoration. Projects should also ensure that the interests and knowledge of women are fully represented. Some of the key approaches to restore and rehabilitate degraded lands that would help achieve LDN are discussed below. Other measures include increased government subsidies and other financial support for forestry and forest management and the promotion of private sector engagement and carbon markets.

11.4.1 Natural Regeneration

Natural regeneration on abandoned fields or cut over or degraded lands would come at lower costs and has been found to promote biodiversity, soil conditions, and climate change resilience (Chazdon et al. 2020), while at the same time making the SDG more achievable. As an example, almost all of Turkey's, one of the countries committed to LDN, increase in forest over the last decades is due to natural regeneration on abandoned agricultural land (Atmiş and Günşen 2018). However, for such results the natural seed source needs to be nearer to such sites within the seed dispersal distance. Assisted regeneration with deliberate planting of tree groups could be an alternative in areas where forests used to occur naturally (Chazdon et al. 2020). Restoration techniques based on natural regeneration are less costly than tree planting, making them a viable alternative for restoring degraded lands, although success is likely to depend on the extent of soil degradation and the presence of forest vegetation in the vicinity (Chazdon and Guariguata 2016). There is evidence that natural regeneration on agricultural and pastoral land has great potential to restore biomass (Poorter et al. 2016), soil organic carbon (Bayala et al. 2019), biodiversity (Rozendaal et al. 2019), as well as other essential ecosystem functions (Lohbeck et al. 2015).

11.4.2 Reforestation and Afforestation

Reforestation involves planting trees on sites that contained vegetation before. Therefore, this serves to maintain the amount of forest area over time despite wood utilization. Afforestation is the creation of forests on land not previously forested and thus brings additional area under forests. Both afforestation and reforestation offer control over the selection of species (one or many), use of superior genetics, and appropriate forestry techniques to drastically improve forest productivity of land in a brief period. Afforestation could be adopted as a restoration activity of an integrated land-use plan designed to widen the resource base and add resilience to an otherwise intensively farmed landscape. Brancalion and Chazdon (2017) proposed four principles to guide afforestation and reforestation schemes focused on carbon storage and commercial forestry in the tropics: (1) restoration interventions should enhance and diversify local livelihoods; (2) afforestation should not replace native tropical grasslands or savanna ecosystems; (3) reforestation approaches should promote landscape heterogeneity and biological diversity; and (4) residual carbon stocks should be quantitatively and qualitatively distinguished from newly established carbon stocks. These principles help to establish a platform for implementation and monitoring of forest and landscape restoration programs based on a broad set of socio-environmental benefits including, but not only restricted to, carbon and timber benefits (Brancalion and Chazdon 2017).

11.4.3 Enrichment Planting

Enrichment planting is the process by which one plants trees to increase the population density of existing tree species or increase tree species richness by adding tree species to a degraded forest (Glossary- Forest Restoration Research Unit 2008). It involves introduction of valuable species to degraded forests without the elimination of valuable individuals already present and can be used to restore degraded forests, increase productivity and economic value, conserve biodiversity, and improve wildlife habitats (Forbes et al. 2020; Mangueira et al. 2019; Marshall et al. 2021; Millet et al. 2013; Yeong et al. 2016). Enrichment planting can be done in naturally regenerated as well as reforested and afforested lands, though it is especially useful when natural regeneration is insufficient following logging operations or in areas where soil characteristics are not conducive to other uses (Ådjers et al. 1995). Often, enrichment planting includes fruit trees or other species with commercial or local value that enhance not only forest productivity but also the quality of nutrition of the local population. Enrichment planting with nitrogen fixing tree species will improve soil productivity as well. Silviculturally, enrichment planting is an important technique that can help establish tree species that cannot tolerate open plantation conditions and suffer from continuous direct insolation (Montagnini et al. 1997). Enrichment is often considered a promising clean development mechanism for increasing carbon sequestration in secondary forests (Paquette et al. 2009).

11.4.4 Agroforestry

It involves deliberate combined production of trees and agricultural species on the same piece of land, yielding resources including food, timber, and fuel as well as benefits such as intermittent income, improved soil fertility, erosion protection, and carbon sequestration. Traditionally practiced in many tropical regions, agroforestry techniques are a focus of research into the design of more resilient systems capable of adapting to climate change. Silvopastoralism is a form of agroforestry that integrates the simultaneous production of tree crops, forage, and domesticated animals and is also a traditional practice that involves the management of livestock grazing to maximize the long-term benefits of this diversified farming system. Other practices such as farmer managed natural regeneration (FMNR) are also being considered agroforestry practices (Sinclair 1999). In FMNR, tree regeneration is promoted on agricultural land that is still being farmed and requires farmers to actively manage the regeneration process and tree tending (Chomba et al. 2020; Haglund et al. 2011). Agroforestry practices offer multifunctional agriculture production systems that can increase food production while simultaneously enhancing social and environmental goals, as committed to in the SDGs. Agroforestry practices are resilient to multiple insecurities including climate change, soil degradation, and market unpredictability, all of which reduce sustainability and are likely to exacerbate hunger (Waldron et al. 2017). Agroforestry systems can increase yield while also advancing multiple SDGs, especially for the small developing-world agriculturalists central to the SDG framework (Waldron et al. 2017). Agroforestry also increases resilience of crops and farm livelihoods, especially among the most vulnerable food producers (Nyong et al. 2020; Quandt et al. 2019).

11.4.5 Conservation and Protected Areas

The protection, care, management and maintenance of ecosystems, habitats, wildlife species, and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence can help ensure conservation and preservation of biodiversity and intact natural resource base as well the restoration where land degradation has happened. Closure of the area from human interference has in many areas led to restoration of degraded lands by way of natural regeneration. Long-term effective closures, like wildlife sanctuaries, protected areas, national parks, etc. have not only restored the degraded lands but also had increased local and regional floral and faunal diversity.

Well managed, appropriately located and properly valued protected areas contribute in several ways to meet the SDGs (Dudley et al. 2017a, b; Kettunen and ten Brink 2013). Protected areas safeguard biological and cultural diversity (Naughton-Treves et al. 2005; Vlami et al. 2017) and contribute to human welfare and wellbeing including poverty alleviation (Andam et al. 2010), food and water security (Dudley and Stolton 2003; Meilleur and Hodgkin 2004; Stolton et al. 2006), health (Azara et al. 2018), disaster risk reduction (Dudley et al. 2015), sustainable cities (Wang et al. 2013), and climate change mitigation and adaptation strategies (Dudley et al. 2009; Gross et al. 2016). Building on this, they can even play a role in sustaining peaceful societies and mitigating the risks for conflicts (Sandwith and Besançon 2010).

11.4.6 Protection of Wildlife Corridors

At the landscape level, understanding how plants and animals move, interact, and reproduce is key to effective forest restoration. A corridor connecting forest fragments can allow animals to travel among forest fragments, significantly improving their chances of surviving, reproducing, and flourishing. Given the increasing population and forest fragmentation, the role of maintaining corridors has become increasingly important. Protection of corridors help maintain the quality of ecosystems, ensure sustainable use of shared natural resources, and improving the livelihoods of people.

11.4.7 Invasive Species Management

Invasive species can have harmful effects on native forested systems and cause serious loss of biodiversity and land degradation. Such invasions may seriously hamper the capacity of ecosystems to maintain their functions and ecosystem services and, by doing so, hinder the achievement of SDGs. Non-native species, whether weeds or pests in agricultural crops or forests, or parasites in livestock, can adversely impact economic productivity and ecological integrity in the agricultural, forestry, and fisheries sectors (Gallardo et al. 2016; Gozlan 2017; Morand 2017). Many invasive species are vectors of human diseases and thus are public healthhazards (Mazza and Tricarico 2018; Nentwig et al. 2017). There is evidence that presence of some non-native invasives in an area reduces human life satisfaction ("happiness") (Jones 2017). Forest health and resilience and capacity of native species to naturally regenerate may diminish when non-native species invade an ecosystem. Ingression of obnoxious weeds/shrubs, e.g., *Lantana camara* in Asia, has suppressed the natural regeneration of native species and, in many places, planted species. In the long term, this ingression would change the forest composition leading to degradation of forest areas. The management of invasive species is therefore critical to promote healthy ecosystems, prevent degradation, sustain biodiversity and the environment, and safeguard productive sectors. Management approaches for invasive species usually involve using adaptive management techniques to reduce non-native and invasive species presence through mechanical removal, herbicide application, and planting with competing native species that can establish and suppress non-native prevalence in a forest ecosystem (Lake and Minteer 2018).

11.4.8 Forest Management

The role of forest management in maintaining naturally regenerated, reforested, or afforested lands cannot be overemphasized. Forest management, including the appropriate planting methods, tending and harvesting methods, and the intermittent cultural operations like fertilization, weed control, and prescribed burning in some forest types, is essential to healthy and productive forest stands. Forest management approaches are forest and objective specific. Some forest species require frequent burning while some require specific densities for optimal performance. Consideration of species and their ecological requirements will help ensure that benefits for these forests are maximized. Forest management may be oriented toward single benefit (e.g., timber production) or meeting a suite of benefits from a unit land. While some forest species (e.g., poplars, eucalypts, several pine species) have been intensively studied and their management systems well developed, effective management approaches for many species are not known. This requires investment in research. Restoration strategies and production ecology of different species need to be developed for effective management and restoration of ecosystems that will help reverse land and ecosystem degradation, increase productivity, and help meet SDGs.

11.4.9 Landscape Considerations for Effective Forest Restoration

All the efforts and interventions to prevent forest and land degradation and restore forests must be planned at the landscape level and implemented at the stand or farm level. The landscape approach combines sustainable management and restoration approaches in different land uses across deforested or degraded forest landscapes, with the aim to better balance ecological, social, and economic priorities. Forest restoration projects using the above approaches can make significant contributions toward forest sustainable development and meeting SDGs, particularly when they are conceived and implemented within a wider framework of action such as LDN. The above restoration activities can help:

- Increase the productivity of forests, wastelands, and farmlands, and make them more resilient in the face of climate change, drought, and catastrophic disturbances.
- Increase tree and forest cover at local and landscape levels, enhancing the provision of ecosystem benefits.
- Improve biodiversity, from a variety of floral to faunal species, which will find more refuge in forest ecosystems, and continue to support the delivery of ecosystem goods and services upon which human livelihood and survival depend in myriad ways.

11.5 UN Decade on Ecosystem Restoration 2021–2030 and Funding to Support Restoration

Recognizing the urgency of preventing, halting, and reversing degradation of ecosystems worldwide, 2021–2030 was declared in 2019 as the Decade on Ecosystems Restoration by the 73rd session of the United Nations General Assembly (UN 2019; www.decadeonrestoration.org). The purpose of this declaration is intended to bring together political, scientific, and financial support to scale up restoration activities spanning millions of hectares. The implementation of the Decade is being led by UN Environment and the FAO in collaboration with their partners and joint initiatives that include Global Partnership on Forest and Landscape Restoration and the Collaborative Partnership on Forests. Aronson et al. (2020) proposed six practical strategies to strengthen the effectiveness and amplify the work of ecological restoration to meet the aspirations of the decade: (1) incorporate holistic actions, including working at effective scale; (2) include traditional ecological knowledge (TEK); (3) collaborate with allied movements and organizations; (4) advance and apply soil microbiome science and technology; (5) provide training and capacity-building opportunities for communities and practitioners; and (6) study and show the relationships between ecosystem health and human health. The above strategies can help identifying possible leverage points and pathways for collaborative action among interdisciplinary groups already committed to act and support the UN Decade on Ecosystem Restoration (Aronson et al. 2020).

While the declaration of the Decade on Ecosystem Restoration is encouraging, huge investments are required for implementing land restoration at the global scale to reach the goals for 2030 and beyond. An estimated $ 837 billion are needed to reach the global restoration target of 350 million hectares in the New York Declaration on Forests. The estimated cost of achieving LDN globally—including measures beyond forests and trees— is US $ 4780 billion (FAO and UNCCD 2015). While the GEF and the World Bank are supporting several large programs and projects around the world that promote LDN, much more effort and funding support is required. This makes collective contribution of individuals (crowd funding) and institutions (institutional funding, including private corporations) critical for maintaining the momentum to meet the SDGs.

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Tree Plantation: A Silver Bullet to Achieve Carbon Neutrality?

12

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Abstract

Rising global atmospheric carbon dioxide (CO_2) concentrations has been a major driver of global climate change. In response, several parties to the Paris Agreement have pledged to achieve "carbon neutrality" where CO_2 emissions are balanced by various CO_2 removal activities. Sequestration of atmospheric CO_2 by trees and locking it in different pools (live biomass, detritus, wood products and soil) is widely seen as an easy, cost-effective strategy that would lead to carbon neutrality. Together with attractive carbon incentives, this strategy has led to the mushrooming of several tree plantation projects all over the world. The carbon sequestration potential of a plantation depends upon several factors like species planted, site history, climate, and management practices. While well-planned tree plantations would enable the harvesting of environmental and socioeconomic benefits, ill-conceived tree planting initiatives may turn into an environmental disaster. Prior risk assessments and adoption of an integrated approach in tree plantations would help in reducing the uncertainties and

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achieving the desired targets. Diversified climate action plans which also include tree plantation as an integral component are necessary to achieve carbon neutrality and climate change mitigation goals.

Keywords

Carbon sequestration · Plantation forests · Climate change mitigation · Risk assessments · Carbon management

12.1 Introduction

The global carbon dioxide (CO_2) emissions and subsequently its atmospheric concentration (418.90 ppm as on July 2022; CO_2 Earth 2022) have risen drastically, especially with the advent of the industrial era, and are regarded as a primary driver of global climate change. Globally, about 1.5 trillion tonnes of CO_2 has been emitted since 1751 (Ritchie and Roser 2020). In the recent decades, most of the CO_2 emissions are from Asia that accounts for 53% of global annual emissions, yet as it harbours about 60% of the world's population, its per capita emissions are lower than that of the whole world (Ritchie and Roser 2020). According to Intergovernmental Panel on Climate Change (IPCC 2018) and United Nations Environment Programme (UNEP 2020), global annual emissions need to fall by 50% by the next decade and reach net zero by 2050s in order to achieve the 1.5 °C target of the Paris Agreement. In response, several parties to the Paris Agreement have pledged to cut back CO_2 emissions, proposed nationally determined contributions (NDCs), and declared a timeline to attain "carbon neutrality" (Weitzel et al. 2019). Carbon neutrality is a state of net zero CO_2 emissions, and this could be achieved by equalizing CO_2 emissions and CO_2 removal by various activities (Qin et al. 2021).

Nature-based solutions (NBS), also called natural climate solutions, are often emphasized to plan carbon offsetting activities in order to achieve carbon neutrality. An important component of NBS is the creation of additional carbon sinks in various natural ecosystems such as forests, grasslands, wetlands, and agricultural systems (Roe et al. 2019). A growing consensus among scientists and policymakers is that tree growth is a cost-effective and most efficient strategy to capture and store atmospheric CO_2 (Bayen et al. 2016). With United Nations Framework Convention on Climate Change (UNFCCC) stressing on carbon sequestration, carbon capture and storage by trees and their wood products are widely recognized as a climate mitigation strategy (Rathore et al. 2021). Reliable estimates of carbon storage are required to calculate carbon emission reduction incentives and implementation of initiatives such as Reducing Emissions from Deforestation and Degradation (REDD +) and the clean development mechanism (CDM; Kenzo et al. 2020) which would also help towards achieving some of the Sustainable Development Goals (SDGs) of the United Nations.

Forest ecosystems are natural reservoirs of terrestrial carbon storage (Sullivan et al. 2020). However, forests have been tremendously stressed due to climate change and various anthropogenic pressures which led to loss of forest cover as well as the carbon sequestered by those forests. As per the Global Forest Resources Assessment (GFRA) report (Food and Agriculture Organization - FAO 2020), about 178 million hectares of forest have been lost globally since 1990 and from tropical forest degradation from 2005 to 2010 alone has released 2.1 billion tonnes of CO_2 (Chayaporn et al. 2021; Pearson et al. 2017). With efforts towards climate mitigation gaining momentum among policymakers and governments, carbon sequestration by means of afforestation and reforestation programmes by planting long-term rotational tree crops as ways to earn carbon credits for many countries has attracted significant attention as both carbon storage and wood production can be combined (Behera et al. 2020). Extensive afforestation efforts have also been implemented in areas considering the suitability of future climates to forest cover (Bastin et al. 2019; Friggens et al. 2020). Reforestation is also singled out as a most important option that can contribute to about 50% of the total carbon sequestration (Griscom et al. 2017). Reforestation strategies can take many forms like assisted natural regeneration, establishing forest plantation, intensive weeding, and thinning (Brown et al. 2020). Plantation forests therefore have a crucial role to play in global carbon cycling and climate regulation.

12.2 Plantations: An Overview

As per the GFRA report (FAO 2020), plantation forests are those forests that are intensively managed, comprising of one or two species, evenly spaced, evenly aged, and established for productive purposes. About 44% of the plantations are mainly comprised of introduced species. Plantation forests currently occupy about 131 million hectares covering 3% of the global forest area and 45% of the total area of planted forests. South America has the highest share of the world's plantations, while Europe has the lowest share (FAO 2020). Plantations cover about 56.8 million hectares in the tropics (Kenzo et al. 2020; Payn et al. 2015). *Pinus* species are often the most planted, while other genera (*Cunninghamia*, *Eucalyptus*, *Populus*, *Acacia*, *Larix*, *Picea*, *Tectona*, *Castanea*, and *Quercus*) are also commonly planted (Kanninen 2010). The choice of the species planted depends on the purpose of plantation and plantations are mostly established for protective (e.g. *Populus*, *Larix*) or productive purposes (e.g. *Tectona*, *Castanea*; Kanninen 2010). Plantations are mostly established to complement the natural forests or act as an alternative for timber and fuelwood production so as to minimize the logging pressure on natural forests (Jinadari et al. 2021). As plantations usually have fast growth due to silvicultural practices and management, they sometimes outweigh the natural forests for some desired benefits (Arora et al. 2014). For example, plantations are expected to take over the role of natural forests in meeting the demands of timber and other wood supplies (Chayaporn et al. 2021).

Besides the commercial benefits, different forms of plantations which vary in composition, structure, and management are established for ecosystem restoration on degraded or deforested landscapes (Campoe et al. 2010). Native species plantations are often favoured due to rapid tree growth and biomass accumulation in such degraded landscapes where invasive grasses may pose a threat to natural forest regeneration (Brancalion et al. 2019; Brown et al. 2020). Even on nutrient-poor soils, tree plantations could act as a source of extra income to farmers, thereby improving their socio-economic conditions (Shepherd and Montagnini 2001). Plantations with appropriate land engineering measures are known to reverse the process of degradation and restore productivity (Dabas and Bhatia 1996; Gao et al. 2018). However, ecosystem restoration via tree planting is often done as monoculture plantations, rather than mixed-species plantations due to limitations on costs and human demands (Richards et al. 2010). Nevertheless, mixed-species plantations are known to be more resistant and resilient to stressors (like extreme weather events, pest outbreaks) and contribute to more productivity and stability than monoculture plantations (Pretzsch and Schutze 2016). In addition, mixed-species plantations add to the habitat diversity, thereby increasing the biodiversity of associated microbes and fauna (Gong et al. 2021; Kooch et al. 2017). Mixed-species plantations provide more diverse wood products and non-timber forest products (NTFPs) than monoculture plantations which add to the financial security of the farmer (Shepherd and Montagnini 2001). Mixed-species plantations are known to produce more biomass per unit zone than monoculture plantations due to the stratified utilization of resources and reduced competition (Montagnini et al. 1995). Mixed-species plantations have higher functional diversity and provide a range of ecosystem services, besides just wood production (Schuldt et al. 2018). Therefore, in order to have a wide range of ecological benefits (such as biodiversity protection, soil rehabilitation, wood production, and restoration of degraded lands), mixed-species plantations may be more preferable than monocultures (Novor and Abugre 2020). Mixed-species plantations are also known to bring more socioeconomic benefits and have more marketing opportunities than monocultures (Messier et al. 2022; Williams 2014).

Very often, besides being considered a mere ecosystem restoration measure, tree planting is also done for its crucial role in enhancing the terrestrial carbon sink (Wang et al. 2019). Carbon sequestration is one of the most desired benefits which are seen as an efficient and cost-effective climate mitigation strategy and a pathway towards achieving carbon neutrality.

12.3 Tree Plantations and Carbon Sequestration

Carbon storage is regarded as a standard metric to assess the ecosystem services and is an indicator of an ecosystem's resilience to climate change (Hoque et al. 2021). Carbon sequestration is a process in which plants absorb atmospheric CO_2 which is converted into carbohydrates through photosynthesis and stored as plant biomass. Plants are known to absorb 3.67 units of CO_2 to form one unit of carbon stored in plant tissues (Chauhan et al. 2016). For every 2.2 tonnes of wood produced, one tonne of carbon is sequestered (Chaturvedi 1994; Dabas and Bhatia 1996). When a plant dies, the live biomass gets converted into detritus, and a fraction of the carbon enters the soil after decomposition (Chauhan et al. 2016). Plantations are therefore viewed as the quickest and cost-effective mechanism to absorb atmospheric CO_2 and store in its varied pools such as aboveground biomass, belowground biomass, and detritus comprising of deadwood and forest floor litter, soil, and wood products (Justine et al. 2017; Stinson et al. 2011; Yen et al. 2020). However, the carbon storage of any plantation depends on many factors such as the species planted, its sequestration potential, age, structure, management, site history, and local climate. The carbon stocks of some plantation types are presented in Table 12.1. A plantation aids in carbon sequestration not only by stocking the carbon within its own ecosystem, but also by reducing the timber demand on old-growth forests, thereby conserving the carbon stocks of large-sized trees (Lutz et al. 2018; Mildrexler et al. 2020).

Short-rotation tree plantations have high ability to accrue substantial amounts of carbon within a limited time period. They are fast-growing and give high yields to the timber industry and intensively managed plantations yield more biomass than natural forests, thereby reducing the pressure on the latter (Prasad et al. 2012). The wood products derived from these plantations (such as construction materials, wooden frames, and baskets) may act as a long-term carbon storage pool (Behera et al. 2020). Short-rotation plantations (e.g. *Casuarina*, bamboo) are mostly established due to their fast growth rates, maximized wood production in a shorter span of time (stored as durable wood products), and higher carbon sequestration potential than slow-growing plantations/naturally regenerating forests (Dabas and Bhatia 1996). However, there are also reports that state that if wood is harvested in short-rotation plantation and is burnt (*e.g.* as fuelwood), then the stored carbon gets rapidly lost (Ajit et al. 2013; Arora et al. 2014). Long-rotation plantations (e.g. *Tectona grandis*, *Araucaria angustifolia*), on the other hand, mainly consist of slow-growing species but have potential for longer-term carbon storage. In many cases, long-rotation plantations contain higher aboveground carbon stocks than naturally regenerated secondary forests (Brown et al. 2020). Long-rotation plantations also enrich soil organic carbon stocks due to the production of large volumes of litter.

Compared with monoculture plantations, mixed-species plantations are known to enhance the size of the soil organic carbon pool (Gong et al. 2021). Long-rotation plantations are perceived as an attractive climate mitigation strategy as they can be grown on deforested or degraded lands, require less-intensive management, have higher timber value, and sequester more carbon (Brown et al. 2020).

Substantial amounts of carbon are sequestered by plantations in both tropical and temperate regions (Malhi et al. 2008), although the potential for carbon sequestration is greater in the tropical zone than in the temperate zone (van Minnen et al. 2008). Despite facing huge pressures such as deforestation, land-use change, and land degradation, the potential of tropical plantations to sequester carbon is higher due to their higher productivity per area and time favoured by optimum climatic conditions (Dabas and Bhatia 1996). Often, land engineering measures are required along with plantation establishment to sequester more carbon in the temperate region (van Minnen et al. 2008).

Table 12.1 Carbon storage in biomass and soil pools of different plantations

Plantation	Country	WBC	SD	SOC	Source
Pinus patula, *Tectona grandis*	Colombia	99.6, 85.7	0–50	168.7, 54.8	Usuga et al. (2010)
Monoculture and mixed-species (*Castanopsis hystrix*, *Pinus massoniana*)	China	46.7–106.4[a]	0–60	186.56–266.55	He et al. (2013)
Different plantation types (*Populus deltoides*, *Eucalyptus tereticornis*, *Dalbergia sissoo*, *Mangifera indica*, *Litchi chinensis*, *Prunus salicina*)	India	4.51–43.39			Kanime et al. (2013)
Different plantation types (*Theobroma cacao*, *Elaeis guineensis*, *Hevea brasiliensis*, *Citrus sinensis*)	Ghana	21.7–213.6[b]			Kongsager et al. (2013)
Eucalyptus tereticornis	India	81.33[b]	0–100	74.69	Arora and Chaudhry (2014)
Tectona grandis	India	73.58[b]	0–100	55.46	Arora and Chaudhry (2014)
Syzygium cumini	India	63.64[b]	0–100	77.72	Arora and Chaudhry (2014)
Populus deltoides	India	0.5–90.1[b]	0–30	63.9–83.8	Arora et al. (2014)
Tectona grandis	India	32.0–111.8			Behera and Mohapatra (2015)
Roadside	Bangladesh	56.75–380.11 (mean 192.8)			Rahman et al. (2015)
Zanthoxylum bungeanum	China	0.02–7.56	0–30	75.22–80.06	Cheng et al. (2015)
Hevea brasiliensis	India	16–105.73			Brahma et al. (2016)
Dendrocalamus strictus	India	8.39–49.08[b]			Kaushal et al. (2016)
Pinus patula	Nepal	109.5–158.5 (mean 136.4)	0–30	77.31	Dangal et al. (2017)
	Côte d'Ivoire	22.7–250.2			N'Gbala et al. (2017)

(continued)

Table 12.1 (continued)

Plantation	Country	WBC	SD	SOC	Source
Theobroma cacao, *Tectona grandis*, and secondary forest					
Hevea brasiliensis	China	2.8–98.5	0–100	107.1–170.5	Yanci et al. (2017)
Pinus massoniana	China	85	0–100	237.05	Justine et al. (2017)
Pinus taeda	Mozambique	215.4	0–50	135.2	Guedes et al. (2018)
Eucalyptus grandis	Mozambique	261.2	0–50	138.8	Guedes et al. (2018)
Caragana intermedia	China	14.27			Li et al. (2018)
Eucalyptus camaldulensis	Ethiopia	15	0–30	142.5	Kendie et al. (2019)
Timber (*Aucoumea klaineana*, *Cedrela odorata*, *Tarrietia utilis*, *Terminalia ivorensis*)	Ghana	159.7[b]			Brown et al. (2020)
Eucalyptus cloeziana	Mozambique		0–60	62.18	Magalhães et al. (2021)
Pinus sp.	Mozambique		0–60	76.88	Magalhães et al. (2021)
Eucalyptus	Sri Lanka	175.91[b]			Amarasinghe et al. (2021)
Tectona grandis	Thailand	45.4[b]			Chayaporn et al. (2021)
Pinus patula	Ecuador	62.3	0–45	258	Dahik et al. (2021)
Areca catechu	India	36.48		61.76[c]	Dabi et al. (2021)
Citrus sinensis	India	13.37		29.27[c]	Dabi et al. (2021)
Hevea brasiliensis	India	43.1		46.73[c]	Dabi et al. (2021)
Areca catechu	India	7.8–20.5	0–100	100.63–125.77	Das et al. (2021)
Bambusa tulda	India	36.34–64			Devi and Singh (2021)
Dendrocalamus longispathus	India	50.11–65.16			Devi and Singh (2021)
Pinus nigra	Turkey		0–100	61.08–85.96	Güner and Güner (2021)
Tectona grandis	Sri Lanka	36–43.1[b]			Jinadari et al. (2021)
Eucalyptus tereticornis	India	18.7–96.2			Kumar et al. (2021)

(continued)

Table 12.1 (continued)

Plantation	Country	WBC	SD	SOC	Source
Tectona grandis	India	109.1	0–30	91.5	Kothandaraman et al. (unpublished)
Hevea brasiliensis	India	204.6	0–30	77.3	Kothandaraman et al. (unpublished)
Areca catechu	India	29.5	0–30	63.4	Kothandaraman et al. (unpublished)

WBC woody biomass carbon (Mg C/ha), *SD* soil depth (cm), *SOC* soil organic carbon (Mg C/ha)
[a]Total vegetation carbon
[b]Aboveground biomass carbon
[c]Soil carbon

Establishment and management of plantations by local communities which would supplement their incomes is often an important topic of discussion during climate change negotiations and calculations of carbon credits (Avtar et al. 2014; Dabi et al. 2021). However, several aspects should be considered before implementation of any such scheme in order to prevent an environmental and/or socio-economic disaster(s). Plantations with the objectives of carbon sequestration and sustainable development for climate change mitigation should be best established on a degraded land or an abandoned agricultural landscape (Ayers and Huq 2009; Verchot et al. 2007). For example, abandoned agricultural lands can be used to establish plantations for carbon and economic gains, rather than converting them to grasslands (Cotter et al. 2009; Li et al. 2008). However, the expansion of plantations into areas of old-growth forests would lead to higher emissions of carbon than that sequestered (Gibbs et al. 2008; Kongsager et al. 2013). In addition, some recent studies have reported a decrease in soil carbon pool with the establishment of plantations and have suggested that ecosystem-level carbon storage must be considered before using plantation as a climate mitigation strategy (Friggens et al. 2020; Ibarr et al. 2022). While some studies (Chen et al. 2017; Veloso et al. 2018) have reported the recovery of soil carbon stocks with time, other studies did not record increase in soil carbon stocks even after 50 years (Liao et al. 2012; Tau Strand et al. 2021). The rate of carbon sequestration by plantations also varies with seasons. Plantations are known to have had 4–9% higher carbon sequestration rates than natural forests during the wet season, but the same declines to about 29% in the dry season (Osuri et al. 2020). Therefore, the number of wet months/dry months and potential future climate scenarios in the region of interest should be taken into account as these would influence the carbon sequestration potential of plantations. Thus, tree plantations with the aim of carbon sequestration need to be planned with a broader perspective considering the whole ecosystem-level consequences it may have rather than focusing only on biomass production.

12.4 Effects of Management Practices on Carbon Sequestration

Management practices play a crucial role in determining the size of the carbon pools and preparation of carbon budgets (Iovino et al. 2021). The effect of stand management is typically expressed in terms of the carbon stock (He et al. 2013). Management regimes can both decrease or increase carbon sequestration (Pan et al. 2011). Appropriate management practices are necessary to not only avoid a decline in carbon sequestration but also to enhance the sinking strength of the ecosystem (Zarin 2012). The effects of some management practices on the carbon sequestration potential of plantations are discussed below.

12.4.1 Species Planted

The choice of tree species planted is a key management decision which greatly influences carbon sequestration. The carbon sequestration potential of a tree species is determined by the time required for it to attain maximum biomass. If the objective of the tree plantation is carbon mitigation, then slow-growing plantations with their long-lasting wood products would be a better option for long-term carbon storage (Dewar and Cannell 1992). Planning species mixtures for mixed plantations is also a critical step in management that influences productivity (He et al. 2013).

12.4.2 Spacing

Initial spacing among tree individuals affects the growth rates and tree sizes as it determines the intensity of competition among tree individuals for resources (Harrington et al. 2009). A close spacing may lead to branch mortality and production of higher quality stem volume (Rais et al. 2014). The carbon sequestration potential of a species is interrelated with wood production which is greatly dependent on the initial spacing (Erkan and Aydin 2016). Appropriate tree spacing reduces the fuel load, thereby protecting the plantations from fires (Saharjo 1997). It is very important to conduct spacing studies before taking key decisions on planting density for achieving timber- and carbon-based objectives (Cox et al. 2021).

12.4.3 Site Preparation

Stand growth is highly influenced by site quality. Sites which lack water and nutrients may be amended by irrigation and fertilizer application to accelerate biomass accumulation (Mead 2005). Site preparation and treatments may lead to biomass accumulation and carbon sequestration, although the latter may depend on several factors (Pietrzykowski et al. 2021). Site preparation and treatments by adopting physical, chemical, and/or mechanical means may lead to biomass production but may often lead to soil disturbances and soil carbon losses (Jandl et al. 2007).

In order to consider site preparation measures for enhanced carbon sequestration, trials and studies must be conducted to assess the impact(s) on all of the carbon pools, including soil (Böttcher and Lindner 2010).

12.4.4 Age

Carbon storage typically increases with the age of the plantations (Dabi et al. 2021; Tamang et al. 2021). However, the carbon sequestration potential may vary with the age class and growth stages (Houghton 2005) as in general, the carbon sequestration potential is higher in younger plantations due to high growth rates than the mature plantations. Therefore, chronosequence studies on tree plantations are very crucial to assess and report changes in carbon accumulation and growth stage and also to predict future carbon trajectories (Justine et al. 2017).

12.4.5 Rotation Length

Rotation length refers to the time from stand establishment to harvest. Rotation length directly influences the distribution of age classes and determines the timber yield carbon storage (Kaipainen et al. 2004). Rotation length, in general, influences both biomass and soil carbon stocks and also the harvested wood products. Changing the rotation length is a way of managing carbon sequestration in plantation systems (Böttcher and Lindner 2010).

12.4.6 Thinning Intensity

Thinning is an important management practice that manages distribution patterns in a stand. Intensive thinning or thinning at a wrong timing may reduce tree density and deplete the carbon stocks of biomass, deadwood, and forest floor litter pools (Jimenez and Navarro 2016). On the other hand, optimal intensity of thinning done at an appropriate timing would increase the stand volume and carbon stock (Nyland 1996). Appropriate thinning could maximize the carbon sequestration potential by making the site resources available to the fewer tree individuals and reducing the vulnerability of the ecosystem to natural disturbances. For example, thinning reduces the fuel load which protects the stand from fires, and it also reduces stem and branch breakages due to wind, snow, etc. (Böttcher and Lindner 2010). Overall, thinning exerts a positive effect on carbon sequestration (Iovino et al. 2021).

12.4.7 Fate of the Products

Thinning and harvest operations generate a significant pool of wood products that contain carbon that was originally stored in the biomass (Eriksson et al. 2007).

Thinning and harvest operations mimic the process of natural mortality and the latter may lead to a greater carbon loss (Böttcher and Lindner 2010). The fate of the wood products produced and their lifetimes and recycling rates are often used in modelling to calculate carbon flows in plantations (Masera et al. 2003). In most cases, the wood and wood products produced are used in the making of wooden panels and construction materials which serve as a means of long-term carbon storage (Jasinevičius et al. 2015).

12.5 Caveats in Tree Planting

Tree planting is often seen as a simple NBS that can concurrently mitigate a range of problems such as climate change, land degradation, soil erosion, and poor socio-economic status. While tree plantations that are well-planned and well-executed are a great part of the global effort to harvest environmental and socio-economic benefits, ill-planned and improper tree planting initiatives may have unintended and undesirable consequences. It is important to take stock of the caveats in tree planting before making careful and wise decisions in order to achieve the desired objectives, considering the huge efforts and costs involved in these projects.

12.5.1 Inappropriate Land Selection

Several countries have proposed ambitious pledges to increase forest and tree cover to mitigate climate change. However, the availability of suitable lands and regional variations to set up plantations are constraints that are mostly ignored by policymakers (Gopalakrishna et al. 2022). Tree plantation projects carried out by governments in the wrong places are unlikely to receive public support due to the loss of ecosystem services and associated livelihood incomes, which may trigger sociocultural conflicts (Nilsson and Schopfhauser 1995). If tree plantation is carried out in the wrong landscape, for example, where trees did not exist before such as grasslands and savannahs, it would affect the local biodiversity and several other key ecological processes like fire and herbivory. As the belowground structures of grassland vegetation have the potential to store more carbon than trees (Ratnam et al. 2020), clearing grasslands for plantation not only negates the carbon benefits from the plantation but creates a 'carbon debt,' contrary to the aim of tree planting.

12.5.2 Loss of Diversity

Tree plantation efforts can play a great role in conserving biodiversity, if carried out on degraded or deforested lands by providing shade, resources, and habitats and also by minimizing the pressures on natural forests (Newmark et al. 2017; Griscom et al. 2017). However, tree plantations done with the sole purpose of increasing tree cover/ carbon sequestration typically have a lower diversity (Holl and Brancalion 2020).

Bio-perversities, defined as ‘negative outcomes for biodiversity,’ can potentially occur in three ways as a result of inappropriate plantation projects: (i) if natural vegetation is cleared to make way for plantations; (ii) if a newly planted species turns out to be invasive in the future; and (iii) if the newly established plantations adversely affect the ecological processes of the landscape (e.g. by altering fire or hydrological regimes; Lindenmayer et al. 2012). Loss of biodiversity may also lead to the loss of some ecosystem services (Wall and Nielsen 2012).

12.5.3 Potential Invasion

Some of the newly planted tree species, when established outside of their native range, might become invasive in the future. In such a case, plantation projects may lead to unforeseen consequences like genetic swamping and biotic homogenization, and some of these effects may be irreversible (Olden et al. 2004; Richardson and Rejmanek 2004). In addition, the newly introduced species may affect the indigenous plant community, structure, and ecosystem services due to allelopathic and greater resource acquisition propensities, which may lead to local extinctions (Omomoh et al. 2022).

12.5.4 Species Incompatibility

Species utilize space, light, water, soil nutrients, and other environmental factors to grow. In case of mixed-species plantation, it is important to check for species compatibility before planning large-scale plantation projects. If the species are incompatible, they might compete for resources and hinder each other by ways of allelopathic effect, shading the slow-growing species, etc. (Otsamo 2000). Therefore, misconceived mixed-species plantation projects may fail to achieve the set objectives (Novor and Abugre 2020).

12.5.5 Disruption of the Hydrological Balance

Establishment of tree plantation sans proper prior environmental assessment has been reported to severely impact the water balance at different spatial and temporal scales (Farooqi et al. 2021). Jackson et al. (2005) noted that globally, plantations decreased the stream flow by 227 mm per year and about 13% of streams dry out for at least 1 year. Inappropriate plantations, especially with exotic species result in depletion of soil moisture and severe desiccation in deep soil layers in semi-arid and semi-humid regions (Chen et al. 2008; Gao et al. 2018). Water levels in streams and deep soil layers are also rapidly lost by fast-growing tree individuals of plantations due to their high transpiration rates (Feng et al. 2016). Ecosystems with improper hydrological balance may not be able to sustain plantations for a long-term given their high transpiration demands.

12.5.6 Soil Nutrient Depletion

Besides increased uptake of water, plantations also require additional soil nutrients and base cations for attaining optimal growth. Such increased nutrient demands along with loss of soil moisture typically result in altered patterns of nutrient cycling, soil acidification and soil salinization (Ewel et al. 1991). Soils under plantations are usually found to be more acidic due to the production of acidic litter, root and canopy leachates, etc. (Jackson et al. 2005). The depletion of soil nutrients in a relatively short span of time lowers soil fertility in the short term and productivity of plantations in the long-term (Lindenmayer et al. 2012). These effects may manifest more seriously if plantations are established without trials on already nutrient-poor soils (Montagnini and Porras 1998).

12.5.7 Lack of Maintenance and Monitoring

Lack of proper maintenance of planted trees often results in the failure of plantation projects, despite large expenditures and efforts. For instance, following the plantation of mangrove trees in Sri Lanka after the Indian Ocean tsunami, it was found during reassessment after 5 years of plantation that only <10% of the trees have survived in about 75% of the sites due to improper project planning and lack of maintenance of tree seedlings (Holl and Brancalion 2020). Periodic monitoring of plantations is also necessary to protect it from anthropogenic disturbances and assess its growth and impacts on the environment.

12.5.8 Sociocultural Conflicts

Displacement of native communities and/or lack of community participation in tree planting projects often lead to loss of native livelihood support that most often result in sociocultural conflicts. Another root of this constraint is that even in cases involving community participation, due to language barriers and/or unfamiliarity with technicalities, the local or tribal people are shunned by the authorities (Ratnam et al. 2020). The lack of stakeholder engagement and social inequity triggers sociocultural conflicts which prevent the plantation projects from achieving the desired success (Di Sacco et al. 2021).

12.5.9 Ecological Uncertainties

Most tree plantation projects set targets for how many seedlings/saplings to plant, rather than trying to assess how many would be able to survive over time in order to get the desired objectives (Holl and Brancalion 2020). This is important because huge uncertainties remain about how many trees could survive future droughts, pest outbreaks, fires, or any unforeseeable natural disaster (Anderegg et al. 2013). Also, many species may express maladaptation to the newly introduced sites (Ratnam et al. 2020). Interactions among species may also determine tree survival and rate of carbon uptake. Lack of adequate funding to continue the management practices and market price fluctuations also hinder the progress of plantation projects (Qin et al. 2021). Failure to have prior plan of management responses to such incidents and lack of inclusion of uncertainties in decision-making also affects plantation programmes.

12.6 Future Directions

Tree plantations can be better established and managed from the lessons learnt in the past and careful planning in the future. Adopting an integrated framework with a wider perspective would help in accomplishing the set targets through tree plantations without further deteriorating the environmental quality. Some of the important aspects/measures to be considered while establishing tree plantations are listed below.

12.6.1 Setting Realistic Targets as per Land Availability

The lands should be carefully identified considering the previous land-use history, socioeconomic, financial, and operational factors for tree plantation projects. Misclassification of savannahs, grasslands, and shrub lands as degraded/deforested lands should be avoided (Ratnam et al. 2020). According to Zeng et al. (2020), even though 121 million hectares of land are classified as degraded and available for reforestation in Southeast Asia, only 0.3–18% are actually feasible for such projects. The carbon neutrality targets and climate action plans by means of tree plantations should be reasonably set considering the suitable land availability and other environmental and economic constraints (Gopalakrishna et al. 2022).

12.6.2 Appropriate Species Choice

Tree species selected for the purpose of plantation should be based on a sound understanding of the surrounding land-use matrix, species' stand dynamics, and development (Cox et al. 2021). If the objective of the plantation is carbon mitigation in a deforested area, for example, and there is no foreseeable threat to biodiversity in the neighbouring area or other ecosystem services, then species that are well-known to have high carbon sequestration potential can be planted (Diaz et al. 2009; Hamilton et al. 2010). In case of mixed-species plantations, species' compatibility can be checked by conducting spacing trials as spaces create less competition and less canopy overlap among species (Novor and Abugre 2020).

12.6.3 Risk Assessments

Risk assessments before establishing plantations on a large scale help in lowering the uncertainties and increasing the chances of success of a project. For example, risk assessments can help to predict the performance of an introduced species in a new location, tendency of the species to become invasive, and any possible tradeoffs with ecosystem services (Lindenmayer et al. 2012). Plantations established after proper evaluation of risks and those that are well-managed are known to improve ecosystem functioning such as preventing soil erosion, salinity, etc. and also help in the conservation of some native biota by providing habitats (Reino et al. 2010). Accurate quantification of ecosystem-level biogeochemical processes and carbon fluxes of all the pools including that of harvested wood products is also essential to predict the carbon sequestration and storage potential of the plantation (Friggens et al. 2020; Moomaw et al. 2020). This would in turn help in the preparation of carbon budgets and carbon incentives (Chayaporn et al. 2021). Moreover, preparing in advance on the management responses to any catastrophe is also a proactive and protective measure. The effects of timing, intensity, and frequency of different management practices (like thinning, harvesting) on carbon storage and ecosystem resilience of the plantations must also be well-tested before application on a large-scale (Altieri et al. 2015; Kumar et al. 2020).

12.6.4 Ecological Monitoring

Periodic maintenance and monitoring of plantations and the surrounding areas are necessary to provide early warnings of any undesired consequences and therefore to take any necessary interventions (in the cases of invasion, site disturbances, etc.; McNeely et al. 2003). Periodic recording of the biophysical parameters helps to precisely estimate the growing biomass and carbon stock, thereby to plan carbon credits (Kendie et al. 2019). Such documentation and record-keeping would provide insights on stand dynamics and effects of different management interventions, which can be used in the amelioration of future plantation projects (Cheng et al. 2015).

12.6.5 Encouraging Community Participation

Sociocultural conflicts are significantly lower in community-based plantations than those in which the local communities are excluded from participation (Shin et al. 2007). Plantation projects should be sensitive to the needs and opinions of the local people (Brown et al. 2020). Providing training to the local communities to overcome the language and technicality-related barriers, and appreciating their participation through equitable sharing of benefits would reduce social inequity and enhance the community’s economic sustainability (Oldekop et al. 2019).

12.6.6 Integrative Approach from Collaborative Research

The integration of remote sensing and empirical modelling approaches to the field-based inventories would help in precise quantification of biomass and carbon stocks (Dabi et al. 2021). Incorporating land-use and land cover data into modelling can help predict landscape changes in the future and in shaping plantation projects accordingly to maximize the regional carbon storage (Hoque et al. 2021). To ensure the delivery of maximum benefits from future plantation programmes, collaborative research support is needed from various experts of different disciplines such as ecology, economics, policymaking, ethnobotany, modelling, remote sensing, sociology, and management. The regional data across different parts of the world could be digitized and shared across a common platform/repository to benefit various stakeholders which would help in betterment of existing plantation models or adoption of new models, especially in developing countries.

12.7 Conclusion

Tree plantations established after appropriate risk assessments with the objectives of delivering balanced ecosystem services and socio-economic benefits would play an immense role in global climate regulation. Besides, such tree planting initiatives would also contribute towards achieving SDGs 1 (No Poverty), 10 (Reduced Inequalities), 13 (Climate Action), 15 (Life on Land), and 17 (Partnerships for the Goals) of the United Nations. However, considering the various constraints in tree planting, in particular, the suitable land availability, tree plantations cannot be a silver bullet towards achieving carbon neutrality, but it can certainly help to cover the extra mile. This needs to be realized in order to overcome the obsession with tree plantation projects in target-setting and environmental policymaking for climate action. Rather, climate action plans should be diversified with substantial contributions from energy and industrial sectors alongside well-planned tree plantation projects to achieve carbon neutrality.

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Role of Protected Area in Conservation and Sustainable Management of Biodiversity: An Indian Perspective

13

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Abstract

Protected areas (PAs) are the terrestrial or marine regions that are preserved for conserving biodiversity and their habitats to serve a range of socioecological functions including scientific research and education, protection of wildlife, conservation of biodiversity, and securing a range of ecological goods and services. India has strong legislation for the protection and conservation of biodiversity through the protected area network (PAN) through government investment. In India being a developing country, PA management has a great challenge due to the rapidly growing human population and their higher dependency on natural forests for their sustenance needs and livelihood security, political and economic instability, and higher poverty. Local socioeconomic conditions, the long-term scientific ecological studies on biodiversity in buffer and transition zones, development of assessment and monitoring techniques, and evaluation of economic and ecological benefits are some of the key aspects that become more important to determine the success of PAs towards environmental and socioeconomic sustainability. Therefore, the present chapter focused on the scientific, environmental, socioeconomic, and cultural values of Indian PAs and their specific role in the conservation of biodiversity.

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Keywords

Biosphere reserves · National parks · Wildlife sanctuary · Protected area network · Biodiversity conservation

13.1 Introduction

Biodiversity is the variety and variability among flora, fauna, and microorganisms that reflect the organization of organisms at different levels (NRC 1999). Biodiversity is considered an important resource as it provides a range of products and services including food security, health care, and industrial raw materials that have led to upgraded standards of life (Gadgil 2003). Besides, it holds ecological significance through pollutant recycling, nutrient cycling, and climate regulation and provides opportunities for recreation and scientific studies, aesthetic, and monetary benefits through tourism (Norton and Ulanowocz 1992). India has distinctive biodiversity exceeding 45,000 plant and 91,000 animal species (Reddy et al. 2016) due to its diverse physiographic, edaphic, and climatic conditions (Kumar and Saikia 2020). Globally there are 17 mega biodiversity nations; India ranks sixth among them (Mittermeier and Mittermeier 2005) and also has four biodiversity hotspots with high endemism and habitat loss (Saikia and Khan 2018). India occupies only 2.5% of the total land surface of the earth, but it contributes ~8% of overall biodiversity (Joshi 2019). It has ~21.67% forest cover (ISFR 2019) which compliments ~1.8% of the world's total forest area (Maan and Chaudhry 2019). Global changes, including human-induced climate change, environmental pollution, overexploitation of natural resources, destruction of natural habitats, deforestation, and invasive species are the main reasons for biodiversity loss worldwide (Mantri et al. 2020). Habitat change due to destruction and fragmentation by human development and modernization are the most direct reasons for overall biodiversity loss. Other significant causes include human disturbance and changes in ecosystem structure due to the invasion of invasive weeds and fauna (Kettunen and ten Brink 2006) that have adequately curtailed biodiversity conservation measures (Gillespie 1997). The changing climate is also responsible for the shift of distribution ranges of various species of plants and animals and for their local extinction in various regions of India (Gokhle 2015). Besides high population densities, population pressure, poverty, rapid economic growth, industrialization, urbanization, agricultural intensification, and the development of infrastructures including roads, power lines, railways, etc. are the most serious threats to biodiversity loss in the tropical regions (Bargali et al. 2019; Karanth and de Fries 2010). Developmental projects mainly mining and power plants in India predominantly in mineral-rich states such as Jharkhand, Odisha, and Chhattisgarh have posed serious risks to wildlife habitats over the past many decades resulting in biodiversity loss (Gokhle 2015). On the other hand, the Indian Himalayan forests are severely affected by landslides in the hilly regions and floods in the plains, earthquakes, cloudbursts, heavy rain falls, and different biotic interferences (Saikia et al. 2017). There is an enormous anthropogenic pressure on the forests of India, and per capita forest availability and productivity of resources are very low among the world, making the conservation of biodiversity a very challenging task (Maan and Chaudhry 2019).

Protected areas (PAs) are well demarcated terrestrial and marine areas that are legally recognized for long term conservation of biodiversity and natural resources. These areas are preserved primarily for conserving biodiversity and geological features in their natural habitats (Dudley 2008). PAs serve as a major tool for the conservation and protection of biodiversity; they are considered vital cornerstones for sustainable development. They provide various environmental and economic benefits and generate opportunities for investment and employment. These PAs are an important storehouse of ecological and sociocultural capitals to support the livelihood security and human welfare of millions of forest-dependent communities of the world. PAs in most developing countries are considered as the regions with the highest biodiversity with legal protection (UNEP-WCMC, IUCN 2016) where human activities are restricted, and the exploitation of natural resources is within limits. An additional benefit of PAs includes climate regulation, pollution control, and guards against environmental disturbance (Secretariat of the CBD 2008). According to the record published by the World Database on PAs, there are 217,155 designated PAs globally from 244 countries of which 202,467 are terrestrial and 14,688 marine PAs (UNEP-WCMC, IUCN 2016). PAs can be categorized as follows.

13.1.1 Category Ia (Strict Nature Reserve, SNR)

SNR are the PAs established to conserve biodiversity and the different geomorphological attributes of the area where anthropogenic disturbances such as recreational visits and developmental projects are strictly prohibited and resource uses are strictly restricted to ensure the preservation and conservation of biodiversity. It serves as an essential recommended area for scientific monitoring, assessment, and research (IUCN 2008).

13.1.2 Category Ib (Wilderness Area)

These PAs are modified to some extent depending on the need. No human intervention and settlements are permitted within the area. They retain their natural characteristics and aim for long term environmental conservation goals without any significant human disturbances and keeping it free from infrastructural development, with a predominance of natural processes (IUCN 2008).

13.1.3 Category II (National Park)

These are large natural areas consisting of large-scale species diversity with characteristic ecosystems set aside for conservation of natural habitats, flora, and fauna within the geographical regions. Wildlife sanctuaries also fall into IUCN category II, limited use of resources is allowed in these PAs (IUCN 2008).

13.1.4 Category III (Natural Monument)

These PAs are recognized for the protection of specific natural features, their associated biodiversity, and habitats. These can be geomorphological or living elements with high visitor value such as rock forms, waterfalls, sacred groves, oldest living trees, etc. (IUCN 2008).

13.1.5 Category IV (Habitat/Species Management)

These PAs are mainly concerned to protect particular species or habitats. The main priority of these PA is conservation and restoration of species and habitats (IUCN 2008). Conservation of specific species helps in indirect protection of other indigenous species (Roberge and Angelstam 2004).

13.1.6 Category V (Protected Landscape/Seascape)

These PAs have distinct characteristics with significant ecological, sociocultural, and scenic value developed with time and human-nature interaction. These PAs are categorized to protect and conserve the environment through traditional management practices. It maintains the balance between humans and the natural world in terms of sustainable development (IUCN 2008).

13.1.7 Category VI (PA with Sustainable Use of Natural Resources)

These are large areas in their natural conditions. The main aims of these areas are natural resource management and nature conservation; simultaneously natural resources are utilized in sustainable ways for nonindustrial purposes by local communities. It promotes mutual benefits of conservation and sustainability and promotes economic security to local livelihoods (IUCN 2008).

Unfortunately, despite the significant ecological and economic significance of PAs, their importance is greatly undervalued that resulting in inadequate protection and management. PAs are facing tremendous challenges of effective management that result in biodiversity loss with increased human population and greater demand for natural resources (Kideghesho et al. 2013). Therefore, the present study focused on the scientific, environmental, socio-economic, and ethnic values of Indian PA and their specific role in the conservation of biodiversity and future research perspectives.

13.2 Protected Area Network (PAN) of India and Its Present Status

Around 15% of the total global land area is under PAs, while India officially protects ~5% of its total geographic area covering almost all the ecoregions (Dinerstein et al. 2017). National park, wildlife sanctuary, conservation reserve, and community reserve are the four legal categories of PAN in India with a total of 981 (171,921 sq. km) PAs including 104 (43,716 sq. km) national parks, 566 (122,420 sq. km) wildlife sanctuaries, 97 (4483 sq. km) conservation reserves, and 214 (1302 sq. km) community reserves covering 5.03% of the total geographic areas of the country (WII 2021) (Table 13.1) as on 1 August 2021.

Greater than 70% of the community and conservation reserves are in three Indian states, and union territories of which 122 community reserves are in Meghalaya and Nagaland and 34 conservation reserves in Jammu and Kashmir. Besides, India has a total of 18 biosphere reserves (BRs) recognized under the Man and Biosphere (MAB) program of UNESCO to promote economic and ecological development in a sustainable manner by community efforts and proper scientific interventions (http://www.wiienvis.nic.in/Database/br_8225.aspx), 07 natural world heritage sites (http://www.wiienvis.nic.in/Database/whs_pas_8227.aspx) (Table 13.2), 46 Ramsar wetland sites for the protection from further degradation and sustainable utilization of wetland resources as notified by MoEFCC, GoI (WII 2021; Hindustan Times 2021), and 4 biodiversity hotspots, viz., Himalaya, Western Ghats and Sri Lanka, Indo-Burma, and Sundaland spread throughout the Indian subcontinent (Saikia and Khan 2018). The first BR in India is the Nilgiri Biosphere Reserve notified in 1986 which spreads among Tamil Nadu, Karnataka, and Kerala (source: www.wiienvis.nic.in), while Kachchh is the largest BR in India located in Gujarat, covering ~12,454 sq. km area notified in the year 2008 (Pardeshi et al. 2010).

However, pressures on the natural environment increase with the ever-growing human population, climate change, pollution, agricultural expansion, industrial growth, urbanization, development of dams, highways, and mining have led to

Table 13.1 PAs of India. (Source: www.wiienvis.nic.in)

PAs of India	No.	Total area (sq. km)	% of India's total geographical area
National parks (NPs)	104	43,716	1.33
Wildlife sanctuaries (WLSs)	566	122,420	3.72
Conservation reserves (CRs)	97	4483	0.14
Community reserves	214	1302	0.04
Protected areas (PAs)	**981**	**171,921**	**5.03**

Table 13.2 Biosphere reserves and natural world heritage sites in India. (Source: www.wiienvis.nic.in)

Biosphere reserves	Total area (sq. km)	Year of notification	Location (States)
Nilgiri	5520.00	1986	Tamil Nadu, Kerala, Karnataka
Nanda Devi	5860.69	1988	Uttarakhand
Nokrek	820.00	1988	Meghalaya
Great Nicobar	885.00	1989	Andaman and Nicobar Islands
Gulf of Mannar	10,500.00	1989	Tamil Nadu
Manas	2837.00	1989	Assam
Sunderbans	9630.00	1989	West Bengal
Simlipal	4374.00	1994	Odisha
Dibru-Saikhowa	765.00	1997	Assam
Dehang-Dibang	5111.50	1998	Arunachal Pradesh
Pachmarhi	4926.00	1999	Madhya Pradesh
Khangchendzonga	2619.92	2000	Sikkim
Agasthyamalai	1828.00	2001	Kerala
Achanakmar-Amarkantak	3835.51	2005	Madhya Pradesh, Chhattisgarh
Kachchh	12454.00	2008	Gujarat
Cold Desert	7770.00	2009	Himachal Pradesh
Seshachalam Hills	4755.997	2010	Andhra Pradesh
Panna	2998.98	2011	Madhya Pradesh
Natural World Heritage sites			
Great Himalayan National Park Conservation Area	905.40	2014	Himachal Pradesh
Western Ghats	7953.15	2012	Maharashtra, Goa, Kerala, Karnataka, Tamil Nadu
Nanda Devi and Valley of Flowers National Parks	630.00 87.50	1988	Uttarakhand
Sundarbans National Park	1330.10	1987	West Bengal
Kaziranga National Park	429.96	1985	Assam
Keoladeo National Park	28.73	1985	Rajasthan
Manas Wildlife Sanctuary	391.00	1985	Assam

habitat destruction, fragmentation, degradation, and overexploitation of natural resources (UNEP-WCMC, IUCN 2016; Joshi 2019; WWF 2020). Besides, unsustainable natural resource extraction and illegal wildlife trade have severely threatened much Indian flora and fauna (UNEP-WCMC, IUCN 2016). However, India's conservation challenges are different from other developed countries including the USA, Brazil, and China as in developed countries, the majority of PAs are situated in sparsely populated areas with relatively low biodiversity value (Pimm et al. 2014), while in India, millions of people live within a few km peripheries of PAs and perhaps 04 million reside within the PAs where the dependency on PAs for livelihood security is very high (Narain et al. 2005).

13.3 Roles of PAS in the Conservation of Biodiversity

PAs offer various ecosystem products and services including energy and nutrient cycling, ecosystem restoration, habitat for wildlife, decomposition of wastes, pollution mitigation, help in pollination and disease-pest management, carbon sink, soil stabilization, disaster control and mitigation, etc. (Secretariat of the CBD 2008) that ultimately provides economic, social, cultural, spiritual, and scientific benefits (Maan and Chaudhry 2019). The principal motive of the PAs is to protect, conserve, and improve natural habitats that help in reducing the rates of habitat loss, degradation, and fragmentation (UNEP-WCMC, IUCN 2016; Boucher et al. 2013). Besides, it plays a crucial role in mitigating the impacts of climate change by reducing greenhouse gas (GHG) emissions and ecosystem restoration that helps in switching from carbon sources to sinks (IUCN 2012; Shukla 2016). They act as cornerstones of different cultural and religious practices which bring pride in community, confidence, and scientific discovery (Secretariat of the CBD 2009).

Exploring PAs offers opportunities to understand nature, and healthy outdoor recreational activities through ecotourism, exercise, education, and research by educational institutions. It brings a sense of adventure, challenges, and new discoveries (Secretariat of the CBD 2008). PAs are a kind of global tourism industry that provide opportunities for livelihood earning to local communities and generate income for funds and development. Entry fees, souvenir concessions, and hospitality generate income that helps in running protected areas and their management (Boucher et al. 2013; Secretariat of the CBD 2008). Terrestrial PAs, especially forest communities, play an essential role in climate regulations through the large potential of carbon sequestration (Gibbs et al. 2007). It regulates water and energy cycles and soil conservation, protects from natural disasters, and increases resilience capacity (Avissar and Werth 2005). The drinking water supply in around one-third of the world's largest cities was directly fulfilled by the PAs (Secretariat of the CBD 2008; IUCN 2012; MacKinnon et al. 2019). PAs maintain essential ecosystem services through their genetic resources which can withstand climate change impacts by increasing resistance and resilience to the vulnerability of livelihoods (Secretariat of the CBD 2009). They are able to absorb excessive rainfall, control stream flows, accommodate floodwaters thereby minimizing their damaging potential, and control fires through effective fire-protection measures (Shukla 2016).

PAs have played an essential role in protecting various rare, endangered, threatened, and endemic flora and fauna from further loss and extinction (Karanth et al. 2010; Walston et al. 2016) as it can be used as supportive measures to attain sustainable use of biodiversity. Divyabhanusinh (1999) states that none of the fauna (birds and mammals) has been lost from India since the cheetah (*Acinonyx jubatus*) was extinct in 1952. More than 85% of the total global one-horned rhinos (*Rhinoceros unicornis*) and ca., 70% of the total global tigers live in India, mainly due to the efficient functioning and effective conservation of India's tiger reserves (Jhala et al. 2015; Walston et al. 2016). Besides, almost 97% of the total population decline of the three *Gyps* vulture species is due to the veterinary uses of the drug diclofenac which are now limited inside or near PAs (Prakash 1999). The conversion of grasslands into agricultural farmlands, pasture, and plantation belts throughout India (Rahmani 2012; Arasumani et al. 2018) threatened a number of birds including the Great Indian bustard (*Ardeotis nigriceps*), which has less than 250 individuals throughout India (Rahmani 2012; Bird Life International 2021).

13.4 Problems in Protected Area Network (PAN) of India

Global climate change is causing threats to biodiversity at an individual level (Bellard et al. 2012) creating an accelerated pressure on each species, population, and community for migration and directional selection (Thomas et al. 2004; Parmesan 2006) leading to decreased resilience of the ecosystem and loss of genetic diversity (Meyers and Bull 2000; Botkin et al. 2007). Management of PAs in India is becoming challenging due to biotic and abiotic pressures such as population explosion, human-wildlife conflict, overgrazing, irresponsible tourists' attitudes and their negligence, encroachment in PAs, poaching, and developmental projects (railway lines, highway, high tension power transmission) within and around PAs (Maan and Chaudhry 2019). Human settlements within PAs are permitted without compromising the conservation goal, but sometimes, the local inhabitants exploit forest resources for their livelihood and other economic activities including traditional cropping, slash and burn agricultural practices, and assisting poachers resulting in decline in wildlife (Rangarajan and Shahabuddin 2006; Maan and Chaudhry 2019). These PAs need proper management for the sustenance of its socioeconomic, ecological, and cultural values.

The PAs of India are facing several challenges such as lack of legal protection, management plans, and their proper implementation to fulfill the requirements of the growing human population. Legal protection measures under the different government policies and local community level initiatives are unable to support in a large way to conserve biodiversity and promote local livelihoods. In Nokrek Biosphere Reserve, Meghalaya (Singh and Borthakur 2015) fund managers lack scientific understanding, limited knowledge of biodiversity, and also lack proper training to enhance the skill and capabilities of biodiversity conservation and protection. The main cause of failure is the lack of adequate provision of technical and financial input for successful agriculture-based livelihoods. Relocation of the human population is also a challenging task and displacement activities can solve proper conservation of natural resources and better living conditions for people living in the forest (Agrawal and Redford 2009). In addition, a cooperative environment with collaborative and sincere efforts is necessary for success in these ventures (Maan and Chaudhry 2019).

Human-wildlife conflict negatively affects communities and poses serious challenges to governments and organizations to align wildlife conservation with sustainable development. Different terrestrial and aquatic species move from core zone to buffer for easy access to food and a greater abundance of palatable grasses (IUCN 2020). The major basis of human-wildlife conflict is a reduction in the size and quality of available habitat due to encroachments, deforestation, denotification of protected areas, and expansion of cultivation and habitation (Singh 2002). The northeast region of India is significant as a habitat for a large number of wild animals where Asiatic elephants are the major reason for human-wildlife conflict and almost 1150 humans and 370 Asiatic elephants died from 1980 to 2003 (Choudhury 2004). The burgeoning human population and the increasing needs for housing and agriculture are the main reasons for such conflicts. The annoyed inhabitants in Assam, NE India, have targeted crop-raiding elephants by selectively poisoning their paddy fields and inflicting violent elephant carcasses known as "Paddy Thief Bin Laden" (Gureja et al. 2002). The majority of Indian protected forests are suffering from the dwindling pressure of cattle grazing due to a lack of sufficient pasture and grazing lands (Singh and Borthakur 2015) which ultimately reduces the plant growth by removing newly grown saplings, affecting the natural regeneration process, and altering the overall ecological processes. Proper management and functioning of Indian PAs may be a problematic task due to the insufficient funds and facilities, lack of public awareness, trained staff, limited jurisdiction, and necessary information base (WII 2012). The inadequate remuneration, processing delays, and corruption in the process of compensation paid for livestock killed or crops damaged by wild animals (Maan and Chaudhry 2019) and the overall situation warrant action on multiple fronts, with due consideration of social realities.

13.5 Protected Area Management and Maintenance in India

Management of PAs in developing countries like India extends significant challenges due to the higher level of poverty, ever-increasing population growth, and higher dependency of people for livelihood security, along with lack of strong institutional mechanisms with the state forest departments towards protecting and safeguarding biodiversity. Conservation measures should never be imposed on the local inhabitants, and there must be involved from the local people in various levels of conservation efforts according to their knowledge base, interests, skills, self-reliance, and traditions (Panwar 1982). The management of PAs faces constant challenges and difficulties due to issues such as human-wildlife conflicts, habitat encroachments, overgrazing, pressure from tourism, illegal hunting, poaching, wildlife trade, running of vehicular and rail traffic through these areas, and the ever-rising demand for diversion of more land in PAs for developmental purposes (Maan and Chaudhry 2019). India has made significant achievements in enhancing the PAN, and it plays an important role in protecting biodiversity (Karanth et al. 2010; Walston et al. 2016). Almost 89% increase in the number of national parks, and 38% in wildlife sanctuaries established from 1988 to 2012 (WII 2012). The Government of India (GoI) and its ministry act as a guide with the policies and planning of wildlife management and conservation, while the state forest departments have the responsibility to implement national plans and policies. The GoI has implemented various types of acts, laws, and legislation to limit the growing damage to forest resources, wildlife, and biodiversity. The major acts related to conservation and sustainable management of biodiversity include the following.

13.5.1 Forest Act 1927

It is an act with a full set of documented laws related to forests, forest biodiversity, forest resources, and their transport and the duty liable on timber and other non-timber forest products. This act prohibits any clearing of forests, setting fires, trespassing of domestic livestock into reserve forests, felling of trees for timbers, stone quarrying, clearing of land for cropping and other agricultural practices, hunting, shooting, fishing, and poisoning of water or set of traps for wildlife. The accused of any crime should be punished with imprisonment or fine or both, in addition to compensation based on the type of crime and the verdict of the convicting court (source: www.indiacode.nic.in).

13.5.2 Wildlife (Protection) Act 1972 (WLPA) and Wildlife (Protection) Amendment Act 2006

It is an act to provide the protection to wildlife including animals, birds, and plants and for matters connected therewith to ensure the ecological security of the country. It safeguards all the wild animals other than vermin and specific plant species from killing, trapping, and selling animals and their young ones or eggs, animal products, meat, etc. which are considered an offense under this act. The act grants permits and recognition to zoos and central zoo authority, prohibition of harm to wildlife by killing and trading of live animals, penalties for the offense, etc. The act was amended in 2006 with the addition of two new chapters which are mainly concerned with the conservation of tiger and endangered species of flora and fauna (source: www.indiacode.nic.in).

13.5.3 Forest (Conservation) Act 1980

It is an act to provide conservation of forests and the matters connected therewith. It acts on the forest resources of all of the Indian states and territories and the act checks further deforestation and conservation of forest and forest resources. It limits the utilization of forest lands for non-forest activities like the cultivation of commercial crops like coffee, rubber, cocoa, spices, tea, etc. It promotes conservation, sustainable development, and management of forests and forest resources through the establishment of check-posts for forest security, fire lines, wireless communications, construction of fencing, bridges and underpass, check dams, territorial boundary marks, pipelines for water supply, etc. and impose a penalty for violation of the provisions of the act (source: www.indiacode.nic.in).

13.5.4 Environment Protection Act 1986

It provides protection and helps to improve the environment and the matters connected therewith. The act is comprehensive legislation to ensure the safety for the environment to all the Indian states and territories, which defines the power of the central government to take necessary measures and frame rules to protect and improve the environment, regulate environmental pollution, prevention, control, and its abatement and to also decide penalty and miscellaneous power. It provides different standards for controlling emissions and discharge of selective pollutants from particular industries and to establish, recognize, and operate environmental laboratories for inspection of any industrial plants, equipment, manufacturing units and processes, materials, or substances (source: www.indiacode.nic.in).

13.5.5 National Forest Policy 1988

It aims to maintain stable environmental conditions and ecological balance for the sustenance of all life forms. The major objective of this policy is to conserve the gene pool of flora and fauna within the remaining natural forests. It limits soil erosion, improves water conservation, and mitigates floods, droughts, and siltation. It also helps in increasing forest and green cover of the country through afforestation efforts and social forestry projects on degraded and unproductive lands. It helps to provide livelihood including fuelwood, fodder, minor forest products, and small timber to the rural tribal populations. It also promotes people's participation and women's empowerment to increase forest productivity to meet the essential needs of the country and minimize the growing pressure on the existing natural forests. Strategies to achieve its goals mainly include afforestation and forestry programs, wildlife conservation, promoting a synergistic relationship between the tribal community and forests for the conservation of forest and forest resources and sustainable development (source: www.indiacode.nic.in).

13.5.6 National Biodiversity Act 2002

It is an act to ensure the conservation of biodiversity, their sustainable use, and equitable sharing of the benefits of the use of biological resources. It safeguards traditional and historic knowledge prevents biopiracy, prohibits people's claims on patents without the governments' approval, etc. The act takes charge of assessment and approvals of biodiversity, national development plans, the harmful effects on the conservation of biodiversity, endangered and threatened species, and prohibiting their collection. It consists of 12 chapters with detailed explanations about various biodiversity boards, committees, and their functions with provisions for punishment and penalties for offenses under the act (source: www.indiacode.nic.in).

13.5.7 Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006

The act safeguards the rights of forest-dwelling scheduled tribes and other traditional forest dwellers living in forests for generations but whose rights could not be recorded. The act empowers the scheduled tribes and forest dwellers to traditionally use the forest areas for self-cultivation, basic needs, livelihood, habitation, and sociocultural perspectives. It protects the rights of forest dwellers from unlawful evictions with the provisions of basic facilities for the tribal community and forest dwellers to access development facilities like education, health, nutrition, and infrastructure, and their traditional knowledge helps to protect, conserve, and manage forests, biodiversity, wildlife, catchment areas, and water sources (source: tribal.nic.in; forestrights.nic.in).

13.6 Community Conservation Efforts Outside the Protected Area Network (PAN)

Biodiversity conservation in India has been practiced since the Vedic period (Kumar 2008), and it is continued today. Many tribal communities and forest dwelling societies residing outside PAN play a crucial role in biodiversity conservation through cultural concepts like sacred forests, grooves, corridors, and ethno-forestry (Berkes et al. 1998); these efforts are known as community conservation. Forests provide food, fuel, fodder, and income opportunities to tribal and forest dwellers. It plays an important role in their sustenance, sociocultural life, and economic support to the tribal population of India. Joint forest management (JFM) has become a comprehensive effort of forest conservation initiated by the GoI in 1990 in context with the National Forest Policy (1988). It aims to conserve forests, forest biodiversity, and sustainable development through the involvement of local communities with the forest departments in forest management activities (Murali et al. 2003) within the PAs and degraded forest regions (Damodaran and Engel 2003; Balooni and Inoue 2009) that have been originated in West Midnapur district of West Bengal in 1971 (Directorate of Forests, Govt. of WB 2016). In JFM certain rules are made by the forest department regarding the use of forest resources by the local communities which helps in their sustenance without any negative consequences on the forests and the forest department and government agencies have also developed an initiative to motivate, educate and train people to earn livelihoods to improve their economic status and standards of living.

JFM is a strategy to achieve multipurpose goals such as rural development, poverty alleviation, gender equality, women's participation, and empowerment (Maksimowski 2011) through providing opportunities and training to villagers in a sustainable way to prevent biodiversity loss and forest degradation. The Indian States of West Bengal, Odisha, Bihar, Gujarat, Haryana, Himachal Pradesh, Uttar Pradesh, Uttarakhand, Rajasthan, Karnataka, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Arunachal Pradesh, and Tripura have actively participated in

JFM (Damodaran and Engel 2003; Sundar 2002). In JFM, forests are managed through direct access to locals that help in obtaining their basic needs and benefits like fresh air, water supply, employment opportunities, etc. through increasing forest cover, forest fire control, prevention of poaching and hunting of wildlife, water recharge through adequate precipitation, regulating regional climate, improved pollination, and protecting wildlife habitat (MoEF, GoI n.d.). It also helps in conserving forests biodiversity; checking soil erosion, mitigating floods and droughts; increasing tree cover in degraded forests; fulfilling the basic needs of rural tribal populations with provisions of food, fuelwood, fodder, minor forest products, small timbers, medicines, source of income; and increasing the forest productivity to minimize the pressure on existing forests (MoEF, GoI n.d.; Directorate of Forests, Govt. of WB 2016).

Sacred groves (SGs) are other community-based forest management initiatives to protect forest patches traditionally by local communities due to the faith, belief, rituals, taboos, and various traditional and cultural values associated with these forests (Pandey 2010; Murtem and Chaudhry 2014) where hunting, gathering of forest products, and collection of fuelwood are strictly prohibited. SGs are ideal areas for the conservation of biodiversity as the majority of these forest patches are virgin forests with rich biodiversity (Khan et al. 2008). It is found throughout India mainly in tribal-dominated regions from the Western Ghats to Central and Northeastern India (Balasubramanyan and Induchoodan 1996; Burman 1992; Gadgil and Vartak 1976; Khumbongmayum et al. 2005; Rodgers 1994). There are almost 23,000 sacred groves located in 19 different tribal dominating Indian states covering ca. 68,633 ha forests area (Malhotra et al. 2007). SGs are considered as one the safe places for many rare, endangered, threatened, and endemic species of plants and animals, and they are conserved through sacredness, religious beliefs, and taboos. They provide a number of ecological services such as pollination, seed dispersal, habitat, minimizing erosion by water and wind, conserving soil, maintaining hydrological cycle, and availing water (Khan et al. 2008). SGs play a positive role in maintaining ecosystem health, habitat protection, and preserving cultural and ethical beliefs (Godbole et al. 1998; Godbole and Sarnaik 2004; Ramakrishnan and Ram 1988). SGs can be another effort for biodiversity conservation outside protected areas but at present; they are facing the challenge of losing their identity and importance due to anthropogenic activities, exploitation of resources for economic development by rural tribal populations and by the cultural change among young generations (Khan et al. 2008).

13.7 Land Degradation Neutrality

The concept of land degradation neutrality (LDN) has come up on 2011 at United Nations developed by the United Nations Convention to Combat Desertification (UNCCD) secretariat as a concept for maintaining the balance between "not yet degraded" and "already degraded" land to achieve sustainability (Gichenje et al. 2019). LDN is a state of net zero land degradation defined as "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD 2022). It aims to maintain and enhance ecosystem services on the basis of scientific approaches including planning, implementing, and monitoring of natural land resources (Cowie et al. 2018). It focuses on conservation of biosphere, society, and economic instability through promoting land restoration, multifunctional use of land, and raising awareness (Keesstra et al. 2018). LDN protects, restores, and promotes sustainable use of landscape; it is helpful in forest management, combats desertification, and prevents further land degradation and biodiversity loss (Solomun et al. 2018). It balances land degradation and reclamation by maintaining and improving land quality at on-site and off-site land restoration, thereby eventually helping in achieving healthy soils and stable terrestrial ecosystems (Barkemeyer et al. 2015). LDN can play an important role in minimizing global challenges such as food, water and energy security, poverty alleviation, human health, migration, conflicts, economic crises, and income inequality (Akhtar-Schuster et al. 2017).

PAs can be used as a cornerstone for LDN under the umbrella species concept and flagship conservation strategies for biodiversity conservation and environmental protection (Cantú-Salazar and Gaston 2010). Protected area networks can be used as effective tools to preserve biodiversity and prevent land degradation, in addition to regional and local climate change, anthropogenic disturbance, and other environmental drivers that can be maintained (Beatty et al. 2014). Building capacity alliances with conservationists, ecologists, foresters, land-use planners, bureaucrats, rural union leaders, and indigenous communities within PAs for regulating and conserving PAs will promote sustainable development strategies to support socio-economic and cultural aspects of indigenous communities (Naughton-Treves et al. 2005). This action would help to achieve comprehensive conservation goals with limited funding, time for action, conservation efforts, and shortcuts for the maintenance of biodiversity (Roberge and Angelstam 2004). A total of 1,44,296 protected sites have been reported which accounts for 12.9% of the earth's surface is an achievement and new PAs are continuously established, thus more protected areas mean better conservation and hence less land degradation (Andrade and Rhodes 2012).

13.8 Future Research Prospects

There is interplay between biodiversity conservation and ecotourism. Further research may be able to examine the more complex interaction between environmental and socioeconomic concerns of terrestrial PAs worldwide that will enable us to estimate the achievements of socioeconomic upliftment and biodiversity conservation. The determination of species' adaptive capacity and sensitivity to climate change along with the impacts of anthropogenic disturbances in PAs will help in determining the actual reasons behind the population loss of much important wildlife. Formulation of long-term monitoring and assessment tools of economic and ecological benefits are of particular importance to achieve sustainable development through ecotourism, timbering, and value addition of different forest products.

13.9 Conclusions

Conservation of biodiversity within their natural habitats is ensuring intragenerational and intergenerational equity. The Indian PAs are supporting a range of economic activities, providing industrial goods, and investment with proper maintenance of ecological services and livelihood security, to millions of forest dwellers around the globe. There is a need to take up various conservation projects together with mitigation measures including the corridors for tigers, elephants, and other animals in and around reserves. Planners, policymakers, and common people need to understand that the future security of the national heritage of the country is at stake. The major goals of the policymakers should be the development of proper monitoring and management plans for eco-sensitive zones around PAs and emphasis must be given to preserving the existing PAs, establishing new PAs, and also to enhance the area under the existing PAs to achieve environmental sustainability and limit the biodiversity loss. A balanced view of the country's development, the conservation of biodiversity, and the hardships faced by the local inhabitants residing in and around PAs are also needed to achieve sustainable development. India has strong legislation for the conservation of nature and also has government investments in the forms of more than 50 tiger reserves, government compensation schemes, etc. to facilitate local socioeconomic and livelihood supports, which are considered the good signs of future prospects for conservation.

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Structure, Pattern, and Composition of Riparian Vegetation in North-western Himalayas, India

14

Anu Sharma and Neeraj Sharma

Abstract

Riparian corridors are related to longitudinal and lateral patterns of plant species distribution as well as to species flows and exchanges across ecotonal and ecoclinal boundaries. The present chapter describes the structure, composition, and distribution pattern of vegetation in a riparian corridor spanning 35 kilometers in an elevational range of 839 m (Pul Doda) to 2183 m (Thanthera) along Neeru stream, a major left bank tributary of river Chenab. The study area is characterized by a mix of subtropical, sub-temperate, temperate, and montane climatic bands supporting different vegetational patches along a gradient of 1344 m. In total, 248 species of plants in 193 genera and 78 families comprising 39 trees, 49 shrubs, and 170 herbs were recorded. This included five gymnosperms and 243 angiosperms. The species distribution in the Raunkiaer's frequency classes showed homogenous distribution of vegetation in the riparian and heterogeneous distribution along the upland forests. The riparian forests exhibited random distribution followed by clumped and regular pattern validating better chances of species survival with adequate resource availability. The hierarchical clustering defined the extent of similarity among the plant associations in the riparian corridor. The study will be helpful in prioritizing the sections of stream warranting immediate restoration and ecological monitoring.

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Keywords

Floristics · Forest types · Species richness · Distribution pattern · Plant association · Riparian · Upland

14.1 Introduction

The vegetation forms a critical component of the ecosystem since it helps to define many different aspects of ecological patterns across the landscape. Water supply, soil, environmental variables such as slope, aspect, and elevation, as well as climatic and microclimatic conditions, all influence its pattern, structure, and distribution. Physiognomy, which provides a set of functional and physical qualities of dominating plant communities in a given location, fluctuates through time and space (Jennings et al. 2008). The plant communities found along the margins of a river or stream constitutes the riparian vegetation (Brinson 1990). The word "Riparian" originated from the Latin word "Ripa," which means the bank of a river, pond, or lake of the surrounding landscape (Goebel et al. 2003; Junk and Piedade 1997; Tabacchi et al. 1990). Riparian forest buffers connect terrestrial and aquatic habitats and provide important ecological services at the landscape level. Riparian zones are landforms with vegetation that interact with temporary or permanent aquatic habitats (Meragiaw et al. 2018) and serve as conduits for propagule dispersal to locations that have been made extremely susceptible by a variety of anthropogenic disturbances (Richardson et al. 2007). These are often quite distinctive when compared with upland vegetation as it comprises the plants adapted to high soil moisture (Kocher and Harris 2007). The structure, dynamics, and composition of riparian ecosystems are influenced by complex interactions among hydrology, geomorphology, light, and temperature (Brinson 1990; Malanson 1993). The size of the riparian area and the extent of interaction between the land and the water varies with the size of stream (Bilby 1988). Floristic diversity is essential among natural resources at any spatial scale, as it describes floristic richness, which is valuable for formulating conservation plans and policies (Chhetri and Shrestha 2019). While living trees provide shade that moderates water temperature, the dead and fallen trees decompose into massive woody debris, providing habitat and cover for insects, amphibians, and fish, as well as creating pools that aid in sediment control and nutrient transfer. Because the stream receives little sunlight, the forest supplies food in the form of insects, leaves, needles, twigs, and branches for the insects, amphibians, and fish inhabiting the stream (Gregory et al. 1987).

Neeru watershed is well represented by subtropical, subtemperate, temperate, and alpine elements of biodiversity along the elevational gradient. The forests at lower elevation of 837 m where Neeru meets river Chenab offers a narrow range of subtropical climate supporting the Ban Oak-Chirpine-Himalayan Alder (*Quercus leucotrichophora-Pinus roxburghii-Alnus nitida*), Moru Oak-Bluepine-Himalayan Alder (*Quercus baloot-Pinus wallichiana-Alnus nitida*), associations at lower elevations followed by Bluepine-Himalayan Alder-Deodar (*Pinus* *wallichiana-Alnus nitida-Cedrus deodara*), Moru Oak-Deodar-Bluepine (*Quercus baloot-Cedrus deodara-Pinus wallichiana*) at mid (1350–1700 m), and, Deodar-Spruce-Fir (*Cedrus deodara-Piceasmithiana-Abies pindrow*) at higher elevation (1700–2150 m). The riparian zone is mainly dominated by *Alnus nitida* besides few isolated and mixed stands of *Ficus palmata*, *F. rumphii*, *Robinia pseudoacacia*, and *Melia azedarach* interspersed with conifers along the river bed and flood plains. The upper slopes of the flood plain contain heterogeneous forest communities with a mix of conifer and broad-leaved vegetation along both banks. To explain the vegetation structure, its composition, and distribution in the riparian and adjacent forest buffers, a comprehensive study was conducted along the perennial Neeru stream in district Doda of union territory of Jammu and Kashmir, India during the years 2014–2016. The study focuses on floristic composition, pattern, and distribution of different plant communities in a hilly riparian corridor.

14.2 Study Area

The study area, Neeru stream an important left bank tributary of Chenab catchment was surveyed for a linear stretch of 35 km lying between 32°55′32″ to 33°08′26″N and 75°32′41″ to 75°45′78″E along an elevational range of 837 m (Pul Doda) to 2183 m near Thanalla (Table 14.1, Fig. 14.1). It forms a linear hydromorphological unit covering 35 km in length and 1.5 km in width, encompassing the stream bed, flood plain, and edge upslopes, with its head near Ashapati (Sunbain glacier, the source) and mouth at its confluence with River Chenab at Pul Doda. A total of 15 sampling sites were chosen based on the maximum possible representation of plant associations while maintaining the shortest possible distance between adjacent sites (Table 14.1).

14.3 Topography and Climate

The area is surrounded by lofty mountains on all the sides. Neeru catchment is bounded by Kishtwar and Doda districts in northwest, by Chamba district of Himachal Pradesh in the east, and by Kathua and Udhampur districts of Jammu and Kashmir in the south and southwest, respectively. Terrace farming is a common practice which can be found along both the banks of the stream. Agriculture is the mainstay of region and land is mostly suitable for paddy cultivation. The study area mainly lies in the Pir Panjal and Dhauladhar ranges of Lesser Himalayas. Neeru, a perennial glacier fed stream, forms an important left bank tributary of River Chenab. Originating from Ashapati glacier, it is joined by few tributaries at Thanalla and Sartingal to form the main channel at Monda village. Basti *nallah* with its origin from Kailash *kund* (south westwards) converges with the main channel at Monda beyond which the steam attains the name Neeru *nallah* (stream). It then flows through urban and sub-urban regions of Bhaderwah, Gatha, Amiranagar, Dranga, Drudu, Seri, Bhalla, Pranoo, and Galgander before draining into River Chenab at Pul

Table 14.1 Spatial attributes of sampling sites along both banks of Neeru stream

	Upland left				Riparian			Upland right		
Study sites	Location	Latitude	Longitude	E	Latitude	Longitude	E	Latitude	Longitude	E
1.	Pul Doda	33°08.302′	75°33.446′	862	33°08.293′	75°33.414′	839	33°08.252′	75°33.457′	854
2.	Galgander	33°08.356′	75°33.450′	890	33°08.278′	75°33.832′	854	33°08.118′	75°33.707′	868
3.	Pranoo	33°05.966′	75°34.869′	1060	33°05.925′	75°34.855′	1045	33°06.012′	75°34.746′	1064
4.	Bhalla	33°04.065′	75°36.909′	1220	33°04.089′	75°36.868′	1198	33°04.040′	75°36.849′	1210
5.	Seri	33°02.701′	75°39.320′	1310	33°02.718′	75°39.310′	1269	33°02.886′	75°39.194′	1308
6.	Drudu	33°01.51′	75°39.230′	1372	33°01.379′	75°39.521′	1325	33°01.454′	75°39.377′	1352
7.	Dranga	33°01.074′	75°40.343′	1390	33°01.056′	75°40.362′	1375	33°01.022′	75°40.290′	1384
8.	Amiranagar	33°00.751′	75°41.595′	1425	33°00733′	75°41.581′	1407	33°00.662′	75°41.616′	1467
9.	Gatha	33°00.202′	75°41.841′	1465	33°00.148′	75°41.890′	1459	33°00.036′	75°42.112′	1465
10.	Renda	32°59.225′	75°43.371′	1548	32°59.219′	75°43.375′	1544	32°59.255′	75°43.413′	1550
11.	Guptganga	32°58.811′	75°43.476′	1611	32°58.823′	75°43.489′	1602	32°58.846′	75°43.477′	1627
12.	Dareja	32°58.333′	75°43.602′	1667	32°58.315′	75°43.576′	1615	32°58.357′	75°43.596′	1655
13.	Bheja	32°56.611′	75°44.538′	1769	32°56.646′	75°44.485′	1760	32°56.501′	75°45.227′	1803
14.	Thanthera	32°55.001′	75°43.481′	2180	32°55.030′	75°43.451′	2166	32°55.049′	75°43.472′	2183
15.	Thanalla	32°55.043′	75°45.748′	2131	32°55.048′	75°45.788′	2111	32°55.009′	75°45.737′	2133

E elevation (m asl)

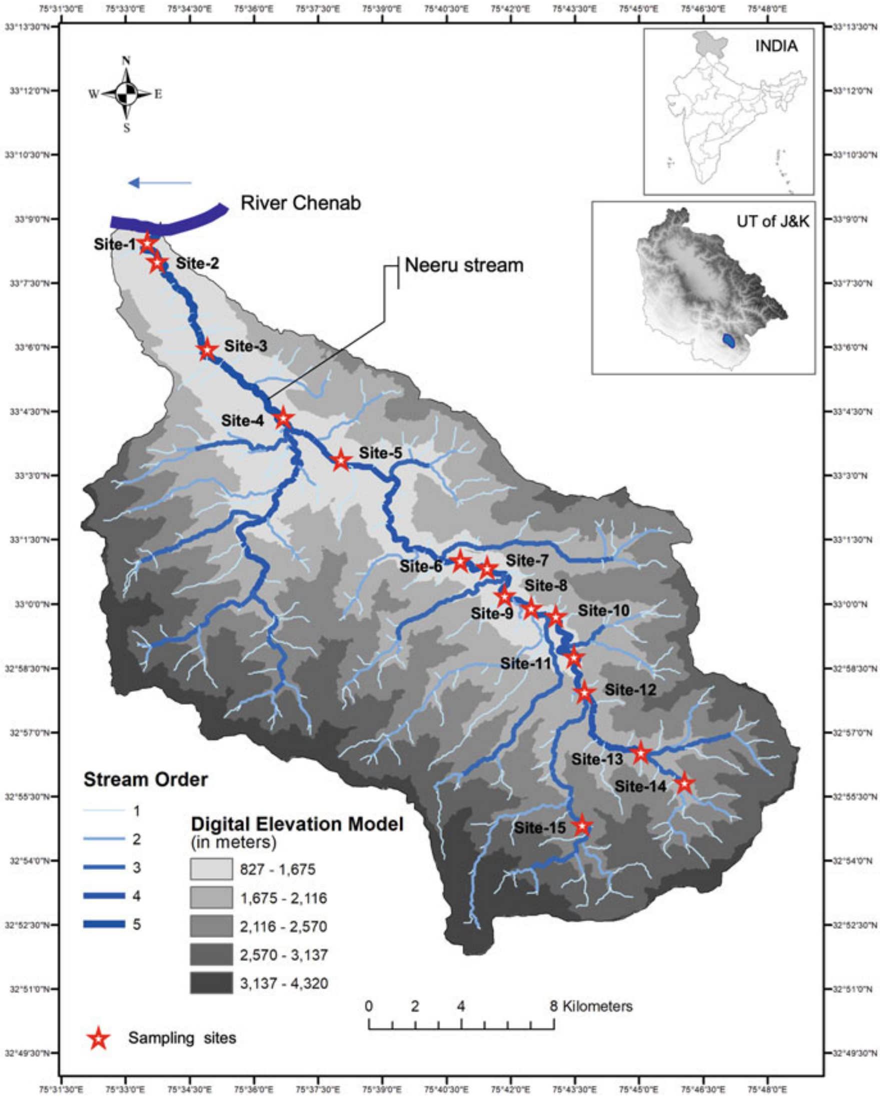

Fig. 14.1 Map of the study area showing the sampling sites in the riparian corridor

Doda (837 m). The area is influenced by cold arid climate with short summers and long dry winters. Temperature in the study area regularly drops as low as sub-zero in the winter and varies primarily with elevation. The area is characterized by four major seasons.

14.4 Geology and Soils

Bhaderwah formation of late Proterozoic consists of slate, phyllite, and quartzite (CGWB 2014). Geology of Bhaderwah and adjoining areas has been extensively studied by Wadia (1931), Gansser (1964), Didwal (1975), and Khajuria (1984) who concluded that Bhaderwah is composed of six types of geological formations (Kumar 1987). These include recent and sub-recent Granite, Sunbain quartzite, Bhaderwah slates, Phyllites, and Schist. Thakur et al. (1995) reported the composition of Muscovite-biotite schist, quartzite, phyllite, and limestone. The soils in the study area are mostly formed by the physical, chemical, and biological weathering of the mica, schist, and granite. There is a discernible shift in the type and composition of the soil and vegetation as elevation increases.

14.5 Sampling Strategy

A total of 1080 quadrates, 360 for trees (10 m x 10 m), shrubs (5 m x 5 m), and herbs (1 m x 1 m) each were laid at 15 sampling points along the stream corridor (main channel) for the analysis. To have a better representation of the communities, their composition and ecological significance, each bank was further divided into two zones, namely, riparian zone close to the stream including flood plain and the upland buffer away from banks. The density, frequency, abundance, and total basal area of each species per site were calculated following Misra (1968). The importance value (IV) was calculated by summing up the relative values of density, frequency, and total basal area following Curtis (1959). The number of species encountered in all the five Raunkaier's frequency classes was obtained for Riparian and Upland forests. The frequency classes at 20% interval are represented as A = 1–20%, B = 20–40%, C = 40–60%, D = 60–80%, and E = 80–100% (Raunkiaer 1934). The abundance to frequency ratio (A/F) of different species was computed (Whitford's index) to define the distribution pattern of species along riparian and upland forest communities.

14.6 Results

14.6.1 Floristic Composition and Analysis

A total of 248 plant species represented by 193 genera and 78 families were recorded from the riparian and adjoining upland forests along Neeru stream from April 2014 to December 2016. Of these 39 were trees, 49 shrubs, and 170 herbs. Of the total species observed, five species, namely, *Pinus roxburghii*, *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow*, and *Picea smithiana* were gymnosperms, and 243, the angiosperms. All gymnosperms belonged to family Pinaceae. Pteridophytes comprised of three species in two genera. Among the angiosperms, Asteraceae dominated the area with 27 species contained in 20 genera followed by Rosaceae (22 species/16 genera), Lamiaceae (15 species/14 genera), Fabaceae (11 species/10

Table 14.2 Comparative account of prominent families of study area and the adjoining areas

S. No.	Prominent families	Study area	Authors
1.	Asteraceae, Rosaceae, Lamiaceae, Fabaceae Poaceae, Moraceae	Neeru stream (present study)	Sharma (2018)
2.	Asteraceae, Rosaceae, Lamiaceae, Ranunculaceae, Orchidaceae	Kailash-Chattergalla ridge (upper Neeru)	Singh et al. (2019)
3.	Asteraceae, Rosaceae, Lamiaceae, Ranunculaceae, Polygonaceae, Fabaceae	Chattergalla (Bhaderwah)	Najeeb (2014)
4.	Asteraceae, Fabaceae, Lamiaceae, Poaceae, Euphorbiaceae, Rosaceae, Acanthaceae	Kathua district	Kumar et al. (2014)
5.	Asteraceae, Fabaceae, Lamiaceae, Rosaceae, Poaceae, Amaranthaceae	Ratle H.E.P catchment (Kistwar)	Kumar (2012)
6.	Asteraceae, Lamiaceae, Apiaceae, Ranunculaceae, Rosaceae, Cruciferae	Neeru watershed (Bhaderwah)	Dutt (2005)
7.	Asteraceae, Fabaceae, Poaceae, Lamiaceae, Euphorbiaceae, Scrophularaceae	Trikuta hills (Reasi)	Kour (2001)
8.	Asteraceae, Lamiaceae, Poaceae, Fabaceae, Rosaceae, Ranunculaceae	Patnitop (Udhampur-Ramban)	Kumar (1997)
9.	Asteraceae, Poaceae, Apiaceae, Labiateae, Ranunculaceae, Cruciferae	Bhaderwah	Kumar (1987)

genera), Poaceae (9 species/9 genera), and Moraceae (8 species/3 genera) respectively. As many as 36 families were represented by a single genus and single species, while 42 families were polytypic. A comparative account of familial representation from adjoining areas with more or less same physiography and climatic regime is provided in Table 14.2.

Asteraceae with 27 species, emerged as dominanting family in Bhaderwah (Dutt 2005; Kumar 1987; Najeeb 2014; Sharma et al. 2016; Singh 2019), as reported in the adjoining regions with comparable physiography and climatic regime (Kour 2001; Kumar 1997; Table 14.2). The trans-Himalayan landscapes of Ladakh and adjoining states of Himachal Pradesh and Uttarakhand also hold Asteraceae as the species rich family (Kachroo et al. 1977; Kanwal and Joshi 2015; Kharkwal et al. 2005; Kumar et al. 2015a, b; Kumar et al. 2014; Pharswan and Mehta 2010; Rana and Kapoor 2015; Singh 2002). Divergent patterns in familial dominance have also been observed in the places with comparable pytoclimate. Kumar and Sharma (2014) reported Pinaceae as most species rich family in Paddar valley, Kishtwar, while Chauhan et al. (2014) recorded Rosaceae being the richest.

14.6.2 Forest Types

Forests in Neeru watershed are characterized by a mix of subtropical, sub-temperate, temperate, and alpine forest types. According to Champion and Seth (1968), the forests of the study area are categorized as follows:

14.6.2.1 Subtype 9/C1: Himalayan Subtropical Pine Forest

This forest type comprises of mixed and isolated stands of Chirpine (*Pinus roxburghii*) scattered from Pul Doda (848 m) to Bhalla (1200 m) with few individuals observed at Seri, little ahead at around 1300 m. The forest community is mostly restricted towards the up slopes. *Prinsepia utilis* forms the major understorey along the left bank while the luxuriant *Berberis lycium* and *Daphne oleoides* grow towards the drier slopes along both the banks of the stream. *Prinsepia utilis* sparsely grows at right bank. The herbaceous layer mainly comprises of *Cannabis sativa*, *Artemisia vestita*, and *Cirsium arvense* along the riparian zone, whereas *Imperata cylindrica* and *Oenothera rosea* occupy the upper slopes on either sides. The soil pH records a fall towards Bhalla and Seri along the rising elevation. Colour of the soil varies from grey to olive grey and pale brown at right and left bank of the stream respectively while organic carbon and organic matter and nitrogen exhibit an increasing trend towards the higher elevations. Potassium is recorded low in this forest.

14.6.2.2 Subtype 10/C1a: *Dalbergia-Melia* Scrub Forest

This forest subtype dominates the riparian zone at Pul Doda (848 m) and extends up to Pranoo at 1180 m. Relatively a drier zone is mainly represented by *Dalbergia sissoo*, *Melia azedarach*, *Olea cuspidata*, *Zizyphus mauritiana*, *Quercus baloot*, *Quercus leucotrichophora*, *Pinus roxburghii*, and *Ricinus communis*. Himalayan Alder (*Alnus nitida*) dominates the riparian zone interspersed with few individuals of *Ficus palmata*. In Pul Doda, the confluence zone is virtually devoid of vegetation, while Galgander being dry and rocky bears the scattered trees of *Olea cuspidata* along the upper slopes. The vegetation diversity starts increasing towards Pranoo. The understorey mainly comprises *Berberis lycium*, *Daphne oleoides*, *Prinsepia utilis*, and *Justicia adhatoda*. *Alnus nitida*, a moisture loving tree, shows a transition towards sub-temperate region. Soil characteristics vary along the slope, aspect, and elevation. Very loose substratum makes the zone prone to landslides and rock falls. Soil in this forest zone is neutral to alkaline and rich in potassium but poor in nitrogen and phosphorus.

14.6.2.3 Subtype 12/C1a: Ban Oak Forest

Lying at the lower elevation, this forest type is found along the up slopes along Site 2 (Galgander), Site 3 (Pranoo), and Site 4 (Bhalla), while to some extent at Seri (Site 5). *Quercus leucotrichophora* is the representative species growing in association with *Pinus roxburghii*, *Alnus nitida*, and *Ficus palmata*. *Berberis lycium* and *Daphne oleoides* form the understory.

14.6.2.4 Subtype 12/C1$_b$: Moru Oak Forest

The moderately higher elevations exhibit the predominance of *Quercus baloot* at Site 14 (Thanthera) and Site 15 (Thanalla). It is found in association with conifers like *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow*, and *Picea smithiana*. The understory forms the gregarious clumps of *Viburnum grandiflorum*.

14.6.2.5 Subtype 12/C1c: Moist Deodar Forest

Pure patches of *Cedrus deodara* interspersed with *Pinus wallichiana* are found at Seri, Drudu, Dranga, and Amiranagar. The broad-leaved associates mostly restricted to riparian and flood plain zones are represented by *Alnus nitida*, *Ficus palmata*, and *Robinia pseudoacacia*. These are found mainly along the left bank of the stream at Seri and seen up to Amiranagar with good representation at Drudu and Dranga. The understorey is formed by *Berberis lycium*, *Daphne oleoides*, *Prinsepia utilis*, *Rubus ellipticus*, and *Rosa brunoni*. Soil is sandy in texture and acidic with medium to high contents of nitrogen, while potassium increases from lower to higher elevation.

14.6.2.6 Subtype 12/C2: Upper West Himalayan Temperate Forest

This forest group includes mainly the conifer forests which include *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow*, and *Picea smithiana* occupying the higher elevation sites namely Thanthera, Thanalla, and above. The broad-leaved forests are mainly represented by *Ailanthus altissima*, *Ulmus wallichiana*, *Quercus baloot*, *Quercus leucotrichophora*, and sparse distribution of *Alnus nitida*. Woody vegetation is mainly represented by *Viburnum grandiflora*, *Indigofera heterantha*, and *Berberis lycium*. There is decreased soil pH and moisture content, increased nitrogen, and phosphorus and low potassium.

14.6.2.7 Subtype 12/1S1: Alder Forest

The Himalayan alder, *Alnus nitida*, is the main constituent of riparian forests in the study corridor. Gregarious healthy patches are seen quite adjacent to the active water channel and flood plains along both banks of the stream. Being a moisture loving plant, its distribution is scanty at lower elevations with Pul Doda and Galgander being the dry sites. It first appears near Pranoo and flourishes up to Bheja (1800 m) beyond which it is very sparsely distributed. The gregarious stands are recorded between Pranoo to Bheja. *Alnus nitida* is found in association with *Ficus palmata* and *Robinia pseudoacacia* with *Prinsepia utilis* the main understory species.

14.6.2.8 Subtype 12/1S2: Riverine Blue Pine Forest

With the predominance of *Pinus wallichiana*, this forest type is found along the intermediate sections (1250–1600 m) of the left banks of the stream. Its prominence is noticed at Seri, Drudu, Dranga, and Amiranagar either in pure patches or mixed with *Alnus nitida* and *Ficus palmata*. The scrub layer mainly contains *Prinsepia utilis*, *Daphne oleoides*, *Berberis lycium*, *Rosa brunonii*, *Rosa webbiana*, and *Rubus ellipticus*.

14.6.2.9 Subtype 12/2S1: Low-Level Bblue Pine Forest

This forest type extends from Seri to Renda at around 1500 m with blue pine (*Pinus wallichiana*) patches that start appearing at Seri around 1300 m. Soil pH further declines. Sites like Amiranagar, Gatha, are low in organic carbon and organic matter, nitrogen, and potassium, whereas phosphorus is high. Soil texture is loamy except at Renda. Condition is almost similar on both the banks of the stream.

14.6.2.10 Type 13/C4: West Himalayan High-Level Dry Blue Pine Forest

The forests around Guptganga, Dareja, Bheja, Thanthera, and Thanalla show the dominance of *Pinus wallichiana*. It gets mixed with *Cedrus deodara* and the plantations of *Robinia pseudoacacia* along both the banks at Guptganga and Dareja. The main understorey constituents in this forest area are *Berberis lycium*, *Daphne oleoides*, and *Prinsepia utilis*. Soil pH recorded is more or less acidic (at Bheja as low as 5.9) in these forests while the soils are loamy in texture. Organic carbon, organic matter, nitrogen, and phosphorus are high, whereas potassium is moderate.

With the estimated forest cover of 21.54% (FSI 2017), the forests of Jammu and Kashmir have been classified into five major forest types and 29 minor forest types (NRSA 2002) following Champion and Seth (1968) classification. Several authors while working on the forests of Jammu and Kashmir including Bhaderwah found different forest types (Ashutosh et al. 2010; Dutt 2005; Farooq and Rashid 2010; Jhangir 2004; Kesar 2002; Kumar et al. 2014; Najeeb 2014; Sharma and Raina 2013; Sharma et al. 2016; Singh 2019).

14.6.3 Species Composition and Richness

In terms of species richness taken as the total count, of the total 248 species recorded, 39 were trees, 49 shrubs, and 170 herbs. In terms of trees, riparian forests exhibited maximum richness (nine species) at Seri and Bheja followed by Thanthera, Thanalla, and Pranoo. Upland forests exhibited higher richness along left bank upland forests with 19 species at Seri. Right bank upland forest was less speciose containing 13 species at Guptganga (1600 m). The shrub richness was high in the riparian corridor with a high number recorded at Dranga, Bhalla, and Thanthera (Table 14.3). The left bank upland forests contained 18 shrubs at Seri, 16 at Dranga, and 15 at Drudu (elevation 1300 m to 1370 m). The herbaceous layer was more species rich in the whole study corridor. The upland forests exhibited a high herbaceous richness in mid-elevation sites from 1250 m to 1450 m (Table 14.3). The subtropical elements mainly included *Olea cuspidata*, *Melia azedarach*, and *Dalbergia sissoo*, while the sub-temperate zone comprised *Pinus roxburghii*, *Pinus wallichiana*, *Alnus nitida*, and the temperate zone dominated with *Ailanthus altissima*, *Abies pindrow*, and *Picea smithiana* along the riparian and upland buffers.

14.6.4 Raunkiaer's Frequency and Vegetation Distribution

The number of species encountered in all the five Raunkiaer's frequency classes (with 20% class interval) was calculated for the whole study area and for the riparian and upland forests along the study corridor. The results revealed that maximum number of species is represented in frequency classes C and D in all three zones. The frequency ratio between E + D and B + C showed a mixed trend with the values obtained less than one (0.95 and 0.78) for riparian forest ($A < B < C > D < E$). Left bank upland forests clearly suggested the heterogeneous distribution of vegetation

Table 14.3 Species richness for trees, shrubs, and herbs along the riparian and upland forests in the study corridor

S. no.	Sites	Upland forest (left)			Riparian forest			Upland forest (right)		
		T	S	H	T	S	H	T	S	H
1.	Pul Doda	6	7	7	3	4	6	6	8	14
2.	Galgander	6	5	13	4	2	8	4	5	10
3.	Pranoo	11	11	21	7	5	17	10	4	24
4.	Bhalla	7	12	23	4	4	16	11	7	18
5.	Seri	19	18	33	9	10	24	11	11	31
6.	Drudu	13	15	32	5	8	23	8	7	20
7.	Dranga	12	16	26	6	11	22	8	6	25
8.	Amiranagar	13	10	30	3	7	20	7	10	23
9.	Gatha	9	9	13	6	3	10	4	5	12
10.	Renda	6	11	14	4	8	23	9	10	16
11.	Guptganga	13	14	23	6	6	23	13	11	21
12.	Dareja	12	12	18	4	6	25	11	9	17
13.	Bheja	11	14	41	9	5	18	10	14	24
14.	Thanthera	7	15	33	7	10	24	6	11	18
15.	Thanalla	8	12	23	7	6	30	8	13	22

T tree, *S* shrub, *H* herb

where A < B < C > D > E. The right bank upland forests on the contrary exhibited homogenous pattern (A < B < C < D > E). When calculated for the whole corridor for all the species, the frequency classes C (33.94), D (32.66) and E (18.34) included 85% of the total species of study area. The Raunkiaer's frequency is represented as A < B < C > D > E with E + D and B + C ratio obtained larger than one (1.07) suggesting a homogenous type of distribution (Table 14.4, Fig. 14.2).

14.6.5 Distribution of Vegetation

Abundance frequency ratio used to interpret the distribution pattern of species was calculated for woody species (trees and shrubs) and herbs in all sites along the study corridor (Tables 14.5, 14.6, and 14.7).

The results revealed that most of the vegetation shows random and clumped distribution with a pinch of vegetation exhibiting regular distribution in a small section of study area. The clumped distribution is the most common pattern in nature, whereas the random distribution occurs only in uniform environments and the regular distribution emerges when individuals are in intense competition. *Alnus nitida*, the principal tree species in the riparian zone, showed more of a clumped distribution with the evidence of random distribution at the lower and moderately higher elevations (Site 3 to Site 13). The upland forests dominated by a mix of species revealed more of a random pattern followed by clumped distribution along the upland forests on both sides of the stream. The right bank comprises of a mix of

Table 14.4 Raunkiaer's frequency classes for the study area

Zones	A	B	C	D	E	RFDn	FR	Dn
RF	0 (0)[a]	12.55 (29)	38.09 (88)	32.46 (75)	16.01 (39)	A < B < C > D < E	0.95	He
UFLB	1.11 (07)	17.77 (64)	37.22 (134)	29.16 (105)	13.88 (50)	A < B < C > D > E	0.78	He
UFRB	0.35 (01)	11.38 (32)	32.02 (90)	34.37 (98)	21.30 (60)	A < B < C < D > E	1.28	Ho
SC	1.65 (18)	13.39 (146)	33.94 (370)	32.66 (356)	18.34 (200)	A < B < C > D > E	1.07	Ho

[a]Number in parentheses is the number of species in case of riparian and upland forests and frequency of occurrence in case of whole study corridor; RF, riparian forest; UF, upland forest (LB, left bank; RB, right bank); SC, study corridor; RFC, Raunkiaer's frequency classes A (1–20%), B (20–40%), C (40–60%), D (60–80%), and E (80–100%); RFDn, Raunkiaer's frequency distribution (He, heterogenous; Ho, homogenous); FR, frequency ratio (E + D/B + C)

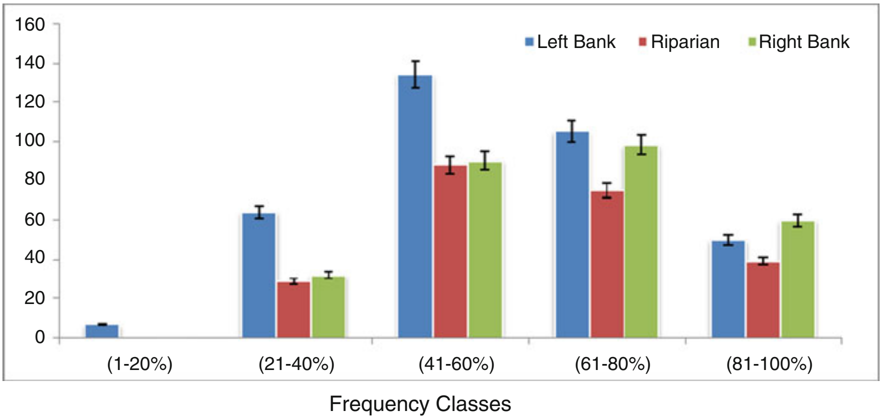

Fig. 14.2 Raunkiaer's frequency classes for the study areas

Pinus roxburghii, *Cedrus deodara*, and *Pinus wallichiana* with representation of *Populus ciliata* at Guptganga (Site 11). All the species except *Pinus roxburghii* at Site 3 (clumped) and *Punica granatum* at Pul Doda (random) exhibited regular distribution. The trees exhibited the random pattern followed by clumped distribution along the upland forests while riparian corridor showed a clumped pattern for most of the sites and random in few sections (Table 14.5).

The abundance frequency ratio obtained for the understorey layer suggests more of a random distribution. The riparian forests showed the random distribution for the dominant *Berberis lycium* at all sites except Sites 11 (where *Cactus* sp. showed random), 14, and 15 where *Prinsepia utilis* showed random and *Berberis lycium* exhibited regular distribution. The upland forests along the left bank again showed random distribution for all the sites except Sites 14 and 15, wherein *Berberis lycium* and *Viburnum grandiflorum* exhibited regular and clumped distribution, respectively (Table 14.6). The herbaceous layer showed a mixed trend of distribution pattern with major vegetation exhibiting random and clumped distribution mixed with few cases of regular distribution. *Artemisia brevefolia* at Site 9 (Gatha) along the riparian, and *Verbascum thapsus* at right bank upland forest showed the regular distribution while other species exhibited random and clumped type of distribution along both the banks (Table 14.7).

14.6.6 Community Structure and Ecological Dominance of Vegetation

It was observed that *Alnus nitida* (IVI 88.37–148.6) dominated all the sites except Pul Doda (Site 1, the lowest elevation) and Thanalla (Site 15, the highest elevation) where *Melia azedarach* (IVI 177.2) and *Robinia pseudoacacia* (IVI 89.69) exhibited the highest importance values along the riparian forest zone (Table 14.5). A patch *Pinus roxburghii* (IVI 107.4) was observed near Galgander (Site 2). On the contrary,

Table 14.5 Distribution pattern and phytosociological attributes (highest IVI) of trees

Sites/	Upland forest (left bank)			Riparian forest			Upland forest (right bank)		
location	Species	IVI	AF ratio	Species	IVI	AF ratio	Species	IV	AF ratio
Site 1 Pul Doda	*Pinus roxburghii*	73.42	0.03 (R)	*Melia azedarach*	177.2	0.04 (R)	*Punica granatum*	56.47	0.02 (re)
Site 2 Galgander	*Pinus roxburghii*	88.80	0.05 (R)	*Pinus roxburghii*	107.5	0.03 (R)	*Quercus baloot*	129.5	0.032 (R)
Site 3 Pranoo	*Quercus baloot*	61.96	0.06 (C)	*Alnus nitida*	128.9	0.077 (C)	*Pinus roxburghii*	65.53	0.053 (C)
Site 4 Bhalla	*Pinus roxburghii*	89.08	0.03 (R)	*Alnus nitida*	148.6	0.05 (C)	*Pinus roxburghii*	64.86	0.035 (R)
Site 5 Seri	*Cedrus deodara*	43.24	0.05 (R)	*Alnus nitida*	136.2	0.09 (C)	*Pinus roxburghii*	64.74	0.04 (R)
Site 6 Drudu	*Cedrus deodara*	56.63	0.05 (C)	*Alnus nitida*	134.1	0.078 (C)	*Cedrus deodara*	95.24	0.046 (R)
Site 7 Dranga	*Pinus wallichiana*	60.78	0.04 (R)	*Alnus nitida*	100.3	0.06 (C)	*Cydonia oblonga*	81.44	0.04 (R)
Site 8 Amiranagar	*Cedrus deodara*	42.6	0.04 (R)	*Alnus nitida*	128.1	0.05 (C)	*Pinus wallichiana*	97.49	0.043 (R)
Site 9 Gatha	*Ficus palmata*	57.75	0.04 (R)	*Alnus nitida*	136.8	0.05 (R)	*Cedrus deodara*	108.8	0.028 (R)
Site 10 Renda	*Robinia pseudoacacia*	92.99	0.05 (R)	*Alnus nitida*	119.5	0.08 (C)	*Cedrus deodara*	50.3	0.029 (R)
Site 11 Guptganga	*Robinia pseudoacacia*	68.36	0.06 (C)	*Alnus nitida*	88.37	0.08 (C)	*Populus ciliata*	43.36	0.032 (R)
Site 12 Dareja	*Populus ciliata*	59.38	0.05 (R)	*Alnus nitida*	134.5	0.07 (C)	*Pinus wallichiana*	52.63	0.034 (R)
Site 13 Bheja	*Cedrus deodara*	53.07	0.02 (re)	*Alnus nitida*	110.8	0.07 (C)	*Pinus wallichiana*	57.78	0.037 (R)
Site 14 Thanthera	*Cedrus deodara*	94.57	0.05 (C)	*Alnus nitida*	94.97	0.06 (C)	*Pinus wallichiana*	97.89	0.042 (R)
Site 15 Thanalla	*Ailanthus altissima*	60.84	0.05 (C)	*Robinia pseudoacacia*	89.7	0.04 (R)	*Pinus wallichiana*	70.14	0.045 (R)

Table 14.6 Distribution pattern and phytosociological attributes (highest IVI) of shrubs

	Upland forest (left bank)			Riparian forest			Upland forest (right bank)		
Sites	Species	IVI	AF ratio	Species	IVI	AF ratio	Species	IVI	AF ratio
Site 1 Pul Doda	*Artemisia myriantha*	62.95	0.049 (R)	*Daphne oleoides*	108.5	0.028 (R)	*Berberis lycium*	76.39	0.028 (R)
Site 2 Galgander	*Berberis lycium*	99.63	0.035 (R)	*Daphne oleoides*	132.3	0.034 (R)	*Berberis lycium*	79.0	0.046 (R)
Site 3 Pranoo	*Berberis lycium*	64.18	0.03 (R)	*Berberis lycium*	141.9	0.034 (R)	*Berberis lycium*	110.7	0.038 (R)
Site 4 Bhalla	*Berberis lycium*	64.20	0.031 (R)	*Berberis lycium*	80.34	0.026 (R)	*Prinsepia utilis*	79	0.027 (R)
Site 5 Seri	*Prinsepia utilis*	35.51	0.029 (R)	*Berberis lycium*	70.33	0.034 (R)	*Berberis lycium*	53.15	0.034 (R)
Site 6 Drudu	*Berberis lycium*	66.25	0.037 (R)	*Berberis lycium*	115.2	0.032 (R)	*Berberis lycium*	98.00	0.03 (R)
Site 7 Dranga	*Berberis lycium*	54.91	0.03 (R)	*Prinsepia utilis*	65.38	0.028 (R)	*Berberis lycium*	81.8	0.03 (R)
Site 8 Amiranagar	*Berberis lycium*	69.8	0.033 (R)	*Prinsepia utilis*	70.58	0.036 (R)	*Berberis lycium*	65.93	0.028 (R)
Site 9 Gatha	*Berberis lycium*	73.82	0.025 (re)	*Berberis lycium*	106	0.036 (R)	*Berberis lycium*	91.41	0.032 (R)
Site 10 Renda	*Berberis lycium*	60.57	0.027 (R)	*Prinsepia utilis*	98.02	0.032 (R)	*Berberis lycium*	72.04	0.033 (R)
Site 11 Guptganga	*Berberis lycium*	54.87	0.028 (R)	*Prinsepia utilis*	86.95	0.03 (R)	*Cactus* sp.	41.10	0.026 (R)
Site 12 Dareja	*Berberis lycium*	40.06	0.04 (R)	*Berberis lycium*	129.6	0.028 (R)	*Berberis lycium*	62.42	0.034 (R)
Site 13 Bheja	*Berberis lycium*	53.86	0.025 (re)	*Berberis lycium*	130.90	0.03 (R)	*Berberis lycium*	38.30	0.049 (R)
Site 14 Thanthera	*Viburnum grandiflorum*	45.78	0.033 (R)	*Prinsepia utilis*	96.01	0.032 (R)	*Prinsepia utilis*	53.06	0.024 (re)
Site 15 Thanalla	*Viburnum grandiflorum*	64.31	0.055 (C)	*Berberis lycium*	81.07	0.025 (re)	*Prinsepia utilis*	43.81	0.029 (R)

Table 14.7 Distribution pattern and phytosociological attributes (highest IVI) of herbs

	Upland forest (left bank)			Riparian forest			Upland forest (right bank)		
Sites	Species	IVI	AF ratio	Species	IVI	AF ratio	Species	IVI	AF ratio
Site 1 Pul Doda	*Anthemis cotula*	58.1	0.08 (C)	*Artemisia vestita*	105.2	0.05 (R)	*Artemisia vestita*	42.5	0.03 (R)
Site 2 Galgander	*Verbascum thapsus*	43.3	0.03 (R)	*Cannabis sativa*	76.11	0.03 (R)	*Artemisia vestita*	50.4	0.04 (R)
Site 3 Pranoo	*Artemisia vestita*	22.9	0.03 (R)	*Artemisia vestita*	39.44	0.05 (C)	*Verbascum thapsus*	30.3	0.04 (R)
Site 4 Bhalla	*Imperata cylindrica*	30.1	0.03 (R)	*Artemisia vestita*	51.91	0.05 (R)	*Oenothera rosea*	34.8	0.04 (R)
Site 5 Seri	*Chrysopogon gryllus*	17.6	0.03 (R)	*Cannabis sativa*	26.68	0.03 (R)	*Verbascum thapsus*	19.0	0.06 (C)
Site 6 Drudu	*Capsella bursa-pastoris*	18.9	0.07 (C)	*Artemisia vestita*	31.82	0.05 (C)	*Imperata cylindrica*	31.7	0.04 (R)
Site 7 Dranga	*Trifolium pratense*	22.9	0.08 (C)	*Cannabis sativa*	39.95	0.05 (C)	*Verbascum thapsus*	34.5	0.04 (R)
Site 8 Amiranagar	*Cannabis sativa*	21.2	0.38 (R)	*Cannabis sativa*	40.38	0.04 (R)	*Verbascum thapsus*	26.9	0.02 (re)
Site 9 Gatha	*Trifolium pratense*	41.2	0.10 (C)	*Artemisia brevefolia*	47.19	0.02 (re)	*Cannabis sativa*	53.9	0.05 (R)
Site 10 Renda	*Verbascum thapsus*	49.8	0.04 (R)	*Cannabis sativa*	44.89	0.04 (R)	*Digitalis purpurea*	33.2	0.09 (C)
Site 11 Guptganga	*Plantago lanceolata*	25.9	0.046 (R)	*Plantago lanceolata*	34.71	0.05 (R)	*Artemisia scoparia*	31.5	0.03 (R)
Site 12 Dareja	*Trifolium pratense*	43.0	0.109 (C)	*Plantago lanceolata*	36.45	0.04 (R)	*Trifolium pratense*	29.9	0.05 (C)
Site 13 Bheja	*Trifolium pratense*	17.4	0.06 (C)	*Artemisia scoparia*	30.23	0.36 (R)	*Artemisia scoparia*	25.0	0.05 (R)
Site 14 Thanthera	*Trifolium pratense*	19.2	0.09 (C)	*Digitalis purpurea*	34.41	0.03 (R)	*Digitalis purpurea*	33.5	0.04 (R)
Site 15 Thanalla	*Digitalis purpurea*	24.5	0.04 (R)	*Aquilegia pubiflora*	25.22	0.04 (R)	*Taraxacum officinale*	21.6	0.04 (R)

C clumped, *R* random, *Re* regular

upland forests along both the banks revealed the domination of conifers in the form of *Pinus roxburghii*, *Pinus wallichiana*, and *Cedrus deodara* interspersed with *Quercus baloot*, *Robinia pseudoacacia*, *Populus ciliata*, *Ficus palmata*, *Ailanthus altissima*, and *Cydonia oblonga*. While the left bank revealed the prevalence of broad-leaved trees, the conifer-broad-leaved mixed upper storey dominated right banks in the riparian zone (Table 14.5).

Among the shrubs, the maximum importance value was exhibited by *Berberis lycium* (IVI 141.90, Site 2) which dominates the whole stretch (Table 14.6). The riparian forests exhibited the dominance of *Prinsepia utilis* that preferred the moister shady locations while *Berberis lycium* showed more or less similar occupancy along the drier up slopes as well. The lower elevations supported gregarious population of *Daphne oleoides* (IVI 108.5, Site 1) and (IVI 132.3, Site 2). *Berberis lycium* dominated the upland forests along both the banks except for Seri (Site 5, IVI 35.50, *Prinsepia utilis*), Thanthera (Site 14, IVI 53.05, *Viburnum grandiflorum*), and Thanalla (Site 15, IVI 43.81, *Viburnum grandiflorum*). *Berberis lycium* grows equally good along both the slopes in the upland forest buffers. *Artemisia myriantha* (IVI 62.95) revealed its dominance at Pul Doda (Site 1) which is taken over by its co-associate *Berberis lycium* along all the sites till Bheja (Site 13) except Seri (Site 5) wherein *Prinsepia utilis* dominated the understorey. The higher elevations at Thanthera (Site 14) and Thanalla (Site 15) exhibited the predominance of *Viburnum grandiflorum* with importance values of 45.78 and 64.3, respectively (Table 14.6).

The dominance of herbs in terms of their importance values varied from site to site with no defined trend in terms of their dominance and distribution as observed for trees and shrubs. All the herb species were distributed more or less equally throughout the study area. Few species like *Digitalis purpurea*, *Aquilegia pubiflora*, and *Artemisia scoparia* were found at the higher elevations whereas the species like *Trifolium pratense*, *Anthemis cotula*, *Taraxacum officinale*, *Cannabis sativa*, and *Verbascum thapsus* were observed widespread (Table 14.7).

14.6.7 Major Tree Associations and Extent of Similarity (Hierarchical Cluster Analysis)

The densely wooded study corridor, displayed a high level of linkage with pure and mixed stands, which were found in many releves along the rising elevation. The upland forests along both the banks supported 15 tree associations each whereas the riparian stretch supported 8 different combinations mostly involving *Alnus nitida* as a dominant species (Table 14.8, Figs. 14.3, 14.4, and 14.5). A hierarchical cluster analysis using average linkages was performed for riparian and upland forests to better understand the similarities between the vegetation types in different sites, and dendrograms were obtained for each. Trees, shrubs, and herbs associations were considered for the analysis (Figs. 14.6, 14.7, and 14.8).

Pinus roxburghii-Quercus baloot-Robinia pseudoacaciaPinus roxburghii-Quercus baloot-Populus ciliata QB-PR-MA Quercus baloot-Pinus roxburghii-Melia azedarach, *PR-AN-MA Pinus roxburghii-Alnus nitida-Melia azedarach*,

Table 14.8 Major tree associations in the study corridor

Upland forests (left bank)	Riparian forests	Upland forests (right bank)
Along the rising elevation		
1. *Pinus roxburghii-Quercus baloot-Robinia pseudoacacia* 2. *Pinus roxburghii-Quercus baloot-Populus ciliata* 3. *Quercus baloot-Pinus roxburghii-Melia azedarach* 4. *Pinus roxburghii-Alnus nitida-Melia azedarach* 5. *Cedrus deodara-Pinus wallichiana-Robinia pseudoacacia* 6. *Cedrus deodara-Populus ciliata-Robinia pseudoacacia* 7. *Pinus wallichiana-Cedrus deodara-Robinia pseudoacacia* 8. *Cedrus deodara-Pinus wallichiana-Alnus nitida* 9. *Ficus palmata-Robinia pseudoacacia-Alnus nitida* 10. *Robinia pseudoacacia-Pinus wallichiana-Populus ciliata* 11. *Robinia pseudoacacia-Pinus wallichiana-Quercus leucotrichophora* 12. *Populus ciliata-Robinia pseudoacacia-Alnus nitida* 13. *Cedarus deodara-Pinus wallichiana-Ailanthus altissima* 14. *Cedrus deodara-Pinus wallichiana-Quercus leucotrichophora* 15. *Ailanthus altissima-Pinus wallichiana-Quercus baloot*	1. *Melia azedarach-Ficus palmata-Robinia pseudoacacia* 2. *Ficus palmata—Pinus roxburghii—Quercus baloot* 3. *Alnus nitida-Ficus palmata-Quercus baloot* 4. *Alnus nitida-Ficus palmata-Quercus leucotrichophora* 5. *Alnus nitida-Ficus palmata-Robinia pseudoacacia* 6. *Alnus nitida-Pinus wallichiana-Cedrus deodara* 7. *Alnus nitida-Ficus palmata-Pinus wallichiana* 8. *Alnus nitida-Ficus palmata-Populus ciliata*	1. *Punica granatum-Ficus palmata-Melia azedarach* 2. *Quercus baloot-Pinus roxburghii-Quercus leucotrichophora* 3. *Pinus roxburghii-Quercus baloot-Quercus leucotrichophora* 4. *Pinus roxburghii-Melia azedarach-Ficus palmata* 5. *Pinus roxburghii-Quercus leucotrichophora-Cedrus deodara* 6. *Cedrus deodara-Cydonia oblonga-Melia azedarach* 7. *Cydonia oblonga-Pinus wallichiana-Cedrus deodara* 8. *Pinus wallichiana-Cedrus deodara-Punica granatum* 9. *Cedrus deodara-Pinus wallichiana-Populus ciliata* 10. *Cedrus deodara-Ficus rumphii-Pinus wallichiana* 11. *Populus ciliata-Pinus wallichiana-Robinia pseudoacacia* 12. *Pinus wallichiana-Ficus palmata-Cedrus deodara* 13. *Pinus wallichiana-Cedrus deodara-Salix alba* 14. *Pinus wallichiana-Cedrus deodara-Quercus baloot* 15. *Pinus wallichiana-Cedrus deodara-Abies pindrow*

CD-PW-RP Cedrus deodara-Pinus wallichiana-Robinia pseudoacacia, *CD-PC-RP Cedrus deodara-Populus ciliata-Robinia pseudoacacia*, *PW-CD-RP Pinus wallichiana-Cedrus deodara-Robinia pseudoacacia*, *CD-PW-AN Cedrus deodara-Pinus wallichiana-Alnus nitida*, *FP-RP-AN Ficus palmata-Robinia pseudoacacia-Alnus nitida*, *RP-PW-PC Robinia pseudoacacia-Pinus wallichiana-Populus ciliata*, *RP-PW-QL Robinia pseudoacacia-Pinus wallichiana-Quercus leucotrichophora*, *PC-RP-AN Populus ciliata-Robinia pseudoacacia-Alnus nitida*, *CD-PW-AA Cedrus deodara-Pinus wallichiana-Ailanthus altissima, CD-PW-QL Cedrus deodara-Pinus wallichiana-Quercus leucotrichophora*, *AA-PW-QB Ailanthus altissima-Pinus wallichiana-Quercus baloot*.

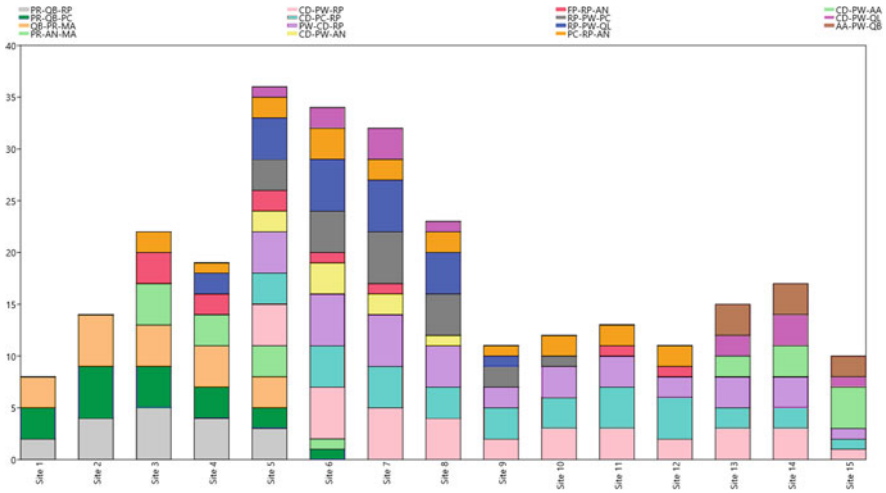

Fig. 14.3 Site wise vegetational associations in terms of number of releves of occurrence per site in upland forests (left bank). PR-QB-RP *Pinus roxburghii-Quercus baloot-Robinia pseudoacacia,* PR-QB-PC *Pinus roxburghii-Quercus baloot-Populus ciliata,* QB-PR-MA *Quercus baloot-Pinus roxburghii-Melia azedarach,* PR-AN-MA *Pinus roxburghii-Alnus nitida-Melia azedarach,* CD-PW-RP *Cedrus deodara-Pinus wallichiana-Robinia pseudoacacia,* CD-PC-RP *Cedrus deodara-Populus ciliata-Robinia pseudoacacia,* PW-CD-RP *Pinus wallichiana-Cedrus deodara-Robinia pseudoacacia,* CD-PW-AN *Cedrus deodara-Pinus wallichiana-Alnus nitida,* FP-RP-AN *Ficus palmata-Robinia pseudoacacia-Alnus nitida*, RP-PW-PC *Robinia pseudoacacia-Pinus wallichiana-Populus ciliata*, RP-PW-QL *Robinia pseudoacacia-Pinus wallichiana-Quercus leucotrichophora*, PC-RP-AN *Populus ciliata-Robinia pseudoacacia-Alnus nitida,* CD-PW-AA *Cedrus deodara-Pinus wallichiana-Ailanthus altissima*, CD-PW-QL *Cedrus deodara-Pinus wallichiana-Quercus leucotrichophora,* and, AA-PW-QB *Ailanthus altissima-Pinus wallichiana-Quercus baloot*

14.6.8 The Upland Forests (Left Bank)

The upland forests along the left banks of Neeru stream are represented by fairly good diversity of trees forming 15 associations (Table 14.8) with the dominance of *Pinus roxburghii* in the lower elevational band followed by *Robinia pseudoacacia* and *Alnus nitida* in the middle and *Cedrus deodara* in higher elevations. Three main clusters have been identified for all three layers, trees, shrubs, and herbs in riparian and upland forests in the entire study corridor (Figs. 14.6, 14.7, and 14.8). In the left bank upland forests, the trees grouped in cluster I comprise of Sites 4, 14, 2, 10, 1, 9, and 15, and cluster II represented in Sites 3, 13, 7, 12, 8, 11, and 6. Cluster III is simplicifolius supporting only one Site 5, Seri (Fig. 14.6). Similarly for shrubs Sites 12, 15, 4, 3, 10, 8, and 9 forms cluster I whereas cluster II includes Sites 6, 14, 11, 13, 7, and 5. Cluster III is bifolius and represented in Sites 1 and 2. For herbs, cluster I is represented by Sites 11, 15, 4, 3, 7, 5, 14, 6, and 8, cluster II (Site 13), and cluster III (Sites 2, 9, 10, 12 and 1). Sites 5, 6, 7, and 8 represented maximum associations of trees in decreasing order with maxima of 13 associations in Site 5 followed by

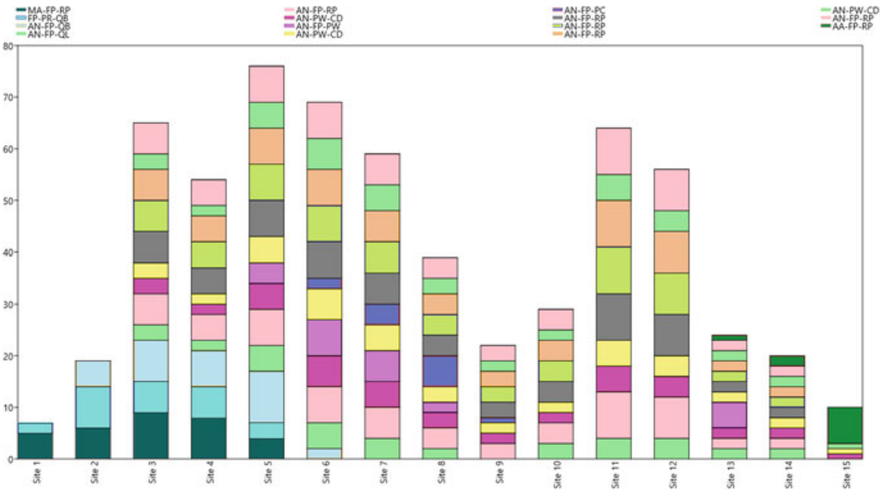

Fig. 14.4 Site wise vegetation associations in terms of number of releves of occurrence per site in riparian forests. *MA-FP-RP Melia azedarach-Ficus palmata-Robinia pseudoacacia*, *FP-PR-QB Ficus palmata-Pinus roxburghii-Quercus baloot*, *AN-FP-QB Alnus nitida-Ficus palmata-Quercus baloot*, *AN-FP-QL Alnus nitida-Ficus palmata-Quercus leucotrichophora*, *AN-FP-RP Alnus nitida-Ficus palmata-Robinia pseudoacacia*, *AN-PW-CD Alnus nitida-Pinus wallichiana-Cedrus deodara*, *AN-FP-PW Alnus nitida-Ficus palmata-Pinus wallichiana*, *AN-FP-PC Alnus nitida-Ficus palmata-Populus ciliata*

11 associations in Site 6 (Fig. 14.3). *Cedrus deodara-Pinus wallichiana-Robinia pseudoacacia*; *Cedrus deodara-Populus ciliata-Robinia pseudoacacia*; and *Pinus wallichiana-Cedrus deodara-Robinia pseudoacacia* emerged as the dominant trees associations along the upland left bank forests (Fig. 14.3).

14.6.9 Riparian Forests

The riparian forests along the study corridor are represented by eight major tree associations dominated by *Alnus nitida*, *Ficus palmata*, *Robinia pseudoacacia*, *Pinus roxburghii*, *Pinus wallichiana*, and *Cedrus deodara* (Table 14.8). Cluster I included Sites 14, 15, 8, 9, 11, 7, and 6; while cluster II comprised of Sites 1, 8, 10, 12, 4, and 2; and cluster III represented by Sites 5 and 18, respectively. Three clusters among the shrubs included Sites 12, 15, 11, 8, 6, and 10 in cluster I. Clusters II and III included Sites 2, 9, 3, 13, 1, and 4 and 5, 14, and 7, respectively. Three clusters were identified for herbs too, and these included Sites 5, 14, 12, 10, 11, 6, and 7 (cluster I); Sites 3, 13, 4, 8, and 15 (Cluster II); and Sites 2, 9, and 1 (cluster III), respectively (Fig. 14.7). The riparian forests showed lesser tree associations when compared with the uplands forest along both banks. Though a more uniformity was observed as 8 sites showed more than 10 tree associations with a high of 13 occurring in Site 5 followed by Sites 3, 4, and 6 (12 associations). *Alnus*

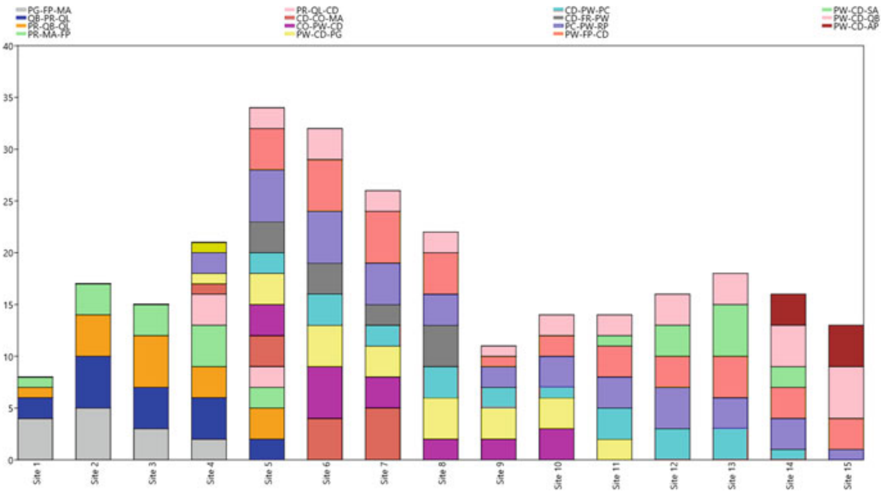

Fig. 14.5 Site wise vegetation associations in terms of number of releves of occurrence per site in upland forests (right bank). *Punica granatum-Ficus palmata-Melia azedarach*, QB-PR-QL *Quercus baloot-Pinus roxburghii-Quercus leucotrichophora*, *PR-QB-QL Pinus roxburghii-Quercus baloot-Quercus leucotrichophora*, *PR-MA-FP Pinus roxburghii-Melia azedarach-Ficus palmata*, *PR-QL-CD Pinus roxburghii-Quercus leucotrichophora-Cedrus deodara*, *CD-CO-MA Cedrus deodara-Cydonia oblonga-Melia azedarach*, *CO-PW-CD Cydonia oblonga-Pinus wallichiana-Cedrus deodara, PW-CD-PG Pinus wallichiana-Cedrus deodara-Punica granatum*, *CD-PW-PC Cedrus deodara-Pinus wallichiana-Populus ciliata*, *CD-FR-PW Cedrus deodara-Ficus rumphii-Pinus wallichiana*, *PC-PW-RP Populus ciliata-Pinus wallichiana-Robinia pseudoacacia*, *PW-FP-CD Pinus wallichiana-Ficus palmata-Cedrus deodara*, *PW-CD-SA Pinus wallichiana-Cedrus deodara-Salix alba*, *PW-CD-QB Pinus wallichiana-Cedrus deodara-Quercus baloot*, *PW-CD-AP Pinus wallichiana-Cedrus deodara-Abies pindrow*

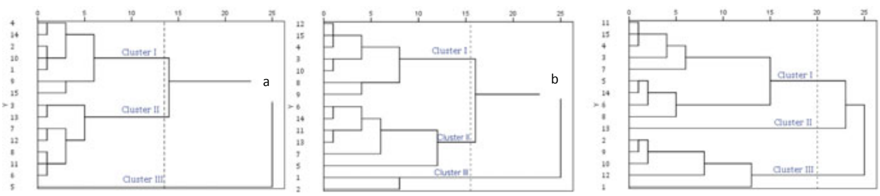

Fig. 14.6 Hierarchal cluster dendrograms for (**a**) trees, (**b**) shrubs, and (**c**) herbs in upland left bank forest

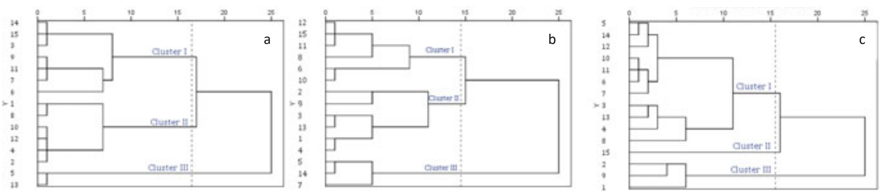

Fig. 14.7 Hierarchal cluster dendrograms for (**a**) trees, (**b**) shrubs, and (**c**) herbs in riparian forest

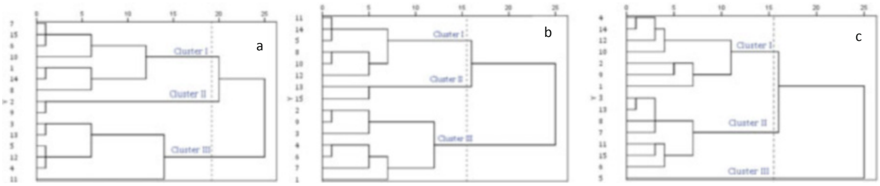

Fig. 14.8 Hierarchal cluster dendrograms for (**a**) trees, (**b**) shrubs, and (**c**) herbs in upland right bank forest

nitida-Ficus palmata-Robinia pseudoacacia and *Alnus nitida-Pinus wallichiana-Cedrus deodara* were the prominent associations found in several releves (Fig. 14.4).

14.6.10 The Upland Forests (Right Bank)

The upland forests along the right banks of Neeru stream are represented by fairly good diversity of trees forming 15 associations (Table 14.8). The lower elevations are represented by *Quercus-Pinus roxburghii* associations, the middle and high by a mix of *Pinus wallichiana* and *Cedrus deodara* patches. The trees along the right bank are represented by three clusters, cluster I including Sites 7, 15, 6, 10, 1, 14, and 8; cluster II (Sites 2 and 9); and Cluster III (Sites 3, 13, 5, 12, 4, and 11). For shrubs, cluster I comprised of Sites 11, 14, 5, 8, 10, 12, 13, and 15 whereas cluster II included sites 2, 9, and 3; and cluster III Sites 4, 6, 7, and 1. For herbs, Sites 4, 14, 12, 10, 2, 9, and 1 contributed to cluster I whereas cluster II comprised of Sites 2, 13, 8, 7, 11, 15, and 6, and cluster III included Site 5 only (Fig. 14.8). The major tree associations encountered in the relevesincluded *Populus ciliata-Pinus wallichiana-Robinia pseudoacacia*; *Pinus wallichiana-Ficus palmata-Cedrus deodara*; *Pinus wallichiana-Cedrus deodara-Quercus baloot*; and *Cedrus deodara-Pinus wallichiana-Populus ciliata* (Fig. 14.5).

14.7 Conclusion

The structure and richness of the riparian vegetation close to the stream, flood plains, and little away from the floodplains are well documented in this chapter. It was observed that the richness of the vegetation in the upland forest is greater than that of the riparian forest; however, the evenness of the vegetation is higher in the riparian forest when the two were compared. The left bank appears more diverse, even and species rich as compared to right bank of the stream. The vegetation pattern and structure exhibit a marked variation along the rising elevation. *Alnus nitida*, the most dominant and widely distributed tree species along the channel, showed clumped distribution in riparian belt and random distribution pattern at lower and moderately higher elevations. The trees exhibited the random pattern followed by clumped along the higher slopes, whereas riparian forests showed a clumped pattern for most of the sites followed by random in few sites. Shrubs showed random distribution in the riparian as well as upland forests. The herbaceous layer being highly heterogeneous showed a mixed trend in the distribution with most of the sites showing random and clumped distribution with few cases of regular distribution. Raunkiaer's frequency classes reveal the highest frequency of occurrence of majority of species in class C and D pointing towards the homogeneity in the riparian corridor, while the upland forests along both the banks were observed to be heterogeneous. The whole corridor as a single unit was however homogenous. The findings confirm that the corridor is resource-rich and that there are better chances of survival and adaptation, resulting in high levels of abundance, frequency, diversity, and species richness along its length. Diverse plant associations were recorded with 8 associations in the riparian zone and 15 each along the left and right bank upland. *Alnus nitida* emerged as a major dominant and *Ficus palmata* and *Robinia pseudoacacia* as codominants along the riparian stretch and conifers interspersed with broad-leaved species along the upland buffers.

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15

Land Degradation Neutrality in Coastal India: Case of Mobius' Strip Linking Pedodiversity and Biodiversity

Tapas Bhattacharyya and Vinayak Patil

Abstract

Land degradation neutrality (LDN) seems to be scale-sensitive depending on various requirements. Although pedodiversity and biodiversity appear to be non-converging, however, appropriate scale used to collect both soil and biodiversity data may help to comment better on this mobius relation. Pedodiversity and biodiversity are both important while adopting LDN methodology. Since land use is dynamic therefore LDN, pedodiversity and biodiversity should be considered holistically to suggest sustainable land use planning for addressing various developmental goals. Present attempt addresses a few such issues with Konkan, Maharashtra, India, as mode.

Keywords

Land degradation neutrality (LDN) · Pedodiversity · Biodiversity · Mobius · Land use planning · Konkan

15.1 Land Degradation Neutrality (LDN)

Discussions around climate change seldom refer to soil, even though the major soil forming factor is climate. Because land mass is fixed in quantity, there is an ever-increasing competition to control land resources in terms of their services for the living organisms. Land area is dwindling due to many reasons. The main reason is its degradation, both natural and anthropogenic. It seems, therefore, logical, to save our motherland and focus on LDN whereby the amount and quality of land resources, necessary to support ecosystem functions and services and to enhance food security,

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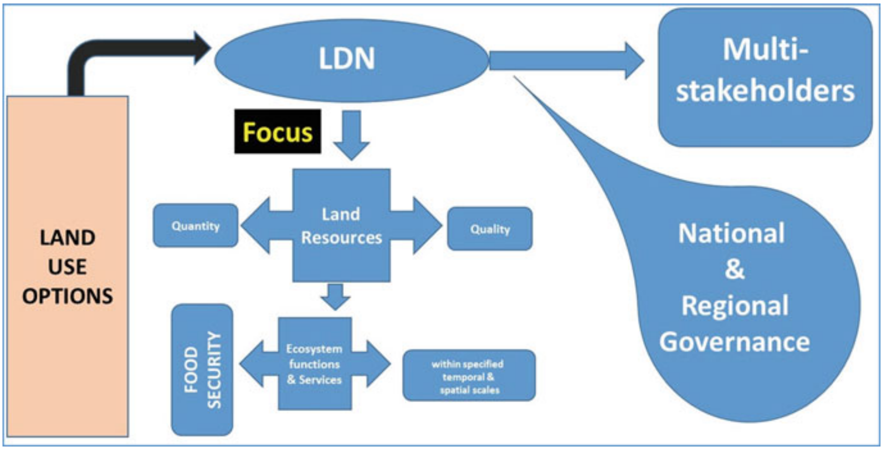

Fig. 15.1 LDN and land options: a schematic diagram (Bhattacharyya et al. 2020)

remain stable or increase within specified temporal and spatial scales and ecosystems. Three case studies, one in high rainfall areas and the two in the semi-arid tropics (SAT), are showcased to address the LDN. These observations can act as model land use options to further LDN in similar areas in other parts of the world including India. Such steps to adopt LDN policies will render land resources to be protected and restored for promoting sustainable use of terrestrial ecosystems including forests since these procedures help reversing land/soil degradation and to combat climate change. Major soil (and landscape) forming factor is climate (Jenny 1941), and therefore, the issues of climate change always involve soils/lands; so far its effect on terrestrial ecosystem is concerned.

LDN assists to keep the land resources stable and may also improve its quality within specified temporal and spatial scales and ecosystems. Since land and/or soil degradation has the potential to cause social problems leading to poverty and malnutrition, the implementation of LDN requires involvement of multi-stakeholders with adequate support of the national and regional governments (Fig. 15.1).

LDN is directly related to land use and land use is related to quality of land/soils which is diverse in nature. This diversity of soil termed as pedodiversity is linked to biodiversity to determine the present and suggested land use. Therefore, to achieve LDN there should be a mutual convergence of pedodiversity and biodiversity to realize its (LDN) success. Do pedodiversity and biodiversity really converge? The present effort delves in this direction citing selected studies in coastal Maharashtra, India.

15.2 Achieving LDN

LDN could be achieved by balancing degradation for which major requirement is the information on soil and land. Soil resource inventory for the entire country (Bhattacharyya et al. 2009), details of soil information system, and other information are available (Bhattacharyya et al. 2021a, b). These datasets provide various case studies in different ecosystems of the country which act as model for replicating in similar situations.

Target audiences for LDN include individuals/organizations which may influence for improving or transforming land management practices and land use planning at different scales. For Indian situations, this may well include (i) each and every citizen, (ii) the farmers (do’s and don’ts), (iii) government organizations (implementation: land use for agriculture a state subject, conflict of interest!), (iv) nongovernmental organizations (NGOs), (v) universities (academia with special reference to agricultural universities (Bhattacharyya et al. 2018a, b; 2021c), and (vi) research institutes (Councils etc.).

15.3 Soil Diversity

It has long been recognized that biodiversity can be the mechanism behind the performance of an ecosystem, particularly in communities of aboveground organisms. In soils below ground, however, the functioning of biodiversity is not well understood. Soils are highly diverse. It has been estimated that 1 g of soil contains up to one billion bacteria cells consisting of tens of thousands of taxa, up to 200 million fungal hyphae, and a wide range of mites, nematodes, earthworms, and arthropods. Besides, soils contain minerals many of which act as modifiers to control the quality of soils affecting its ecosystem service. Among many parameters soil formation is controlled by climate and parent materials (rock systems) which vary in different ecosystems to give rise to different soils and bio diversity. Most of such soil diversity parameters are hidden beneath the earth surface which requires expert knowledge of scientists (pedologists, earth scientists, and others) to decode nature’s signatures. Soil diversity is thus intimately linked to aboveground biodiversity. Diversity is widely considered as synonymous to difference. Various factors cause differences in soils. These could be natural and/or anthropogenic. To understand the diversity of soils, the knowledge on the potential of soil resources and its limitations, different kinds of methods used for management of these soils either for agriculture and non-agriculture purposes is vital (Bhattacharyya 2021a).

15.3.1 Soil Diversity in Coastal India: Konkan, Maharashtra

Konkan, Maharashtra in India is different from other parts of Maharashtra and also from India in terms of variation in geology, climate, soils, and environment (Fig. 15.2). Konkan covers an area of nearly 30 lakh hectares and represents a

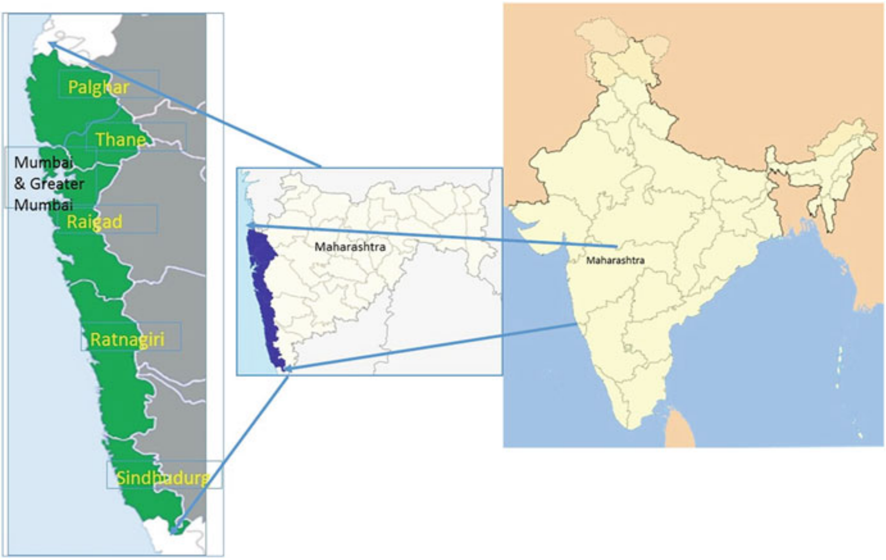

Fig. 15.2 Study area in coastal (Konkan) Maharashtra, India

coast line of 720 km stretching south of Gujarat to north of Goa. This basaltic terrain receives an average rainfall of 2500–4000 mm. The northern part of Konkan comprising of part of Raigad, Thane, and Palghar bear some similarity of typical basaltic landscape like central Maharashtra and Vidarbha. This might be due to the fact that Palghar and Thane are on lower elevation and has more breadth (distance between Arabian sea and the Western Ghats) resulting in the formation and persistence of deep black soils as is common in other parts of Maharashtra. On the contrary, southern Konkan gradually narrows down south to Goa and represent undulating landscape with steep slopes causing severe soil erosion. This happens in spite of the fact that south Konkan has more vegetation. This is the reason why south Konkan is represented by relatively shallow red soils and at places these soils are deep to be qualified as Alfisols. Coastal ecosystem is vulnerable (Bhattacharyya 2021a, b, Bhattacharyya et al. 2021c). The soil diversity in Konkan, Maharashtra, as a part of huge stretch of Indian coast measuring 7517 km is briefed in the following.

15.3.2 Soil Diversity: Its Quantification

The soil diversity index (SDI) was assessed using the concept of occurrence of soil family (Soil Survey Staff 2014) per unit area (Bhattacharyya et al. 2013). To estimate the pedodiversity indices (PDI), various measures were used. The area of a taxon (Soil Survey Staff 2014) in each map unit was calculated by multiplying the component percentage of the taxon by the area of the map unit (Bhattacharyya et al. 2009). The total area of each taxon from all the states and Union Territories were extracted from the existing database. PDI were calculated based on the area abundance of the taxa for India, for zones and for various states of India. Three types of indices were considered in this study: richness (S) (number of soil taxa), and diversity (H') (considers both richness and evenness into account or, in other words, the higher the richness and evenness, the higher the diversity) (Guo et al. 2003). Shannon's diversity index (H') (Shannon and Weaver 1949; Magurran 1988) is also estimated to find out pedodiversity following Eq. 15.1:

$$H' = -\sum_{i}^{S} p_i \times \ln (p_i) \tag{15.1}$$

where S is taxa richness; p_i is the proportion of ith taxa; p_i is estimated by n_i/N, where n_i is the area covered by ith taxa; and N is the total area studied. Shannon diversity index (H') was estimated at different levels of soil taxa following US Soil Taxonomy such as orders, suborders, great groups, subgroups, and soil families (Soil Survey Staff 2014).

Besides, Simpson's index of dominance (D_s) was also estimated to assess the dominance using Eq. 15.2:

$$Ds = \sum \{p_i(p_i - 1)\}/\{N(N - 1)\} \tag{15.2}$$

where p_i and N are parameters as mentioned above.

15.3.2.1 Taxon Richness

The total number of soil orders found in Konkan region is four, i.e., Entisols, Inceptisols, Alfisols, and Vertisols. Vertisols are reported in the northern districts of Raigad and Thane only. Similarly, Alfisols are not reported in the northernmost district of Thane. Thirteen soil subgroups are found in Konkan region. Raigad (10) district has the highest number of soil subgroups followed by Ratnagiri (9), Thane (8), and Sindhudurg (5). Of the 33 soil series identified in Konkan region, Ratnagiri (23) had highest taxon richness followed by Sindhudurg (17) and Raigad and Thane (15 each) (Bhattacharyya et al. 2020).

15.3.2.2 Shannon Diversity

At the taxonomic level of soil series, the diversity (H': Shannon diversity index) was maximum in Ratnagiri district followed by Sindhudurg, Thane, and Raigad (Fig. 15.3), whereas at the level of soil suborder, the diversity was maximum in Thane district followed by Raigad, Ratnagiri, and Sindhudurg (Fig. 15.4). And as expected, exactly opposite trends were found in terms of taxa dominance (Simpson's index) for both the taxonomic levels (Figs. 15.5 and 15.6).

The soil diversity obviously increases as lower levels in soil taxonomy (Soil Survey Staff 2014) are explored. This is corresponding to an earlier study at the national level in Indian (Fig. 15.7; Bhattacharyya 2016). Interestingly, the diversity

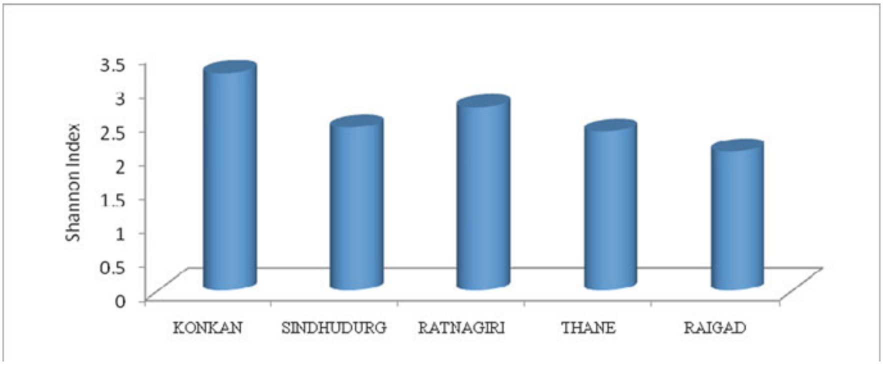

Fig. 15.3 Shannon diversity index (H') in different districts of Konkan region and for the region at the taxonomic level of soil series

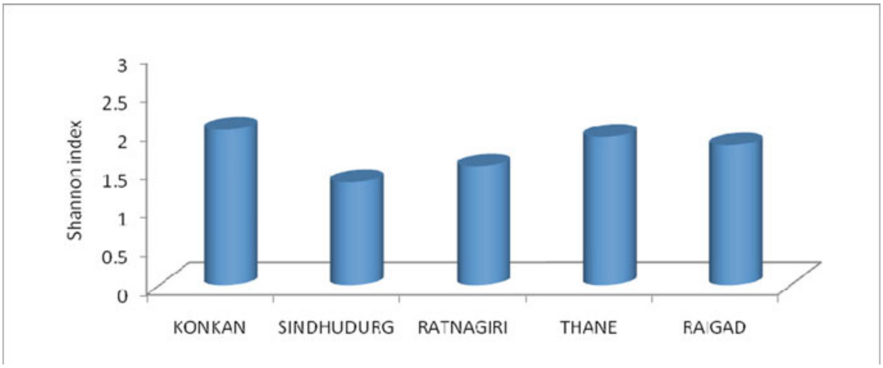

Fig. 15.4 Shannon diversity index (H') in different districts of Konkan region and for the region at the taxonomic level of soil subgroup

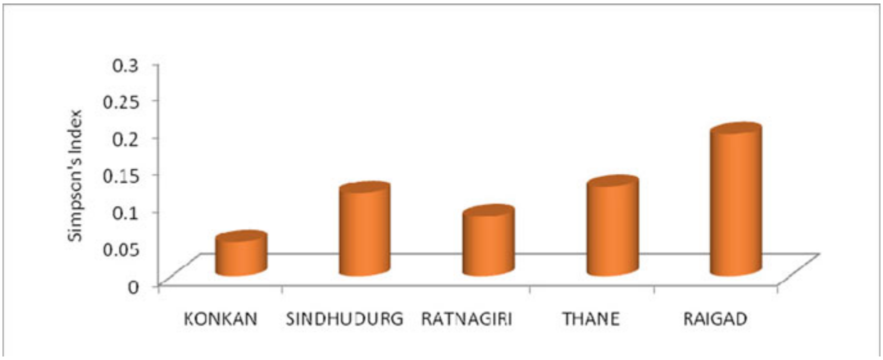

Fig. 15.5 Simpson's index of dominance (D_s) in different districts of Konkan region and for the region at the taxonomic level of soil series

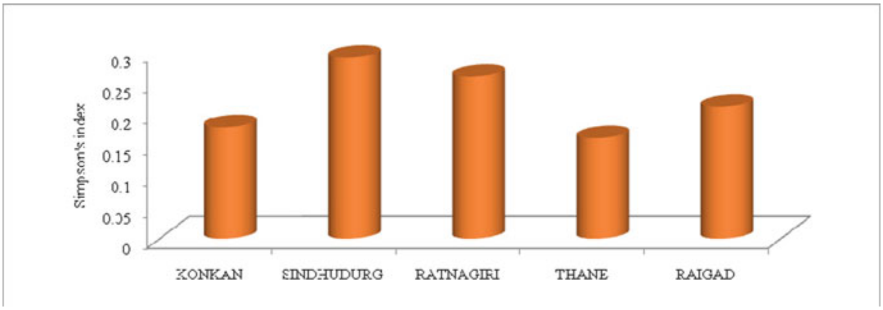

Fig. 15.6 Simpson's index of dominance (D_s) in different districts of Konkan region and for the region at the taxonomic level of soil subgroup

does not increase linearly for Konkan under comparison in the present study. The diversity at subgroup level was highest in Thane district, whereas at the (soil) series level, it was Ratnagiri district that registered the highest value. These findings in corroboration with the earlier national level study (Bhattacharyya 2016) necessitate careful documentation of all taxonomic levels of soil classification which demands a new dimension of research to make an estimate of the number of soil series which can be obtained for the entire country as a whole (Bhattacharyya 2016) using pedo-transfer functions.

The pedodiversity index (PDI) (H') estimated at the level of soil subgroups and the areal extent of various zones in India (Bhattacharyya et al. 2013) indicates a trend between areas of different zones studied versus pedodiversity (Fig. 15.8). The northeastern, eastern, and southern zones are showing more pedodiversity which support commonly found large biodiversity in these three zones; however, this relation is not in line with the previous results of pedodiversity for the USA (Guo et al. 2003) and the world (Ibañez Marti et al. 1998; MacBratney et al. 2000). This might be due to the fact that PDI has been related with soil subgroups unlike the series used in case of the USA. Pedodiversity (Beckett and Bie 1978) and biodiversity (Kilburn 1966) was reported to have a strong species-area relationship. To justify area dependency of taxa richness, larger scale of mapping and soil datasets for India are required.

Earlier, significantly ($p < 0.01$) higher diversity indices were reported in the soils of relatively moist bioclimate as compared to drier ones (Velmourougane et al. 2014). Besides, higher microbial biomass carbon indicating more diversity was found in soil subgroup, viz., Typic Haplusterts as compared to other subgroups of the same soil (Vertisol) order. Interestingly, areal extent of Typic Haplusterts is much higher than other subgroups in the southern, western, and central zones which signify a close species-area relationship reported by others (Beckett and Bie 1978; Ibañez Marti et al. 1998; MacBratney et al. 2000).

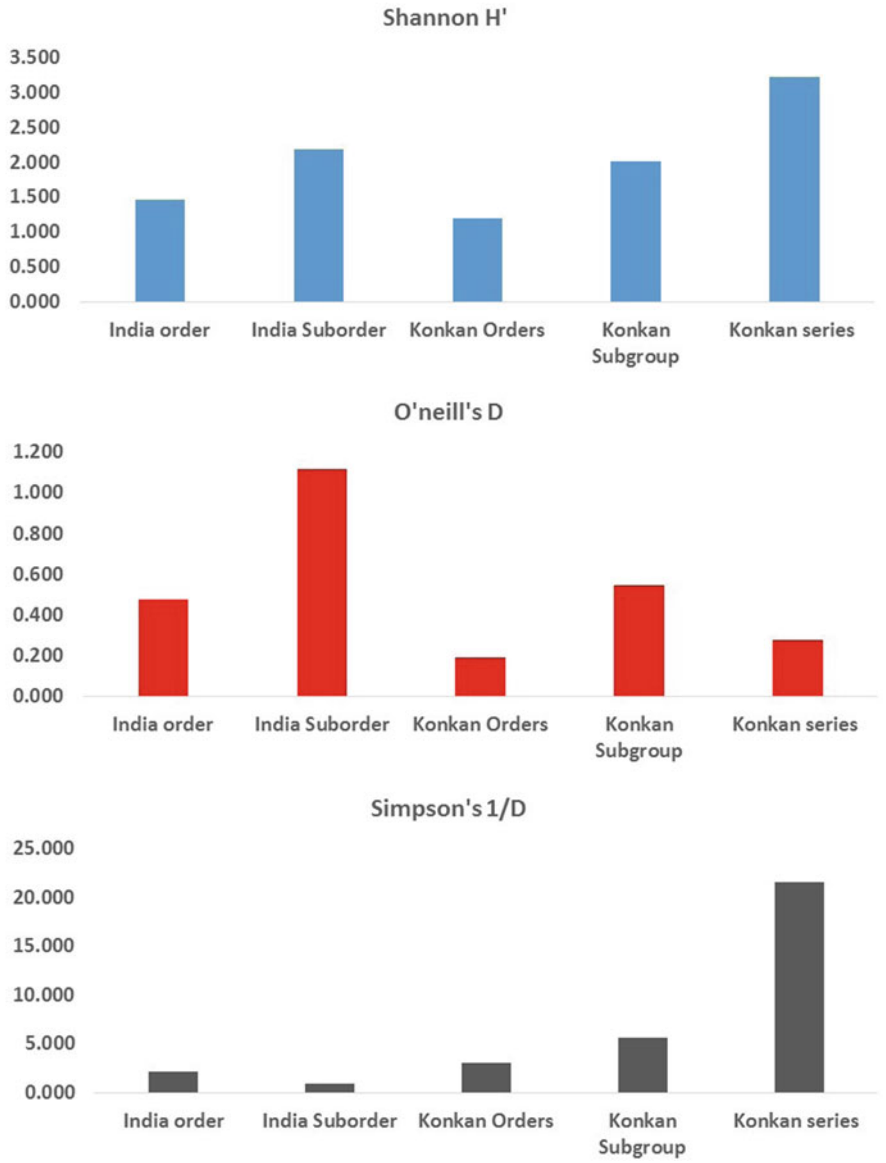

Fig. 15.7 Various parameters of pedodiversity index (PDI) for Indian and Konkan, Maharashtra soils: (**a**) Shannon H' as a measure of PDI; (**b**) O'Neil's D as a measure of relative dominance of one taxon over others; (**c**) Smith's evenness index as a measure of area equitability of the soil taxa; (**d**) Simpson's D, and (**e**) Simpson's 1/D as a measure of relative dominance (the study did not attempt diversity assessment at series level in India)

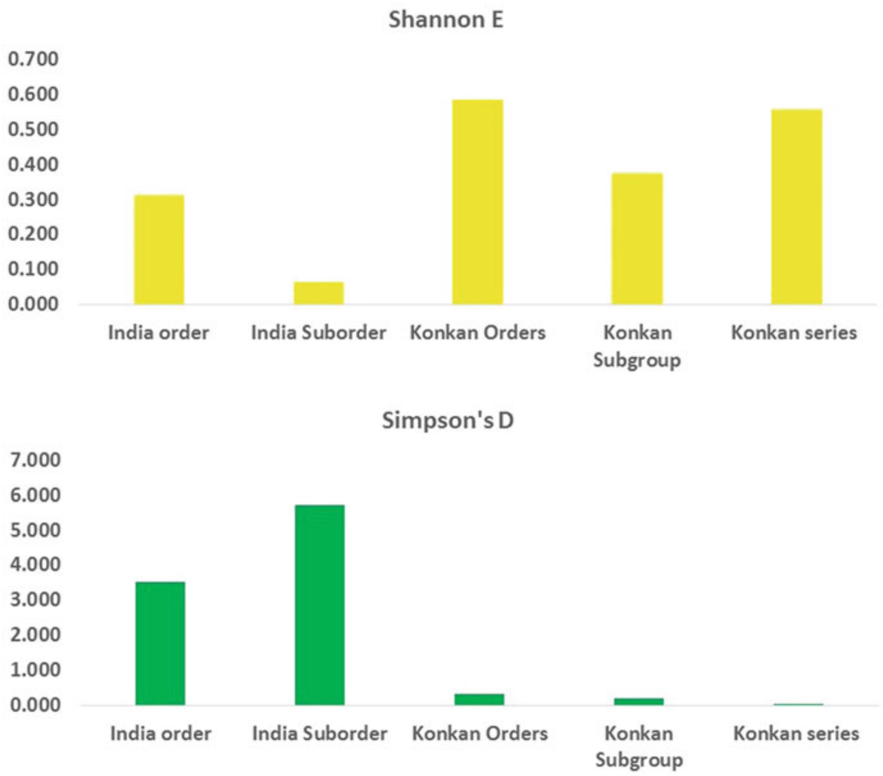

Fig. 15.7 (continued)

15.4 Konkan Biodiversity

Globally, Konkan region is one of the richest in biodiversity. It is part of the Western Ghats-Sri Lanka biodiversity hotspot complex. Recent evidence has indicated that Konkan region has experienced changes in the monsoon since late Pleistocene resulting in the changes in vegetation (Kumaran et al. 2013). These changes in the last 40,000–50,000 years have certainly had implications for the rich biodiversity in this region including the presence of several relic species.

15.4.1 Habitat Diversity

The topography of Konkan is varied and includes coastal lagoons, low-lying valleys, and hills with plateaus, precipitous slopes, and high mountain ridges. The climate also varies across the region from seacoast to mountain crest through coastal hills, middle valleys, and mountain slopes. At the same time, the climate varies from wet

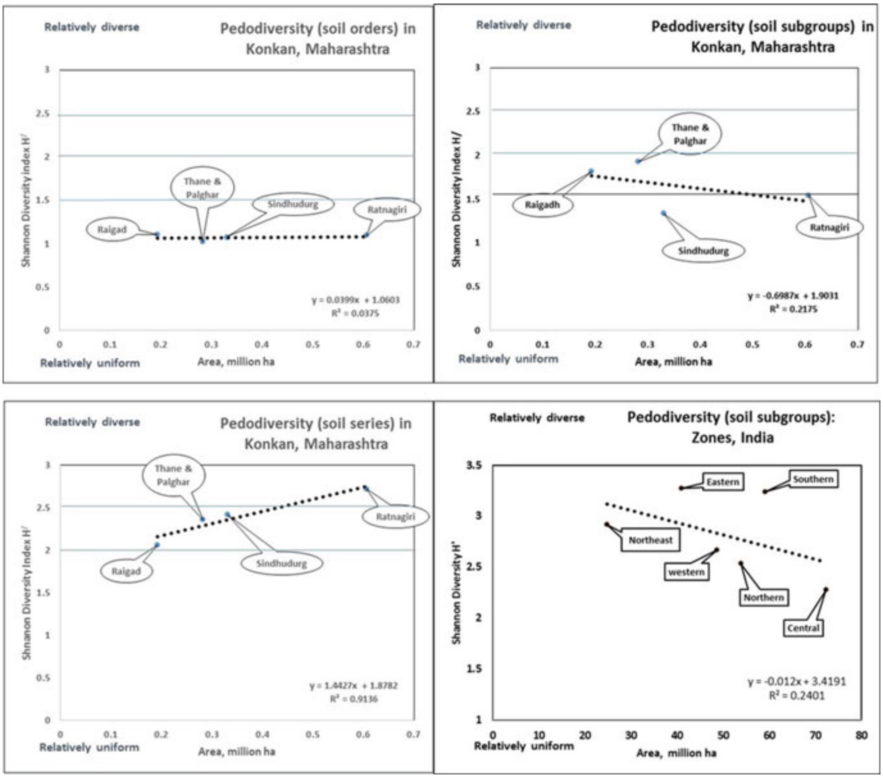

Fig. 15.8 Pedodiversity index (PDI) (H') and area relationship at soil order, subgroup, and series level in Konkan, Maharashtra, India. The last box shows the Diversity index of Indian soil subgroups as comparison. Konkan falls in the western part of India

to dry along the 700+ km south-north stretch of the region. These all together influences the diversity of habitats in this region.

Diversity of habitats in Konkan region may be comprehended by the land use land cover (LULC) classification. In addition, these data can be used to calculate the comparable diversity indices just as those worked out for various soil taxa. The data is summarized in Table 15.1. This LULC classification barely reveals the tremendous diversity of habitats enclosed by these very broad and vague terms, for example, the "Barren" which is around 20% of the total area includes the lateritic plateaus. These lateritic plateaus possess tremendous biodiversity and are of immense conservation importance which has been detailed elsewhere indicating their use for horticulture (Bhattacharyya 2021a, b). These areas Northern Western Ghats and Konkan region show high phylogenetic endemism in lateritic plateaus the predictors of which have been pointed down to poor soil conditions and seasonal ephemeral habitats (Bharti et al. 2020).

The forests of Konkan are a treasure trove of biodiversity. In addition to the evergreen, semi-evergreen, moist deciduous, dry deciduous, and scrub forests, there

Table 15.1 Area coverage ('00 ha) of different land use/land class categories in districts of Konkan region

Particulars	Konkan and districts					
	Sindhudurg	Ratnagiri	Raigad	Thane	Palghar	Konkan
Water bodies	45.56	121.35	121.15	82.92	81.79	452.77
Settlement	890.16	1640.18	863.33	916.54	612.81	5706.56
Agricultural	1173.69	1342.72	1295.94	677.97	1076.16	5556.48
Horticultural	1251.10	1243.34	937.54	932.31	914.83	5579.12
Barren	75.89	2325.5	1522.64	660.57	1164.41	6383.01
Forest	1050.46	2287.99	2217.69	955.28	1377.40	7012.83
Total	5168.88	8461.07	7010.23	4225.62	5225.39	30,094.78

Table 15.2 Extent of mangrove forest in the districts of Konkan region (source: FSI 2020)

District	Mangrove forest area (ha)
Palghar	2908
Thane	2063
Mumbai	277
Mumbai suburban	3723
Raigad	4193
Ratnagiri	1436
Sindhudurg	487
Konkan	15,088

are mangrove forests, beach forests, and coastal plantations (FAO 1998). These latter are transitional ecosystems from terrestrial to aquatic ecosystem. So, a very high level of edge effect is observed in these forests. This also results into a rich diversity of habitats, species, and genes.

15.4.1.1 Mangrove Forests

In India, mangrove forests are found all along the coastline in varying extent. They occupy an area of 4045 square km (FSI 2009). The type of mangrove ecoregion found in Konkan is Indus delta-Arabian sea mangroves found along the western coast. They cover an area of 15,088 ha in Konkan region (Table 15.2).

Mangroves are plant species including trees, shrubs, palms, and ferns growing in saline intertidal coastal habitats such as estuaries and shorelines. There are more than 110 species of these plants throughout the tropics and subtropics. These species are physiologically adapted to overcome the problems of high salinity and frequent tidal inundation resulting in absence of oxygen. They form estuarine tracts of mixed mangrove forests (Rosati et al. 2008). Although mangrove forests are characterized by low floristic diversity at any given place compared with most inland forests in the tropics, they are definitely a rich and typical ecosystem. Mangrove forests are unique, highly productive and socioeconomically and biologically important. People on Konkan coast depend on mangrove forests for wood and a large variety of non-wood forest products like dyes, medicines, fodder, and honey. Mangroves host a wide variety of organisms, including a number of endangered species. They serve as a valuable nursery to many shrimps, crustaceans, and mollusks and act as a breeding and feeding ground for many commercially important fish species (Rosati et al. 2008). Few species of animals are restricted entirely to the mangrove forests. Besides, mangrove forests act as an ideal sanctuary for several migratory birds (FAO 1998). In addition, mangroves play an important role in protecting the coast, especially during surge storms, hurricanes, and tsunamis. These ecosystems are extremely fragile and hence require conservation and protection from permanent loss (Rosati et al. 2008).

15.4.1.2 Beach Forests

The beach forests or coastal forests found in Konkan region are classified as Malabar Coast moist forest ecoregion. This ecoregion represents the semi-evergreen forests along India's Malabar Coast, a narrow strip of land lying between the Indian Ocean to the west and extending up to the 250 m contour of the steep Western Ghats Mountains to the east (www.worldwildlife.org). The ample amount of rains brought by the southwestern monsoon largely influences the vegetation of this region. Although the forest is classified as semi-evergreen, the influence of rainfall and distance from equator has resulted into gradual trend from tropical wet evergreen in the south to drier and deciduous forests to the north. In addition, these forests have been largely replaced or interspersed with teak, giving the vegetation a semi-deciduous character; the teak is now considered indicative of a secondary successional stage or presence of plantations. A large variety of plant species in all the strata of forest ecosystem are found in these coastal forests. Several of these are endemic and near-endemics (www.worldwildlife.org).

15.4.1.3 Coastal Plantations

Plantation activity in India has taken up great strides in the last two decades. The rate of plantation has been more than 15,000 square km per year during this period (Puyravaud et al. 2010). Coastal plantations have often been established for both production and protection purposes. The production functions involve supply of fuelwood and other non-timber forest products (NTFPs). The basic protection purpose is stabilization of coastal sand dunes which keep shifting in inland direction. One of the recent approaches is to create shelterbelt plantations as a mitigation strategy for cyclones and tsunamis. The most popular and important species taken up for coastal plantations is *Casuarina equisetifolia* (whistling pine tree) along with some mangrove species. Others include *Acacias* and *Eucalyptus*. Apart from these forest plantations, Konkan region has extensive plantations of coconut and areca nut that can be included in coastal plantations.

15.4.1.4 Agro-Biodiversity

Konkan region has been proposed as a National Agricultural Biodiversity Heritage Site in India based on cultivation of enriched agro-biodiversity under diverse high-rainfall microclimatic conditions, development of unique tropical mixed cropping systems, generation and conservation of rich genetic diversity in crops (Singh 2014). The connecting link between wild and cultivated diversity, i.e., wild relatives are also very diverse in Konkan region as is evident by 58 species of wild vegetables in the region (Khan and Kakde 2014). The origin of this rich agro-biodiversity can be traced back to the richness of the natural floral diversity and in turn to the pedodiversity.

15.4.1.5 Floral and Faunal Biodiversity

It is important to note that diversity of algae and fungi is also rich in Konkan region. Even the foliicolous fungi are extremely diverse in Konkan. Approximately 191 species of such microfungi were recorded from the leaf samples throughout Konkan and interestingly; none of the species was found to be widespread as to be found in all four districts of this region (Dubey and Pandey 2019). Besides, nearly 29 species of mushrooms from Konkan region have been documented (Borkar et al. 2015). There are nearly 500 species of dicotyledonous angiosperms in Konkan (Singh and Karthikeyan 2000, 2001). The number of plant species in each district of the region is shown in Table 15.3.

Two micro-centers of plant endemism are identified in the Konkan region (Nayar 1996). These are *Mahabaleshwar-Khandala* and *Konkan-Raigad*. According to one recent analysis, out of forty-nine Indian endemic plant genera, three (and five species contained within them) are endemic to these two centers (Irwin and Narasimhan 2011). Nearly 181 endemic taxa, belonging to 84 genera and 36 families are reported in the Northern Western Ghats-Konkan region (Shigwan et al. 2020). Konkan region has been specially highlighted as a center of rapid diversification of genera like *Ceropegia*, *Glyphochloa*, *Dipcadi*, and *Eriocaulon*. The diversity of fauna is equally impressive in the Konkan region. A comparative statement of number of species found in Konkan, Western Ghats, Maharashtra, and India is provided in Table 15.4.

Table 15.3 Floral diversity in districts of Konkan region

Sl. no.	Districts	No. of plant species
1	Thane	417
2	Raigad	392
3	Ratnagiri	454
4	Sindhudurg	484

Table 15.4 Number of animal species in various groups recorded from Konkan region as compared with larger regions

Taxon	Konkan	Western Ghats	Maharashtra	India	World
Mammals	84	137	96	417	6399
Birds	399	500+	535	1287	10,426
Reptiles	62	227	97	518	5817
Amphibians	24	219	43	384	7825

Note: number of species compiled from various sources from a wide temporal range
Sources: Burgin et al. (2018), Dinesh et al. (2015), eBird (2017), Frost D R (2018); Anonymous (1974), Gunawardene et al. (2007), MOEF (2008), Padhye and Ghate (2002), Srinivsaulu et al. (2014)

15.5 Linking Pedodiversity and Biodiversity: A Mobius' Strip

Mobius strip is a curious and intriguing object that can be created with a strip having two surfaces, but once created, it will give an illusion of having only one continuous surface (Alagappan 2021). The Mobius strip was discovered independently by A. F. Mobius and J. B. Listing in 1858. The Mobius strip has been used in the recycling symbol. The relationship between two interrelated aspects of natural diversity namely pedodiversity and biodiversity may be viewed in the image of a Mobius strip. They are distinctly different, yet when we understand the link between them; it is difficult to consider them as two distinct surfaces. We can infer richness of either of these from the richness of the other. Thus, a region rich in biodiversity can be safely assumed to have a high pedodiversity.

The concept of diversity has been widely used in ecological studies, although mainly for the biotic component (biodiversity) (Magurran 1988; Sugihara 1981). Impacts and importance of abiotic influences (stress) of soils on the biota so far as biodiversity are concerned resemble a Mobius strip. The strip is otherwise linked but not perhaps converging in its exactness (Fig. 15.9). However recent observations indicate lot of similarity between these two diversities.

Pedodiversity is conceptually defined as the inventory of the variety of discrete pedological entities, i.e., pedotaxa and pedogenetic horizons, as well as the analysis of their spatial and temporal patterns (Fig. 15.10) (Ibáñez et al. 1990, 1994). There are essentially two components of diversity: the variety of categories (or taxa) and the way in which the individuals are distributed among those taxa (evenness or

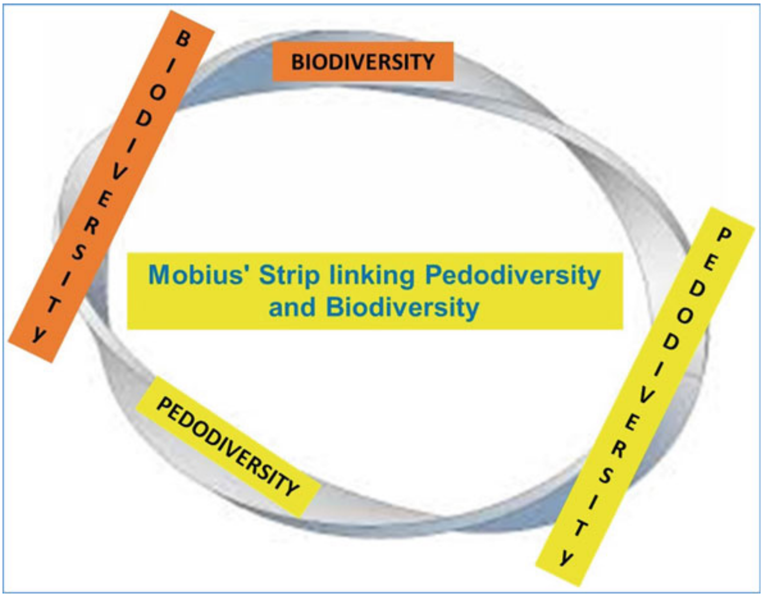

Fig. 15.9 Mobius' strip linking pedodiversity and biodiversity: schematic diagram

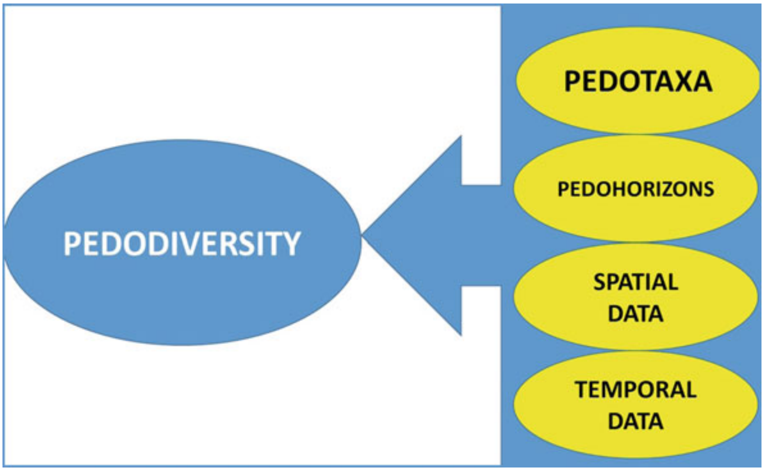

Fig. 15.10 Concept of pedodiversity to link temporal soil information and its spatial domain

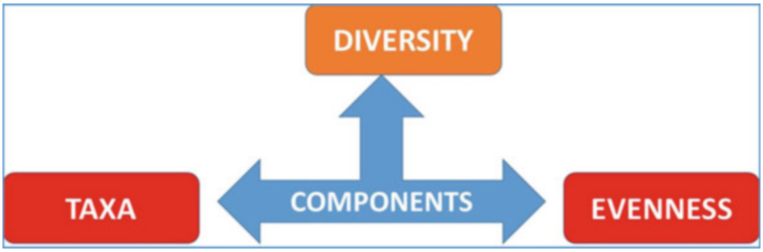

Fig. 15.11 Components of soil/pedodiversity

equitability). Indices of diversity either incorporate both components of diversity into a single value, or less frequently, tend to neglect one of these components. Species diversity measures are divided into three main categories: species richness indices, indices based on the proportional abundances of species (e.g., the Shannon index) and species abundance models (Fig. 15.11) (Magurran 1988). Interestingly soil types are included in the list of possible elements to calculate diversity indices (Huston 1994). For any resource at a given taxonomic level, therefore, it is possible to study its taxonomic diversity.

Diversity analyses utilize mathematical tools which have been applied by ecologists for decades to analyze the intrinsic regularity of ecological entities. Remarkably, the spatial patterns of pedo-geographic units detected by pedologists are rather similar to those reported by biologists for a plethora of ecosystems (Petersen et al. 2010). In summary, biological and pedological systems follow similar mathematical patterns of (i) diversity; (ii) richness and diversity-area relationships; (iii) richness and diversity-time relationships (islands and terrace chronosequence); (iv) abundance distribution models; (v) taxa-range size

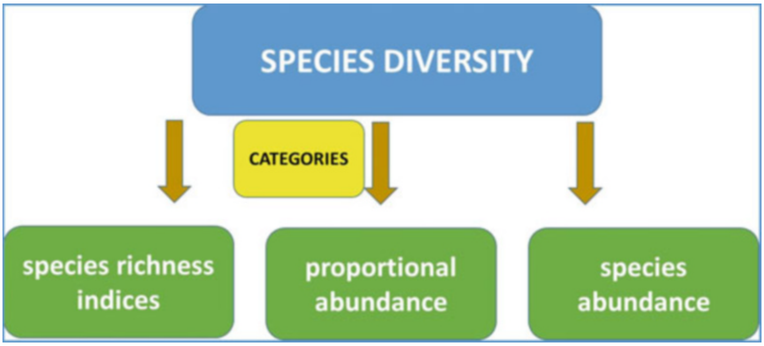

Fig. 15.12 Categories of species diversity: pedological systems

distribution; (vi) nested subset analysis; (vii) fractal and multi-fractal analysis; (viii) complementarity algorithms for selecting areas to design networks of natural reserves; and (ix) mathematical structures of classifications (Fig. 15.12) (Ibáñez 2006). Furthermore, predictions of the theory of Island Biogeography have been used to explain the pedorichness and soil assemblage analyses in archipelagos (Ibáñez and Effland 2011). These are intriguing facts that must be analyzed in depth given that pedodiversity-area relationships cannot be explained using the biological assumptions (MacArthur and Wilson 1967).

15.5.1 Soil Diversity and Pedodiversity

The concept of diversity has been widely used in ecological studies in connection with biodiversity (Sugihara 1981; Magurran 1988). However, discussion to include the abiotic stresses from soils on the ecosystems has found very little attention. Inorganic carbon sequestration and soil/land degradation causing poor crop performance especially in the drier climates due to abiotic stresses in Indian context have been discussed elsewhere (Bhattacharyya 2021a, b, c). This brings a paradigm shift to catch the imagination of other experts in other parts of the globe to use Indian case studies as a model to study pedodiversity (Ibáñez et al. 1995). Soil and pedodiversity is linked so are their contribution to the key aspects of heritage such as biological and cultural (preservation of biodiversity, ancient, and traditional sustainable practices), soil monitoring (benchmark soils in monitoring programs), prehistoric and paleontological (archive of artefacts and remnants of extinct species), bio-geosphere (archive of past environments), and geological (pedodiversity is a part of the concept of geo-diversity) (Ibáñez et al. 2012). Figure 15.13 shows the relation between soil and pedodiversity and their heritage vis-à-vis ecosystem services (Bhattacharyya 2021b). The relationships between pedodiversity and the diversities of other natural bodies are shown in Fig. 15.14.

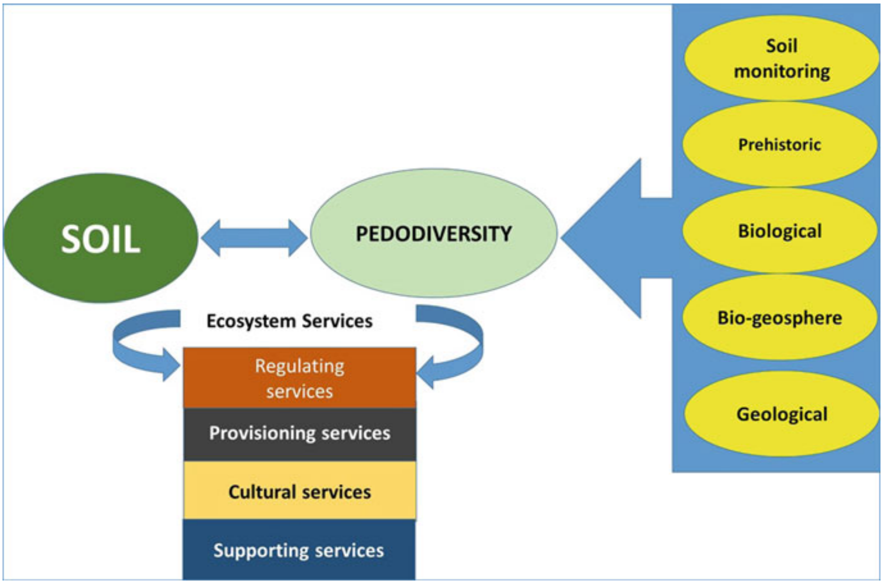

Fig. 15.13 Role of soil and pedodiversity in providing ecosystem services (also see: Bhattacharyya 2021b)

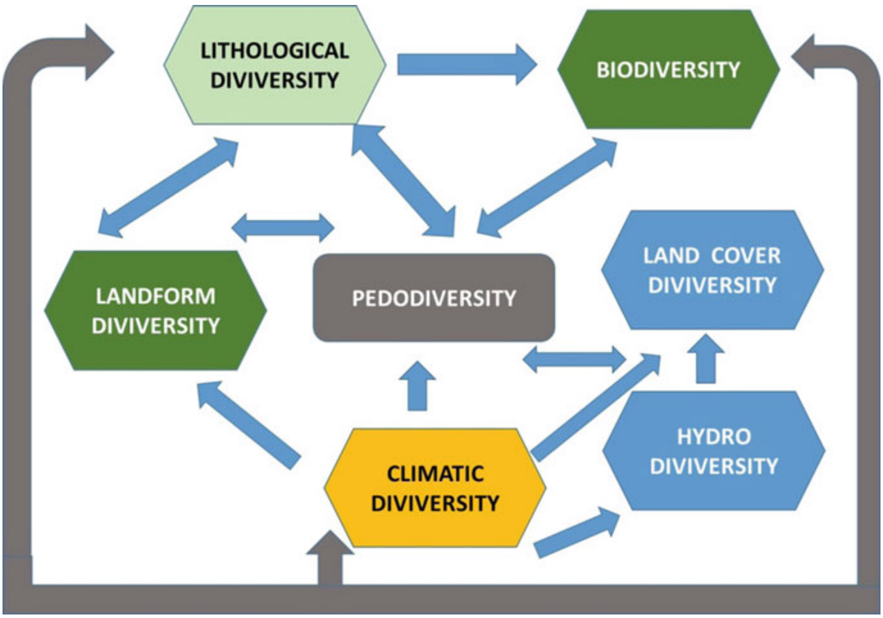

Fig. 15.14 Relationships between pedodiversity and biodiversity with other forms of diversity in nature (adapted from Ibáñez et al. 2012)

15.5.2 Soil Diversity and Biodiversity

Soil diversity and biodiversity may be discussed in relation to (i) rare soils and rare plants and (ii) endangered soils and plants (Ganguli et al. 2019). This will enable planners to think seriously about soil/pedodiversity and biodiversity for preservation of nature and future planning (Amundson et al. 2003). Wild mangoes as an incredible wealth of posterity in India have its own natural biodiversity. Species, *Mangifera indica* is commercially cultivated. Among the other species, the occurrence of *Mangifera sylvatica* in the northeastern parts of India or *Mangifera andamanica* in the Andaman group of islands is worth-mentioning. Variability of this dimension of mango results from the chance seedlings and seed propagation either by natural elements (seed dispersion) or anthropologically over a long period. This demands preservation of these wild mango species and their biodiversity for posterity (Fig. 15.15). There is a great interest and necessity to preserve the wild mango biodiversity which can be maintained globally through efforts of collection, documentation, and plantation to preserve the mother orchards (Ganguli et al. 2019). These are store house of gene pools for evolving future mango varieties with their unique qualities. These wild and edible mangoes are in danger of extinction and most certainly represent the important resources for the future of mangoes (Table 15.5).

In Konkan plant species in terms of taxa richness representing biodiversity in the region showed a type of relation which seems interesting. Pedodiversity, measured by Shannon diversity index (H'), indicated low H' in higher taxa richness (biodiversity). This is more pronounced at the level soil subgroup pedodiversity (Fig. 15.16). This might hint that concept of pedodiversity and biodiversity may merge at some

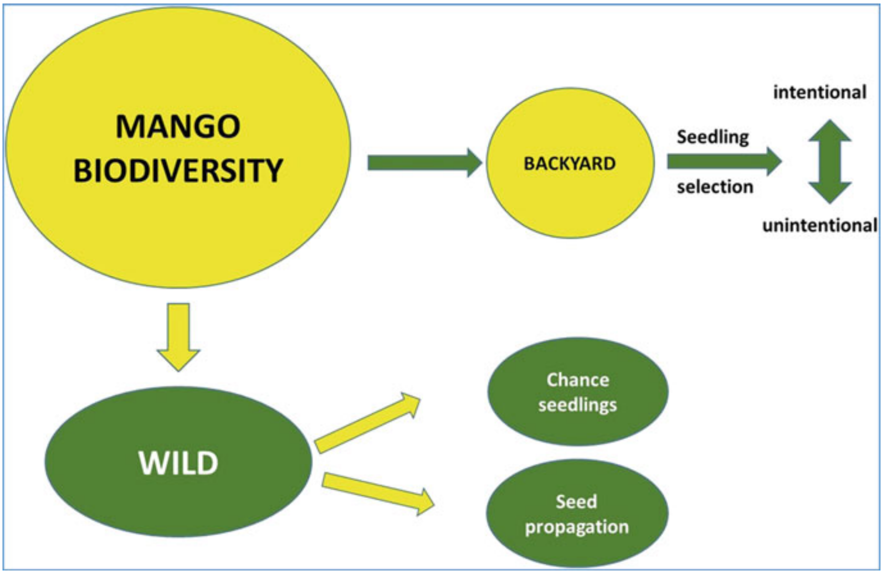

Fig. 15.15 Mango and its biodiversity (Dinesh et al. 2011; Ganguli et al. 2019)

Table 15.5 Mango species under different categories of threats

Threat category	Mango spp.
Rare	*Mangifera andamanica*, *Mangifera camptosperma*, *Mangifera gedebe*
Endangered	*Mangifera cochinchinensis*, *Mangifera flava*, *Mangifera lagenifera*, *Mangifera pentandra*, *Mangifera reba*, *Mangifera superba*
Vulnerable	*Mangifera duperreana*, *Mangifera inocarpoides*, *Mangifera monandra*, *Mangifera timorensis*, *Mangifera zeylanica*

Dinesh et al. (2011), Ganguli et al. (2019), Mukherjee (1985)

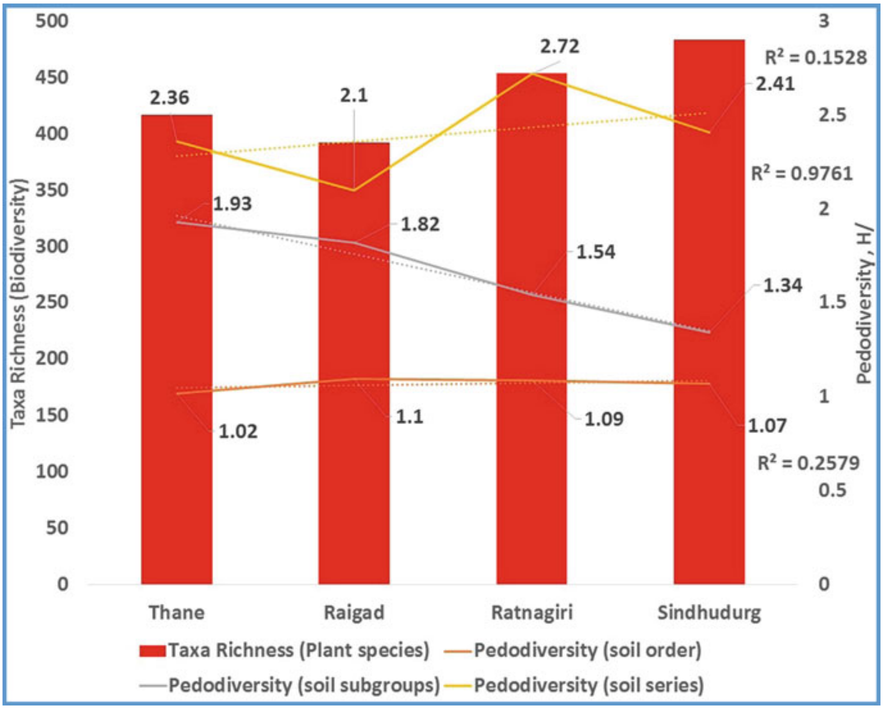

Fig. 15.16 Pedodiversity and biodiversity in terms of plant species richness in different districts of Konkan, Maharashtra

scale of data collection. Usually subgroup level of soil classification may be suggested at a scale of 1:250,000 or above. Biodiversity database may accordingly be collected at that kind of scale depending on other local factors.

There is an example of the relationship of rare soils to plants, in the form of the annual grasslands of eastern Merced County, California region, that is an integral part of the California Floristic Province, one of the top 25 biodiversity hotspots on Earth (Cincotta and others 2000; Myers et al. 2000). A sizable number of endemic species form in these pools (Vollmar 2002). There is a systematic change in pool frequency and soil chemistry (Brenner et al. 2001) with time that creates an edaphic gradient that is a major factor in influencing the plant species composition on a regional scale (Holland and Dains 1990). Similar typical areas exist in India also so far as plants/tress specificity is concerned like Darjeeling tea in Darjeeling and specific areas in North Bengal; Litchi in Mujjafarpore, Bihar; and Alphonso in Konkan, Maharashtra. Such edaphic and crop relations led to soil-site specific characteristic to evolve agroecosystem-based land use planning (Bhattacharyya et al. 2015). Because of the plant/trees preferences for specific soils near a particular agro-ecosystem, there is a need to establish a preservation design to include the soils in those ecosystems. Otherwise, both plants and soils become endangered as a result of land use. There is also a need to prepare a list of type of soils which are endangered due to natural as well as anthropogenic activities to preserve biodiversity (Amundson et al. 2003).

"Concluding no bad effect of poor land use when it really happens" is the precautionary principle which brings conservationists and /developers in the same platform to reduce the possibility of committing a "Type II" error (Shrader-Frechette and McCoy 1993; Noss et al. 1997). This error is specifically relevant to medicine, environmental engineering, and conservation biology resulting in irreversible damage to the patient, ecosystem, or soil (Noss et al. 1997). The conservation of diverse soil scapes should proceed simultaneously with scientific research that fully explores their qualities, values, and functioning and shall help us not to commit irreversible mistakes to destroy nature. The concept of LDN vis-à-vis pedodiversity and biodiversity may address these problems with remedial measures.

15.6 LDN and Maintenance of Biodiversity and Pedodiversity

One of the major soil-forming factors is climate. Therefore, climate change and LDN vis-à-vis pedodiversity and biodiversity require soil as the focal point for discussion. Land area is dwindling due to many reasons. The main reason is its degradation, both natural and anthropogenic. It seems, therefore, logical to save our motherland and focus on LDN whereby the amount and quality of land resources, necessary to support the ecosystem functions and services and enhance food security, remain stable or increase within specified temporal and spatial scales and ecosystems. Appropriate LDN measures will lead to saving soils/land from degradation to restore biodiversity. Business as usual approach will lead to extensive damage to soils/land resulting in loss in our bio-heritage (Fig. 15.17).

Land use and its changes bring major changes in diversity. This could be changes in soil/pedodiversity leading to disturbed biodiversity. Naturally occurring land degradation (chemical soil degradation) requires steps for land degradation neutrality (LDN). This includes, among many other interventions (Bhattacharyya 2020), appropriate land use policy. This needs involvement of multidisciplinary experts (Fig. 15.18) (Bhattacharyya 2020).

The contribution of various experts is paramount not only from biodiversity point of view but also in bringing some areas under agriculture and other allied activities. Both vertical and horizontal expansion of areas under agriculture, animal husbandry,

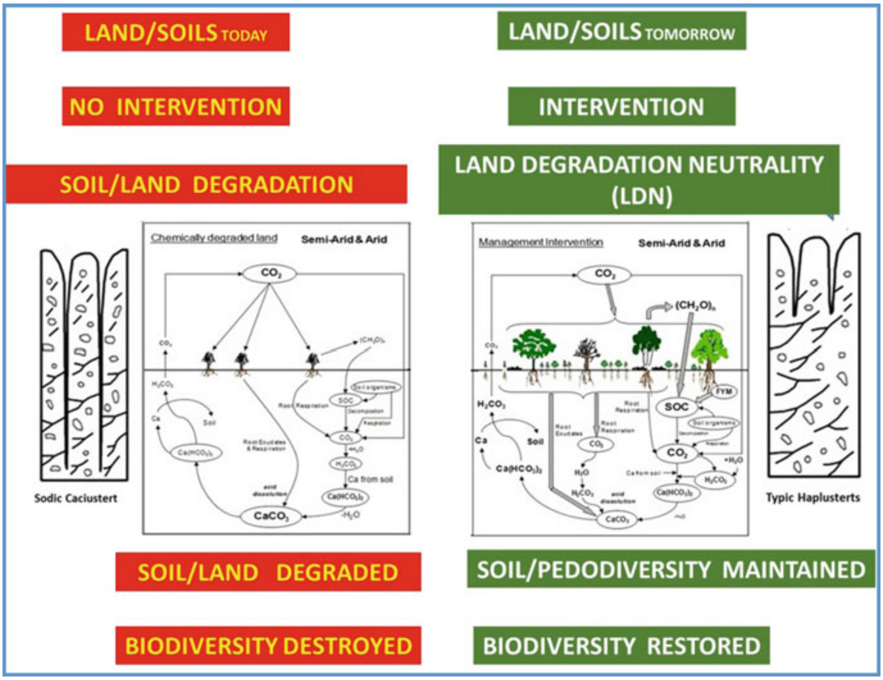

Fig. 15.17 Land degradation neutrality (LDN) shall restore soil/pedodiversity and biodiversity (Bhattacharyya 2020, a, b)

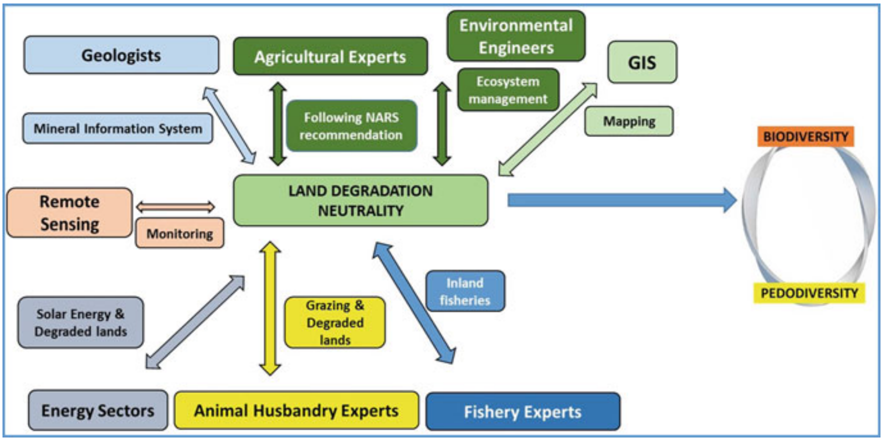

Fig. 15.18 Suggested policy to achieve LDN to help maintaining soil/pedodiversity and biodiversity

fisheries, and other nonagricultural sectors such as forestry will help maintaining biodiversity. Bringing waste land to harness nonconventional source of energy can be useful to help in using alternate source of energy to reduce carbon footprints, and also to enable farmers non-dependable on conventional sources of energy. Land degradation neutrality (LDN) can thus nullify the ill effects of global warming or climate change. Future research should focus to fulfil the target of LDN with an acceptable policy to converge the Mobius strip of biodiversity and pedodiversity.

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Role of REDD+ in Reducing Land Degradation and Achieving SDGs

16

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Abstract

Land and its natural resources are essential for maintaining biodiversity and related ecological processes. Unfortunately, lands are degrading due to natural and anthropogenic factors, which may eventually lead to desertification. Deforestation significantly emits greenhouse gases that devastatingly lead to global warming and climate change. It necessitates a sustainable solution that promotes reforestation combined with emission reductions. Hence, reducing emissions from forest degradation and deforestation (REDD+) arose as an international policy tool to address the forest sector emissions and sustainable management of forests and their ecosystem services. REDD+ projects promise "triple-win" benefits that include mitigating climate change, conserving biodiversity, and uplifting local communities. In addition, REDD+ potentially contributes toward sustainable development goals (SDGs); and there is a mutual relationship between SDGs and REDD+ that integrate sustainability, management, and conservation. The principal SDGs fulfilled by REDD+ is SDG 13 (climate action) and SDG 15 (life on land). REDD+ opens up a new framework and path for forest management through policy-level changes, multi-stakeholder participation, and carbon credit trades. So, this book chapter discusses and reviews various aspects of REDD+ in reducing land degradation and contributing toward SDGs.

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Keywords

REDD+ · Land degradation · Sustainability · Deforestation · Biodiversity

16.1 Introduction

The land sustains diverse organisms and societies worldwide. It comprises natural resources (soil, near-surface air, vegetation, other biotas, and water); ecological processes; topography; and human settlements (Abdulmalik and Zewide 2021; Henry et al. 2018). The land is fundamental for enhancing biodiversity and inherently essential for various activities: forestry, agriculture, water source maintenance, and grazing. Forests, unequally distributed in 31% of the global land area, are home to diverse organisms and sequester enormous carbon (FAO and UNEP 2020). Even though they secure livelihood and mitigate climate change, deforestation and forest degradation continue alarmingly. According to the state of world forest report of FAO and UNEP (2020), the rate of deforestation during 2015–2020 is ten million hectares per year. Simultaneously, land degradation is also of considerable concern at the regional, national, and global levels, since it significantly reduces the capacity of the soil for production. The land degradation process accounts for the changes in topography, climate, vegetation cover, and water rather than soil alone (Mohamed et al. 2019). These changes further impact the biodiversity status of the land and make the environment vulnerable to more threats (Mohamed et al. 2019; Stockings and Murnaghan 2000). In the last 40 years, the world witnessed 33% of arable land loss combined with soil erosion or pollution (Boer and Hannam 2019). In addition to land degradation, desertification and drought also impact land wealth. The main reasons for land desertification include unsustainable farming, deforestation, overgrazing, and mining. Figure 16.1 shows natural and anthropogenic (human-induced) drivers of land degradation with its effects.

Deforestation and forest degradation are responsible for about 25% of global GHG (Green House Gas) emissions (Chand et al. 2021; Pendrill et al. 2019). Several international initiatives emerged during the last few decades to combat the devastating effects of land degradation and deforestation. Some of them that aim for a sustainable future are UNCCD (United Nations Convention to Combat Desertification) and REDD+ (reducing emissions from forest degradation and deforestation). UNCCD is a legally binding agreement that links sustainable land management with both environment and development. The primary objective of UNCCD is to reduce land degradation. Concomitantly, REDD+ restores the land through proper planning and implementation of activities. REDD+ implemented reforestation and afforestation programs on about 162 million hectares of land so far (UNEP 2022). Hence, UNCCD and The Paris Climate Agreement strongly admit the potential of REDD+ in achieving land degradation neutrality and sustainability (Kumar et al. 2021). The book chapter highlights the vital role of REDD**+** in reducing land degradation and reveals the REDD+ as a strategy that contributes to sustainable development goals.

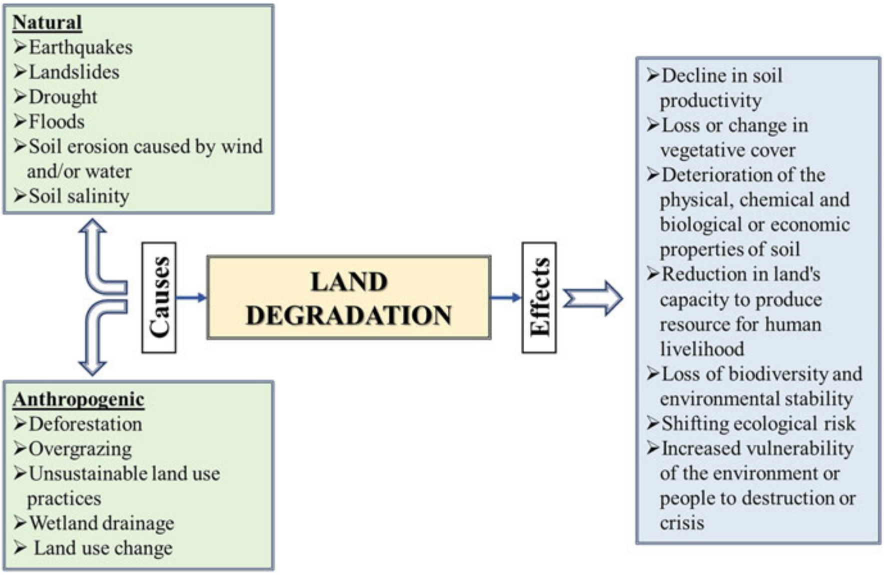

Fig. 16.1 Causes and effects of land degradation. (Source Abdulmalik and Zewide 2021; Boer and Hannam 2019; Kumar et al. 2021; Vinya et al. 2011)

16.2 REDD+

REDD+, created by UNFCC, is a global policy tool that addresses forestry sector emissions (Chand et al. 2021). REDD+ enhances the sustainable management of natural forests and their ecosystem services; additionally, it conserves forest carbon stocks by ensuring the participation of various stakeholders. REDD+ focuses on global action plans and sustainable solutions; moreover, it motivates developing countries to mitigate climate change by preventing deforestation and GHG emission (Kumar et al. 2021). REDD+ projects promise "triple-win" benefits that include mitigating climate change, conserving biodiversity, and uplifting local communities (Milbank et al. 2018).

The concept emerged during COP (Conference of Parties) 11 of UNFCC in 2005 as RED (reducing emission from deforestation); and further broadened as REDD (reducing emissions from deforestation and forest degradation) during COP13 in Bali, Indonesia, in 2007. At COP 14 in 2008, the initiative fully evolved with worldwide acceptance to the current form as REDD+ that included additional concepts of conserving and enhancing forest carbon stocks, managing forests sustainably, improving rural livelihood, and conserving biodiversity (Chacón-Cascante et al. 2011; Chand et al. 2021; Wright 2011). Hence, the REDD+ temporally extends its scope with policies and actions. Currently, REDD+ opens up a new pathway for sustainable forest management through a nested governance structure regionally,

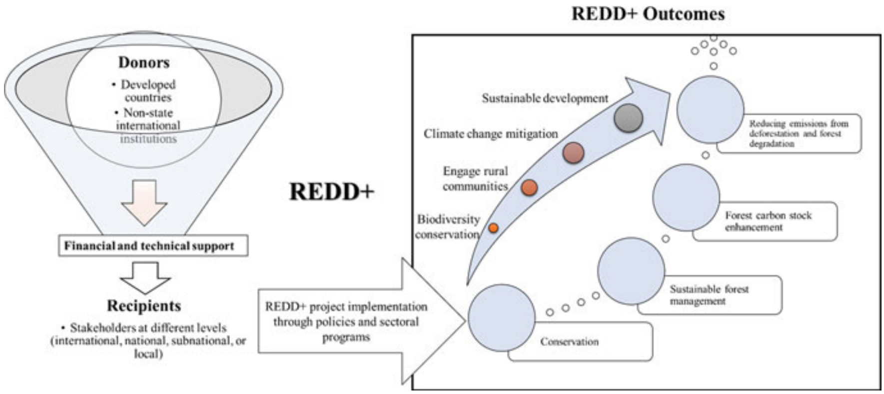

Fig. 16.2 Structure and beneficial outcomes of REDD+. (Figure modified from Shin et al. 2022)

nationally, and internationally; by integrating carbon markets and other innovative ideas (Chacón-Cascante et al. 2011).

In REDD+, donors, consisting of developed nations or international institutes, provide technical and financial support to recipients. This partnership with multiple actors under the global forest and climate change regime is the heart of every REDD + project. Figure 16.2 represents the structure of REDD+ and its beneficial outcomes. REDD+ implementation requires specific actions to improve the project's efficiency, delivery, accountability, and effectiveness that can achieve only with multilevel governance with different stakeholders (Angelsen and McNeill 2012; Shin et al. 2022). Furthermore, the collaboration equips the developing nations in capacity building. Hence, the success and outcomes of every REDD+ project primarily depend on the partnership. Shin et al. (2022) analyzed the REDD+ architecture using data from 480 REDD+ projects implemented in 57 countries and showed the polycentric networks and partnerships across various organizations and research institutes.

Developed nations provide monetary compensation and financial resource to countries, communities, or individuals who reduce carbon emissions from deforestation and forest degradation through REDD+ (Angelsen 2008; Chacón-Cascante et al. 2011; Wright 2011). In other words, "developed nations pay developing nations to keep their forests standing and well-managed" (Wright 2011). In that way, REDD+ ensures the economic upliftment of developing countries, both by offsetting emissions and by selling the carbon stored in forests in international carbon markets. Thus, technically, the REDD+ mechanism provides a new scale to forest governance with a unique motive and complexity (Wright 2011).

REDD+ activities are voluntary actions. Their implementation depends on the capability, circumstances, and capacity of the nation (UNFCC 2022a). Three phases in a REDD+ project include the readiness phase, implementation phase, and result phase (FAO 2022; UNFCC 2022b).

1. Readiness phase: Develop national strategies or action plans, policies, and measures. Assess the drivers and feasibility.
2. Implementation phase: Implement national policies and strategies through capacity building, technology development and transfer. Enable actions by proper land use planning, governance, private sector engagement, and financial mechanisms. Sectoral "AFOLU" actions (agriculture and agroforestry, forestry, other land-use sectors and landscape approaches).
3. Payments for results: Evolve into results-based actions that are fully measured, reported, and verified (MRV).

India is one of the largest CO_2 emitter countries in the world. But India progressed significantly in reducing emissions through systematic REDD+ implementation. The national REDD+ strategy, developed in 2018, supports several REDD+ projects in India (Chand et al. 2021). In addition to the national strategy or action plan, other critical elements of REDD+ in developing countries are the national forest monitoring system (MRV), forest reference level/forest reference emission level, and safeguard information system (MoEFCC 2018).

As a potent reducer of emissions from AFOLU (agriculture, forestry, and other land use), REDD+ mitigates climate change to a great extent (IPCC 2014; Stern 2007). Moreover, REDD+ provides various outcomes (Fig. 16.2) that contribute to SDGs directly or indirectly.

16.3 REDD+ and SDG

United Nations General Assembly in September 2015 developed seventeen Sustainable Development Goals (SDGs) and 169 related targets that together ensure a sustainable future by 2030. SDGs address several aspects of life on earth: socioeconomic well-being of people, environmental stability, and climate change and biodiversity conservation. Globally, these 17 goals are crucial in guiding and formulating the governance policy of several nations. The next 8 years are critical in fulfilling and contributing to those seventeen goals, where comes the importance of REDD+.

There is a mutual relationship between SDGs and REDD+ because REDD+ actions integrate sustainable management and conservation practices (Appiah et al. 2016). The countries engaged with REDD+ activities impart additional considerations on society and the environment using an integrated land-use planning approach (SDG Knowledge Hub 2018; UNEP 2018). It directly or indirectly paves a new path for sustainability. At the same time, SDGs widen the scope of pursuing REDD+ actions by providing additional institutional incentives. According to the Mongolia Ministry of Environment and Tourism report (REDD+ Mongolia 2017), REDD+ is a critical mitigation technique for GHGs and land degradation. In addition, the REDD+ strategy in Mongolia contributes to various SDGs that are not just related to the forest but also poverty eradication, ecotourism, and sustainable agriculture (REDD+ Mongolia 2017).

Among 17 SDGs, REDD+ potentially contributes to SDG 13 (climate action) and SDG 15 (life on land). REDD+ activities reduce emissions, enhance carbon sequestration, and mitigate climate change that fulfils SDG 13. Proper planning and implementation of REDD+ adapt the countries to sustainability in terms of climate action (SDG13) (UNEP 2018). On the other hand, SDG 15 aims to combat land degradation and desertification by conserving and restoring terrestrial ecosystems: forests, wetlands, dry lands, and mountains (Boer and Hannam 2019). Through sustainable management of ecosystems, SDG 15 tries to achieve a land-degradation neutral world, one of the outcomes of REDD+. Reducing emissions through deforestation and forest degradation sustains land productivity and food security. Successively, REDD+ improves the livelihoods of billions of people. Nowadays, several REDD+ projects highlight their role in achieving SDGs. Hence, merging REDD+ with SDGs not only improve the project's scope and success rate but also ensure sustainable co-benefits (Milbank et al. 2018). Table 16.1 listed the influential contribution of REDD+ projects to various sustainable development goals.

Milbank et al. (2018) investigated 25 REDD+ projects at the sub-national level and showed a strong alignment of their objectives with the SDG targets. Figure 16.3 shows REDD+ projects that are regularly monitored and improved to attain planned SDGs in the study. The number of REDD+ projects being valued for SDGs 4, 12, and 15 is high. The analysis reported a prominent gap in the planning and implementations of SDGs in those projects, which can be overcome by strengthening institutes that promote successful project operationalization. Also, the study explores the priorities of REDD+ projects and reveals their potential for positive change in SDGs.

16.4 Challenges and Recommendations

Even though REDD+ coordinates global emission reductions, it contains several challenges. The study in the Bosomtwe District, Ghana, through snowballing method and interviews from 12 communities, revealed that the knowledge of REDD+ and its intended benefit-sharing regimes is inadequate among the smallholder farmers (Appiah et al. 2016). Lack of knowledge is prominent within and among stakeholders regarding sectoral partnerships in REDD+ projects (Shin et al. 2022). Updated knowledge among people can develop with interactive awareness at the local level and scientific research at the institutional level.

Moreover, issues related to community rights, forest dependency, finance, capacity building, and policies often hinder effective REDD+ implementation (Chand et al. 2021). The comprehensive literature review by Kissinger et al. (2012) identified weak forest sector governance and institutions in 93% of countries. In some areas, the lack of decision-making information systems restricts the spread of REDD+ projects (Kissinger et al. 2012). A National Forest and Climate Change Strategy under REDD+ that is well-devised and systematically studied could overcome most of the issues related to policies at the national level. For the implementation of national projects, countrywide policy reforms and associated institutional

Table 16.1 Sustainable development goals and their contribution to the United Nation's Sustainable development goals

SDG		REDD+ contribution
1	No poverty	Helping countries to integrate biodiversity and ecosystem values into national and local planning and poverty reduction strategies (Milbank et al. 2018)
2	Zero hunger	Adoption of improved agricultural practices (Milbank et al. 2018); develop and implement an agricultural policy that contributes to national food security and rural development (Bernard et al. 2018)
3	Good health and Well-being	Ensure improvement of rural livelihood and their Well-being "Avoid unintended consequences on forest-dependent and forest-adjacent populations in developing countries" (Milbank et al. 2018)
4	Quality education	Equip forest institutes for quality implementation of REDD+, proper awareness and education to safeguard the capacity building, improve education, awareness-raising, and human and institutional capacity on climate change mitigation
5	Gender equality	Gender equity is ensured by relevant forest laws, policies, rules, regulations, administration, and management; reservations for women in joint forest management programs (Bernard et al. 2018; MoEFCC 2018)
6	Clean water and sanitation	Slowing and reversing water quality degradation (Alexander et al. 2011)
7	Affordable and clean energy	Address the issues related to the emissions from wood fuels (Bastos Lima et al. 2017)
8	Decent work and economic growth	Equip local communities to protect, regenerate and manage forests (MoEFCC 2018); economic upliftment through forest-based products (Hein and Meer 2012); "Creation of alternative livelihoods through programmes such as community forestry, sustainable biomass energy, community-based natural resource management and sustainable forest (eco)-tourism" (Bernard et al. 2018)
9	Industry, innovation, and infrastructure	REDD+ possesses a well-coordinated infrastructure that involves multiple stakeholders, law, policies, legislation, and governance (Bernard et al. 2018)
10	Reduced inequalities	Safeguards for rights of local communities through national strategies (Bastos Lima et al. 2017); respect for the knowledge and rights of indigenous people; empower a transparent and effective national forest governance structure (Bernard et al. 2018)
11	Sustainable cities and communities	Ecosystem management (Hein and Meer 2012); conserve forest carbon stocks (Bernard et al. 2018); increasing or enhancing the delivery of critical ecosystem services, equitable development and sustainable livelihoods in forest-dependent communities (Alexander et al. 2011)
12	Responsible consumption and production	Reduce human pressure on forests and address drivers of land degradation and deforestation (Bastos Lima et al. 2017); development of national forest monitoring system (Bernard et al. 2018)

(continued)

Table 16.1 (continued)

SDG		REDD+ contribution
13	Climate action	Design interventions that strengthen adaptive capacity and resilience to climate-related hazards and natural disasters Integrate climate measures into national planning, policies, and strategies (UNEP 2018); reduce greenhouse gas emissions and increase carbon sequestration and long-term stability; enhance resilience and the ability of ecosystems and communities to adapt to adverse impacts of climate change (Alexander et al. 2011)
14	Life below water	Conservation and sustainable use of inland freshwater ecosystems and their services (UNEP 2018)
15	Life on land	Sustainable use of forests and halt deforestation; combat desertification; reduce habitat degradation and tackle biodiversity loss; promote equitable forest-based livelihoods (UNEP 2018); aims to land degradation neutral world (Boer and Hannam 2019)
16	Peace, justice, and strong institutions	People-centric approach for project implementation; enacting laws that secure peace and justice; institutional building (National Forest Monitoring Systems, Safeguard Information Systems, etc.), with the full and effective participation of all relevant stakeholders (Bastos Lima et al. 2017)
17	Partnerships for the goals	Partnership with multiple stakeholders is a vital component of REDD+; provides finance and technology to developing countries to support emissions reductions (Bastos Lima et al. 2017)

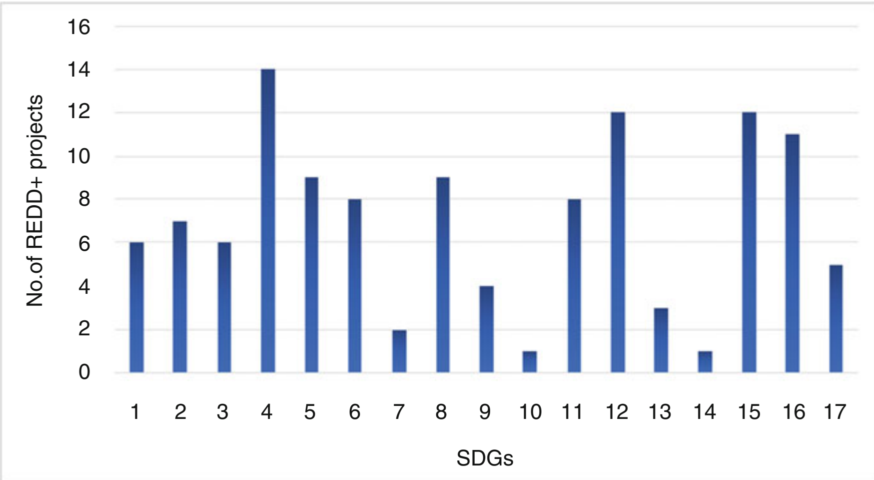

Fig. 16.3 REDD+ projects (out of 25) with evidence of monitoring and improvements on 17 SDGs. (Data extracted from Milbank et al. 2018)

support are mandatory. It restricts the practical application of several REDD+ objectives. Hence, small-scale projects at the sub-national level with people-private partnerships widen the opportunities and scope of REDD+ (Chacón-Cascante et al. 2011).

Another concern in the REDD+ is the difficulty in assessing and monitoring the project implementation. Remote sensing data regarding forest degradation is not always accurate and precise compared to the actual field condition. Therefore, Danielsen et al. (2011) suggest the need for a community-based monitoring system that monitor report and verify REDD+ outputs by ensuring the participation of local communities. By doing so, developing nations can ensure emission reductions from traditional practices and provide livelihood security. Currently, REDD+ objectives are limited to forests, but more explorations need to be done in wetlands, coastal sea grasses, and grasslands since they are good carbon sinks.

Preventing deforestation will not be enough to reduce the emissions for a sustainable future. Agroforestry is a boon in that situation that integrates crops, trees, and/or pastures more or less following typical forest multi stratified structure and diversity. Moreover, agroforestry systems can practice in several geographic and weather conditions: arid, semiarid, dry, and wet regions. The national strategies and action plans are well aware of the importance of agroforestry (Kumar et al. 2021). Agroforestry-oriented projects are recommended in policies to combat desertification and land degradation.

16.5 Conclusion

Reducing emissions from deforestation and forest degradation reverses forest land degradation and greenhouse gas emissions. Additionally, REDD+ practices contribute to all 17 sustainable development goals directly or indirectly. REDD+ opens up a new framework and path for forest management through policy-level changes, multi-stakeholder participation and carbon credit trades. Bottom-up awareness about its phases and structure will equip individuals, societies, communities, and nations to be economically ahead while maintaining sustainability.

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Carbon Sequestration Acts as a Moderator for Soil Restoration of Degraded Coal Mined Lands: An Overview

17

Pardeep Kumar, Sheenu Sharma, Sabir Hussain, and Anand Narain Singh

Abstract

India is one of the global economies where the energy sector is primarily coal driven and ranks third in coal production after China and the USA. About seventy percent coal extraction in India is operated through open-cast mining, which is more devastating for vegetation and topsoil. As a result, the stored C in the soil is released back to the atmosphere and potentially contributes to global warming. Mine soils are pedogenically young soils but pedobiologically no sense, which is deprived of organic matter, acidic in nature, lack essential soil nutrients, thus, unable to support plant growth at initial state. However, ecological techniques for revegetation and proper soil management practices may augment soil organic matter accumulation and ecosystem development. In India, mine soils after revegetation are reported to sequester 3.64 t C ha^{-1} year^{-1}. Reclaimed mine soils in the USA are estimated to offset 30 tera grams (Tg) of CO_2 each year. Amendment of mine spoils by using organic wastes such as biosolids, manures, mulches, and biochar is influential application in alleviating soil's physical, chemical, and biological properties. However, further studies are warranted to understand the positive and negative aspects of organic soil amendment, because minesoil management accelerates ecosystem recovery and enhances sink size for the rising level of atmospheric CO_2 in a changing environment.

Keywords

Coal mine spoil · Soil organic matter · Mine soil · Land degradation · Reclamation

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17.1 Introduction

The mining activities, especially surface mining, for coal and other minerals, degrade natural ecosystems with an irreparable loss of biodiversity, ecosystem services, and displacement of human settlements. In extracting coal, a vast land area is buried under a stock pile of mine waste, known as mine spoil dump. The mine dumps are detrimental to environmental health, causing contamination of air, water, and lands. In addition, one of the major impacts of surface mining is the loss of fertile topsoil, which in turn releases the stored carbon back into the atmosphere. After the commencement of reclamation activities, the coal mine spoils are termed mine soils. The mine spoils might be highly acidic and compact soils, devoid of microbes, lacking soil organic matter (SOM), therefore unable to support plant growth. The natural reclamation of mine spoils is a slow process, thus often assisted by human intervention in artificial plantation of grasses, trees, and fertilizers supplementation. It is not easy to restore the mine soils to their original state. However, reclamation success can be achieved to a certain extent. For this to succeed, careful species selection is essential, because not all species can thrive under hostile mine spoils environment (Singh et al. 2002).

Among the several factors available to determine the success of reclamation projects, soil development is one such critical factor. The development of stable and productive soil aftermath mining operations requires permanent vegetation cover to promote sustainable soil health. Soil is an important sink for atmospheric CO_2 where carbon (C) can be stored below ground for decades/millennia if left undisturbed. Several studies have hypothesized that there is an enormous potential to sequester organic carbon (OC) in reclaimed mine spoils (Ahirwal et al. 2017; Mukhopadhyay et al. 2014, 2016; Singh et al. 2006; Ussiri and Lal 2005; Ussiri et al. 2006). A study conducted by Akala and Lal (2000) showed that carbon sequestration in reclaimed mine soils under pasture and forest land increased over 25 years. Tripathi et al. (2016) showed that reclaimed mine soils act as a significant sink of C with an annual C budget of 8.40 t/ha/year. Thus, the present study is aimed to summarize the existing data on SOC sequestration potential of reclaimed coal mined lands, along with identifying the caveats and critical challenges affecting the reclamation of minesoils.

17.1.1 Mining Activities in India

Coal is a significant energy source for developing countries like India, where it powers the energy sector, mainly used in thermal power plants for energy generation, cement industry, and metallurgical operations. India's total coal production was 716.01 million tonnes during 2020–21 (Ministry of Coal 2021) and ranked third after China and USA. Coal India Limited (CIL) and its subsidiaries are the major contributors of coal production in India, accounting for 602.13 million tonnes of total coal production during 2019–20 (Ministry of Coal 2021). Unfortunately, most of India's coal reserve is buried under thick forests; coal extraction leads to deforestation and biomass carbon loss to the atmosphere. Thus, the rising emission of atmospheric CO_2 due to burning coal and other fossil fuels poses a severe threat to the global C cycle and ecosystem functions.

17.1.2 Reclamation of Mined Lands

As stated earlier, the natural rehabilitation of mined areas is slow and may take thousands of years to retain its original state. Therefore, mined spoils are often employed with human intervention or artificial succession to accelerate the reclamation process. Plantations comprised one of the most commonly used and ancient techniques in ecological restoration. Plantations improve soil physicochemical properties, organic matter formation. This can be done by planting fast-growing exotic or native tree species, introducing grass-legume mixture, or preparing seed bedding. In earlier times, coal mine spoils in India were rehabilitated using the traditional methodology of afforestation, which often proves inadequate. The team of Professor J S Singh at Banaras Hindu University started an integrated ecological study on revegetation of mine spoils at Jayant and Bina projects, NCL, Singrauli. They installed various revegetation models: tree monoculture seeded with grasses and legumes; tree monoculture seeded with crop plants; tree monoculture with ground seeding and fertilizer applications; tree mixed culture seeded with grasses and legumes and mulching of tree mixed-culture plots seeded with grasses and legumes. Additionally, several studies (Ahirwal and Maiti 2017, 2018; Ahirwal et al. 2017; Das and Maiti 2016; Mukhopadhyay and Masto 2019; Mukhopadhyay et al. 2014, 2016; Tripathi et al. 2014, 2016) have evaluated reclamation success and soil development under revegetated coal mined sites.

17.1.3 Properties of Mine Soils

The properties of mine dumps are determined by rock substrata from which they are derived. Coal mine spoils represent nutritionally impoverished and degraded sites. These are mainly comprised of high rock fragments, acidic to neutral pH, high bulk density, low water-holding capacity and pH ranging from neutral to acidic. Mined spoils are devoid of soil organic matter and lack basic soil fertility elements such as N, P, K (Singh et al. 2004a; Tripathi et al. 2014). The high concentration of heavy metals in unreclaimed/overburdened/fresh mine spoils is a serious matter of concern. However, the plantation establishment can reverse the degradation process by modifying the soil properties through the development of extensive root systems. It has been well evidenced in Singh et al. (2004a) where mine spoil under plantations achieved significant improvement in physicochemical properties such as lower bulk density, increased water-holding capacity, and raised concentration of exchangeable nutrients, that is, Na, Mg, K, and Ca. The lower pH of mine spoils increased the bioavailability of these metals, leading to the transfer of heavy metals to the ecological food chain (Maiti 2007).

17.2 Soil Organic Carbon Sequestration

The concentration of atmospheric CO_2 reached 405 ppm in 2018 from its preindustrial level of 278 ppm (State of Global Climate 2020). Consumption of fossil fuels and land-use change are the two major causes of CO_2 emission (Watson et al. 2000). India's energy sector is primarily coal driven, and so is the emission of CO_2. Carbon sequestration refers to the process of absorption of atmospheric CO_2 and secures storage in long-lived pools. Soils are the largest reservoir of carbon in the terrestrial pools with longer residence time (Yu et al. 2019) and store three times more carbon than vegetation (Schmidt et al. 2011). They are estimated to account for ~2300 Pg of C in the top three meters (Jobbágy and Jackson 2000). SOC is an integral constituent of the global carbon cycle (Doetterl et al. 2012) and plays important ecosystem services such as water infiltration, increasing soil fertility, channelizing nutrient cycles, and biomass development (Krishan et al. 2009). Moreover, it plays a remarkable role in predicting climate change and its effects. Mine soils are pedogenically young soils and often deprived of OM; therefore, these degraded lands can sequester atmospheric CO_2 through revegetation and management practices.

SOC sequestration in reclaimed mine soils depends on biomass productivity, root biomass development in subsoil, and changes in properties due to overburden weathering (Haering et al. 1993; Ussiri et al. 2006). Also time since reclamation, vegetation type, climatic conditions, and management activities influence SOC sequestration rate in reclaimed mine soils (Ussiri and Lal 2005). Reclamation of postmining sites after revegetation has been observed to alleviate SOC stock. In India, a study conducted by Singh et al. (2006) underplanted woody species found the highest SOC stock, 11.12 Mg C ha^{-1}, after 5 years of reclamation. Similarly, Das and Maiti (2016) at Jharia coal fields estimated 16.33 Mg C ha^{-1} under mixed plantation. In another study, Ahirwal et al. (2017) reported that SOC stock increased significantly from 20.20 to 45.4 Mg C ha^{-1} after 8 years of reclamation. After 25 years of reclamation in Ohio, USA, the SOC pool rose from 15.3 to 44.4 Mg C ha^{-1} under pasture land and 12.7 to 45.3 Mg C ha^{-1} under forest at 0–15 cm soil depth (Akala and Lal 2000). A detailed account of SOC stock on reclaimed coal mined lands is given in Table 17.1. However, achieving SOC stock equivalent to natural forest soils may take 100–150 years (Akala and Lal 2000).

17.3 SOC Accumulation in Mine Soils

Carbon and nitrogen are the major limiting factors in mined spoils. In most studies, the more significant amount of C is concentrated in the topmost layer of soil, emphasizing the idea that vegetation regulates the SOC sequestration in mineral horizons (Singh et al. 2006). However, with the onset of revegetation programs, SOC accumulation over time has been observed in mined spoils.

A study conducted by Singh et al. (2004a) in Singrauli coalfields observed that the rates of OC accumulation varied between 1256, 1886, and 395 Kg ha^{-1} in

Table 17.1 A comparative account of soil organic carbon stock estimations in reclaimed mine soils globally

Study area	Vegetation/land use type	Age (years)	Soil depth (cm)	SOC stock (Mg ha^{-1})	Reference
Reclaimed minesoil Ohio, USA	Pasture	25	0–30	36.7	Akala and Lal (2000)
Reclaimed minesoil Ohio, USA	Forest	25	0–30	37.1	Akala and Lal (2000)
Reclaimed minesoil Ohio, USA	Pasture	25	0–15 15–30	9.2–55.4 7.8–37.8	Akala and Lal (2001)
Reclaimed minesoil Ohio, USA	Forest	21	0–15 15–30	14–48.4 8.4–14.5	Akala and Lal (2001)
Reclaimed minesoil Ohio, USA	Hardwood forest	–	–	81	Jacinthe et al. (2004)
Reclaimed minesoil Ohio, USA	Grassland	–	–	71	Jacinthe et al. (2004)
Redeveloping mine spoil, Singrauli, India	Dry tropical native plantations	4	0–20	24.13	Singh et al. (2006)
Redeveloping mine spoil, Singrauli, India	Dry tropical native plantations	5	0–20	32.03	Singh et al. (2006)
Reclaimed minesoil Appalachian, USA	Pine	–	–	11	Amichev et al. (2008)
Reclaimed minesoil Appalachian, USA	Hardwood	–	–	13	Amichev et al. (2008)
Reclaimed minesoil Appalachian, USA	Mixed stands	–	–	17.7	Amichev et al. (2008)
Reclaimed mine soils, Poland	Scots pine (poorest sandy soil)	12–30	–	0.73	Pietrzykowski and Krzaklewski (2010)
Reclaimed mine soils, Poland	Scots pine (Sandy-clayish soil)	12–30	–	2.17	Pietrzykowski and Krzaklewski (2010)
Reclaimed mine soils, Poland	Scots pine (carboniferous substrate soils)	12–30	–	5.26	Pietrzykowski and Krzaklewski (2010)
Reclaimed minesoil Ohio, USA	Forest	25	0–15	38	Shrestha and Lal (2010)
Reclaimed minesoil Ohio, USA	Pasture	25	0–15	35	Shrestha and Lal (2010)
Reforested surface-mined lands, Appalachian, USA	Mixed plantation	5	–	7.02	Avera et al. (2015)

(continued)

Table 17.1 (continued)

Study area	Vegetation/land use type	Age (years)	Soil depth (cm)	SOC stock (Mg ha^{-1})	Reference
Reforested surface-mined lands, Appalachian, USA	Mixed plantation	11	–	13.52	Avera et al. (2015)
Reforested surface-mined lands, Appalachian, USA	Mixed plantation	21	–	21.35	Avera et al. (2015)
Reforested surface-mined lands, Appalachian, USA	Mixed plantation	30	–	16.62	Avera et al. (2015)
Revegetated mine wasteland	Dry tropical ecosystem	19	0–30	22.9	Tripathi et al. (2014)
Reclaimed mine soils, Jharia coalfields, India	Mixed plantation	4	0–15	16.33	Das and Maiti (2016)
Reclaimed mine soil, Jharkhand, India	Afforested woody trees	5	0–10	7.5	Ahirwal and Maiti (2018)
Reclaimed mine soils, Telangana, India	*Prosopis juliflora*	8	0–60	45.30	Ahirwal et al. (2017)
Jharia coalfield, Jharkhand, India	*Cassia siamea*	3–16	0–30	6.61–24.04	Mukhopadhyay and Masto (2022)
Jharia coalfield, Jharkhand, India	*Albizia lebbeck*	3–16	0–30	6.10–21.43	Mukhopadhyay and Masto (2022)

Albizia lebbeck, *A. procera*, and *Tectona grandis* plantations, respectively. In another study, Singh et al. (2006) under four native woody species observed maximum organic C stock (11,128 kg ha^{-1}) under *A. lebbeck* plantations, while highest organic carbon accretion rate (3241.8 kg ha^{-1}) under *Dendrocalamus strictus* plantations was observed. Studies conducted on mined spoils (Kaye et al. 2000; Singh et al. 2004b) observed a substantial increase in soil organic carbon under *Albizia* plantations.

The rate of SOC sequestration varied land-use type wise. A study conducted by Akala and Lal (2000) in reclaimed mine soil, Ohio, USA, found pasture lands to have higher SOC accumulation than forests. Burger (2004), in reclaimed mine soils of Appalachian, USA, found a rate of C accumulation 4 Mg C ha^{-1}. In another study conducted on reclaimed mine soil under Scots pine, Pietrzykowski and Daniels (2014) estimated SOC accumulation rate of 1.45 Mg C ha^{1}. In India, recently, several studies have focused on assessing the SOC sequestration potential of mined lands. Das and Maiti (2016) at Jharia coal fields reported SOC accumulation rate of 4.8 Mg C ha^{-1} year^{-1}. Ahirwal and Maiti (2017), in dry tropical, mined spoil

Table 17.2 Accumulation rate of SOC at various reclaimed mine spoil sites

Study area	A	SAR	Reference
Jharia coalfields, Jharkhand, India	5	1.5	Ahirwal and Maiti (2018)
Central coalfields, Jharkhand, India	14	1.9	Ahirwal and Maiti (2017)
Northern coalfields, Singrauli, India	19	1.35	Tripathi et al. (2014)
Jharia coalfields, Jharkhand, India	4	4.08	Das and Maiti (2016)
Reclaimed mine spoil, Ohio, USA	25	1.5	Akala and Lal (2000)
Mixed forests, Czech Republic	22–32	0.1–1.2	Frouz et al. (2009)
Forests and cropland, China	22–25	0.2–2.8	Yuan et al. (2017)
Scots pine, Poland	–	1.5	Pietrzykowski and Daniels (2014)
Reclaimed mine spoil, Ohio, USA	25	1.5	Shrestha and Lal (2010)
Reclaimed mine spoil, Ohio, USA	10	2.4	Ussiri et al. (2006)
Reclaimed mine spoil, USA	8	2.9	Maharaj et al. (2007)

A age in years, *SAR* soil organic carbon accumulation rate (mg C ha^{-1} $year^{-1}$)

estimated SOC sequestration rate of 1.9 Mg C ha^{-1} $year^{-1}$ after 14 years of reclamation. In another study at Singrauli coal fields, Tripathi et al. (2014) evaluated C accumulation at a rate of 1.35 Mg C ha^{-1} $year^{-1}$. However, Ussiri et al. (2006) found a comparatively higher value of SOC sequestration 2.4 Mg C ha^{-1} $year^{-1}$ under black locust plantations. A comparative account of SOC accumulation on coal mine spoils in India and at the global level is given in Table 17.2.

Several studies have shown that mined spoils attained higher SOC accumulation in the young stage of plantations, while it decreases with age (Akala and Lal 2001; Shukla and Lal 2005; Vindušková and Frouz 2013). According to Shrestha and Lal (2006), maximum SOC accumulation occurred under forest soils after 14 years in postmining sites and under pasture after 6 years. The accumulation of SOC is a time-bound process; generally improve over time, as evidenced in the Raniganj Coalfield in eastern India, where MBC and soil CO_2 efflux approached the levels of natural forestland after 21 years of revegetation (Kumar et al. 2015). Similarly, Mukhopadhyay et al. (2014) reported that the MBC and soil CO_2 efflux in the North Karanpura area of India exceeded the levels of natural forestland after 17 years of reclamation.

17.4 Stabilization of SOC in Reclaimed Mine Soil

Carbon stabilization refers to the process where C molecules resist microbial degradation, respiration, soil erosion, and leaching. There are different mechanisms of carbon stabilization in the soil such as (1) physical stabilization, where C molecules are held within soil aggregates, which form a barrier and retard the microbial action; (2) chemical recalcitrance: in this process, an abundance of polychromatic, c-alkyl carbon compounds such as lignin, polyphenols, etc. alter the chemical forms that make them less easily accessible to microbial action and their degrading enzymes; (3) mineral complexation: mineral compounds, such as clay and silt, because of their large surface area, absorb a significant amount of organic matter. SOM and aggregates are essential structural parameters of mine soil quality, and both are intricately linked to each other (Goh 2004).

SOC promote aggregate formation in soil, and these aggregates encapsulate C molecules, providing physical protection against microbial decomposition (Oades 1984). Aggregate size classes determine the stability and residence time of C molecules inside the soil. Macroaggregates comprise higher C content but turnover more rapidly than microaggregates, which are low in C content but with higher residence time (Jastrow et al. 1998). Several studies on reclaimed mine spoil have reported a positive correlation between SOC and aggregate formation (Golchin et al. 1994; Li et al. 2021; Ussiri et al. 2006). In the reclaimed coal mine spoil of Southwest Virginia, Wick et al. (2016) observed higher aggregate formation in soil upon adding varying concentrations of biosolids. They further inferred that the organic amendments greatly influence soil development in the early years of reclamation (<10 years), while vegetation plays a dominant role in subsequent years. Biochar application to mine soils can increase the residence time of C molecules inside the soil. Due to its recalcitrant nature, biochar provides more stability to soil organic matter. Several studies have reported the long-term stability of SOC in biochar amended soils (El-naggar et al. 2019; Jeffery et al. 2011; Wang et al. 2016). Therefore, soil management of mined spoils is a prerequisite for accumulating C and their long residence time.

17.4.1 Factors Affecting the Development of SOC in Coal Mine Spoils

The accumulation and development of soil carbon is governed by several factors such as climatic conditions, nature of mine spoil, soil depth, age of mine spoil, and the vegetation types.

17.4.1.1 Vegetation Type

Vegetation contributes a significant amount of organic matter; its establishment is the only source of organic matter in reclaimed mine soils. Different species influence organic matter accumulation as the quantity and quality of litter determine the C input to soil. In addition, the developing plant roots in association with fungal or microbial exudates strengthen soil aggregation and improve soil organic matter accumulation. Singh et al. (2006) studied organic carbon stock under four different planted species on coal mine spoil after 5 years of reclamation in a dry tropical environment. They found higher SOC stock under *Albizia lebbeck* (11.128 t ha^{-1}) plantation followed by *Dendrocalamus strictus* (10.728 t ha^{-1}), *Albizia procera* (6.581 t ha^{-1}), and *Tectona grandis* (3.837 t ha^{-1}). A study conducted by Zhao et al. (2013) in 1–13-years old reclaimed coal mine spoil in Loess plateau of China observed higher microbial population with improved soil properties under sea buckthorn plantations than other planted species.

In another study, Helingerová et al. (2010) observed that microbial biomass increased with age in postmining sites near Sokolov, Czech Republic. This increase was more pronounced in Alder reclaimed sites than in unreclaimed sites. On a reclaimed mine soil in Pernik, Bulgaria, Filcheva et al. (2000) examined the impacts of two tree species, black pine and black locust, on initial pedogenesis after 25 years of plantation. Due to its higher litter decomposition property, they observed that black locust sponsor larger microcoenosis than black pine. A recent study by Mukhopadhyay and Masto (2022) reported higher SOC content and nutrient stock under *Cassia siamea* plantations than *Albizia lebbeck*. Thus, careful species selection is vital while establishing revegetation programs for degraded lands.

17.4.1.2 Root Biomass

Roots mediate the transport of photosynthetically fixed carbon (C) from plant canopies to the soil. In addition, the release of root exudates, root litter, and their turnover act as a significant C input to soil (Matamala et al. 2003). Root C has been reported to possess high stability and longer residence time in soil than C input from aboveground parts, that is, shoots. It could be due to the greater prevalence of aromatic compounds such as lignin, phenol, tannin, and suberin in roots, enhancing their chemical recalcitrance (Rasse et al. 2005; Ussiri et al. 2006). Also, root exudation and rhizo deposits may promote soil aggregate formation and help in the physical protection of SOC against microbial decomposition. Several studies (Srivastava et al. 1989; Tripathi et al. 2012; Ussiri et al. 2006) have observed an increase in root biomass on reclaimed coal mine soils provided better improvement in the soil redevelopment.

Despite playing a crucial role in SOC formation on postmining sites, role of roots in forest succession is still understudied. A study conducted by Tripathi et al. (2012) found that after 12 years of revegetation, plant roots significantly enhance dump slope stability by providing firm plant anchorage and enhanced factor of safety. Therefore, selecting suitable plant species with a more proliferative and deeper root system may help enhance SOC sequestration by transferring more OM into deeper horizons (Ussiri and Lal 2005). A recent study by Świątek et al. (2019) on reclaimed techno sol (Poland) found that the fine roots under Alder plantations deliver more nutrients to soil than aboveground under canopy litterfall.

17.4.1.3 Microbial Biomass

Microbes constitute only 2–4% of soil organic matter, but they play a central role in soil formation due to their high turnover and OM transformation rate. The microbial communities play a vital role in key ecosystem processes such as decomposition and mineralization (Coleman et al. 2004), the channeling of nutrients, transformation and conversion of organic and inorganic compounds, and their subsequent availability to plants. For a stable plant community to form on a mined site, there must be an active soil microbe community (Singh et al. 2004a, b). Microbial activity is so crucial in mine soil recovery that sometimes it has been referred to as an index of soil genesis's progress. Microbial biomass is a function of soil organic C and N. It has been well evidenced in Singh et al. (2004a, b). They observed a positive correlation between soil organic C and microbial biomass C (MBC).

17.4.1.4 Litter Carbon

Nutrient release from the deposited litter for reuse of plants and soil microbial community depends on decomposition rate. A comparatively low litter decomposition rate has been reported on the mine spoils (Singh and Singh 1999; Singh et al. 2004a, b). Litter decomposition rate can be used to indicate the degree of soil ecosystem recovery, since it essentially controls nutrient cycling. Giardina et al. (2001) documented that high-quality litter leads to high-quality organic C and N in the mineral soil. A comparative study by Singh et al. (2004b) under two *Albizia* sp. observed that soil C and N increased with plantation age in both species. Even though both species produce the same amount of litter fall, they found substantially higher soil organic carbon values in *Albizia lebbeck* than in *A. procera* plantation. They accredited to the faster rate of litter breakdown under *A. lebbeck*. In another study in a dry tropical environment in India, Tripathi et al. (2014) found that litter mass (2.88 t/ha) contributed significantly to the annual C budget (8.40 t C ha^{-1}) as compared to other components.

17.5 Management Activities to Enhance SOC Sequestration

The establishment of vegetation on mine soils is cumbersome for various reasons, including lack of organic matter, the abundance of stone particles, coarse texture of mine soils, high acidic conditions, low water-holding capacity (WHC), and metal toxicity. Soil development is a central component of land reclamation, and thus, the quality of the soil determines the success of reclamation (Kuang et al. 2019). The traditional techniques to reclaim mine spoils include fertilizer application and soil amending using topsoil from undisturbed areas. Sometimes, these techniques are uneconomical due to the associated cost of transportation and degradation of the area from where topsoil is being transported. Organic amendments or biowaste in the form of manure, biosolids, pulp and paper mill sludge, and food processing waste provides an immediate and readily available source of C and promotes soil physicochemical properties (Fig. 17.1). A large amount of biowaste materials is generated as a by-product of livestock and poultry industry (Wijesekara et al. 2016). The main aim of using organic waste products to amend degraded soils is to build SOM and the subsequent initiation of microbial communities. Thus, biowaste material provides a readily available, cost-effective, and efficient solution to improve mine soil quality. Some of the organic amendments suggested in the literature to initiate soil ecosystem formation on coal mined lands are discussed below.

17.5.1 Sewage Sludge or Biosolids

The chief advantage of using organic amendments is that these are comparatively cost-effective and readily available compared to other soil amendments. Sewage sludge or biosolid is one such organic amendment that has been successfully used to reclaim coal mine sites globally (Antonelli et al. 2018; Sopper 1993; Tian et al.

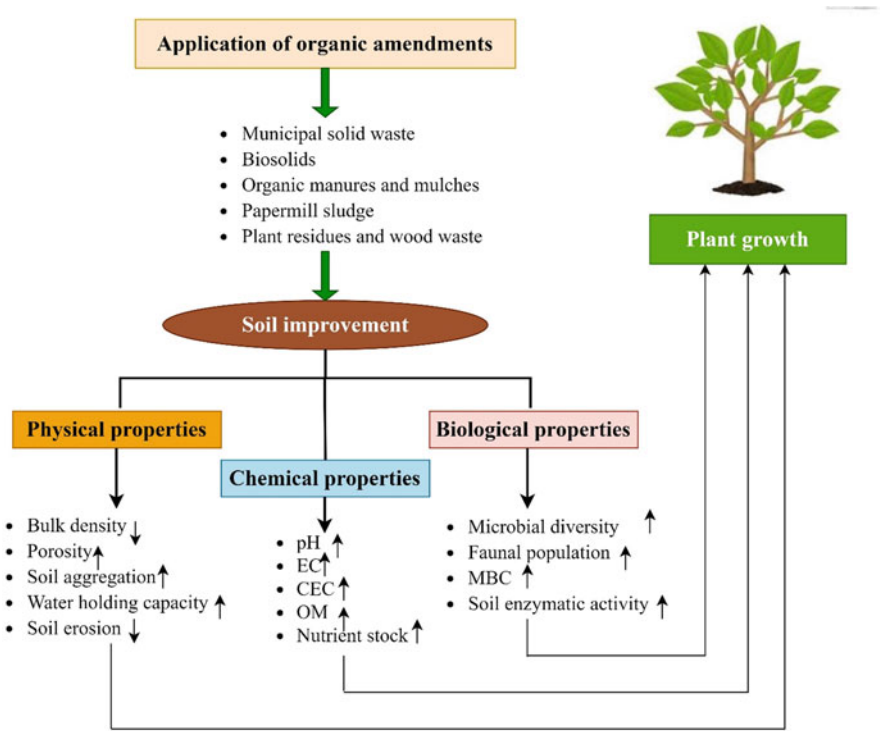

Fig. 17.1 Schematic representation of application of organic amendments in soil development on coal mine spoil. *EC* electrical conductivity, *CEC* cation exchange capacity, *OM* organic matter, *MBC* microbial biomass carbon

2009). Sewage sludge amendment to mine spoil has been reported to accelerate the development of microbial communities, which is a prerequisite for soil fertility. A recent study by Li et al. (2021) found that sewage sludge amendment promotes aggregate binding agent content and soil aggregate stability on postmining lands. They observed that sludge amendment increases SOC and light fraction SOC (LFOC) by 151% and 247%, respectively, compared to control treatment. Therefore, the use of sludge amendment is a cost-effective approach to enhance the terrestrial C sink.

17.5.2 Organic Manure and Mulching

In a country like India, where agriculture is a prime source of income, it generates a large quantity of organic manure from livestock, which is a significant source of nutrients such as nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) (Thangarajan et al. 2013). Application of animal manure has been reported to promote the faunal population in soils. A study conducted by Leroy et al. (2008)

found a more significant earthworm population after applying farmyard manure and cattle slurry to the soil. In another study, Shrestha et al. (2009) at eastern Ohio, USA, found a significant increase in SOC upon adding cow manure (10 Mg ha^{-1}) after 5 years of reclamation. In another study, Lv et al. (2011) observed that the application of pig manure at a rate of 833 kg/ha substantially improved SOC, total N, available N, and P by 19.2%, 14.4%, 13.2%, and 78.3%, respectively, as compared to control. Organic amendments serve as a readily available source of C to microbial communities. This can be evidenced in Tejada et al. (2006), where they observed that soil microbial biomass and enzymatic activity increased after amending soil with poultry manure.

Apart from organic manure, plant residues or mulching has also been suggested to improve soil quality. According to a survey, India annually produces approximately 8.0, 99.0, 129.8, 227.6 million mega grams of barley, maize, paddy, and wheat plant residues, which can be potentially utilized to enhance soil nutrient value if appropriately managed (Thangarajan et al. 2013). However, there is an excellent variety of organic materials for mulching, such as green pruning, wood chips, leaves, tree barks, stem husks, etc. However, crop residues from agricultural waste or straw of cereals such as wheat and oat are commonly employed for mulching purposes. Mulching can positively impact reclamation of mine spoils through (1) increasing water infiltration and water-holding capacity of soils, reducing evaporation of water, (2) maintaining soil temperature and enhancing biological activity, (3) increasing soil aggregate stability, and reducing crusting of soil, (4) improving cation exchange capacity of soil and availability of plant nutrient and biomass production, and (5) humus or soil organic matter formation.

17.5.3 Biochar

Biochar is a black carbon powdery substance produced after pyrolytic degradation of organic waste under high temperatures in an oxygen-free environment. Because of its high C content, biochar amendment has been advocated for soils with low C content. The presence of surface carboxyl, hydroxyl, and carbonyl groups gives biochar particles a negative charge, increasing cation exchange capacity (CEC) in soil. The highly porous carbonaceous material with a negatively charged surface is responsible for its high CEC in soil and absorption of organic and inorganic compounds. Biochar addition has been suggested to reduce soil bulk density and subsequent soil aeration, root penetration, water infiltration, and soil aggregate stability (Sun and Lu 2014). Biochar enhances soil C content and other essential nutrients like N, P, and exchangeable cations like Ca, Mg, Na, and K in soil (Major et al. 2010). Biochar application to soils has been suggested as a viable option for long-term storage of C in soils. Biochar amendment can be beneficial for the reclamation of coalmine spoil. The acidic nature of mine spoils can increase the bioavailability of heavy metals, which hampers microbial activity and thereby nutrient mobilization in soil. Several studies have reported the acid-neutralizing property of animal biochar (Rajkovich et al. 2012), chicken manure biochar (Hass et al. 2012) in soils. In a recent study, Ghosh et al. (2020) evaluated *Lantana camara* biochar's amended mine spoil's effect on the growth of *Zea mays*. They observed significant improvement in SOC content (2.9 times), CEC (2 times), WHC (0.13 times), and decrease in bulk density (0.5 times) in the mine spoil.

17.5.4 Industrial Combustion By-Products

Apart from organic amendments, two coal combustion by-products, namely, fly ash and flue-gas desulfurization (FGD), have been recommended in the literature for restoration of severely degraded mined lands. Fly ash (FA) is a solid waste product with aluminosilicate composition comparable to soil generated from coal combustion in power plants. It is a cheap, alternative, and readily available material for reclamation of mining sites and wastelands (Bradshaw 2000). Whereas, FGD is a by-product of SO_2 scrubbing technology used in electricity generation plants. FGD is alkaline in nature, consisting of excess sorbent (calcite or dolomitic limestone, CaO, Ca $(OH)_2$ and MgO), S-bearing compounds ($CaSO_4$, $CaSO_3$ and $MgSO_4$) (Crews and Dick 1998; Palumbo et al. 2004).

Fly ash is used mainly for engineering purposes to modify soil texture and as a source of trace nutrients for plant growth. In contrast, FGD by-products are used as liming agents and sources of divalent cations to improve soil aggregation. It contains several essential nutrients such as K, Ca, Mg, S, and P and is useful for soil fertility. It is beneficial for overall soil health as it improves soil aeration, decreases the bulk density, increases water-holding capacity, and neutralizes acidic soil pH. FA application in acidic open cast mines has enhanced crop yield (Ram et al. 2006). This probably is due to the acid neutralization activity of FA as it increases the availability of Ca^{2+} and Mg^{2+}. Also, it enhances soil microbial diversity, increases organic matter, and the physical quality of the soil. In a recent study, Mukhopadhyay and Masto (2019) studied the effect of fly ash on C mineralization under biochar and organic manures added mine soil. They observed a significant decline in CO_2 emission under fly ash added minesoil. Also, the stable C pool was enhanced after applying fly ash accredited to its physical protection mechanism against microbial degradation. Therefore, future management strategies should focus on increasing the size of the C pool with long term residence times.

17.6 Conclusion and Future Recommendations

The accumulation of soil organic matter is the critical process in mine spoil reclamation, because it ameliorates the physicochemical properties of mine spoil. In recent times, the focus has shifted toward estimating the SOC sequestration potential of mine soils. Studies have shown that if appropriately managed with careful species selection and top soil management, the coal mine spoils can exceed natural forest soils in terms of C accumulation and nutrient stock. Application of biowaste (organic amendments) has proven effective in the reclamation of mined lands. Biochar prepared from noxious weeds such as *Lantana camara* offers new possibilities for mine land reclamation, because it improves mine soil health and eliminates the competition posed by invasive species. However, a holistic approach is required globally to underpin the associated irregularities with biochar. Regular monitoring of SOC content in coal mine lands is vital for management and reclamation perspectives. The traditional methods for the determination of SOC content are laborious and time consuming. Also, the associated high cost and poor real-time performance make them ineffective. However, these shortcomings of traditional methods can be overcome using advanced technics such as Visible-near infrared (Vis-NIR) spectroscopy (Sun et al. 2018). Fine roots play a crucial role in SOC formation. Very few studies have specifically evaluated the structure and functioning of roots concerning SOC formation on coal mine spoils. Therefore, there is a need to study fine root dynamics under revegetated coal mine lands to enhance our understanding of SOC sequestration in mine soils.

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Nature Conservation Effects on Forest Carbon Sequestration, Biodiversity of Plants, and Macrofungi: A Case Study in Central Lesser Khingan Mountains, NE China

18

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Abstract

The conservation of species diversity and improvement of forest structure are essential roles of the Natural Reserve Policy and the Natural Forest Protection Program (NFPP) in China. However, the long-term effects of NFPP are still not well defined, and a natural reserve (Liangshui) and surrounding region in the central Lesser Khingan Mountains were surveyed as a proxy of NFPP for approaching the protection effects. This chapter showed the alteration of above-ground carbon sink function, the dominant species composition and diversity, forest structural features of trees, shrubs, and herbs, and macrofungi under natural

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conservation. This study provides essential data to evaluate the impact of the nature reserve in northeastern (NE) China. These findings can be used to guide the implementation of NFPP in the long term in the future.

Keywords

Nature conservation · Carbon sequestration · Species diversity · Macro-fungi · Lesser Khingan Mountains

18.1 Introduction

In 1998, the flood occurred in China's Yangtze River, Songhua River, and Nenjiang River. The high water level, the large amount of water, the long duration, and the wide damage area were unprecedented and caused considerable losses to the national economy. The disaster had an inseparable relationship with the severe destruction of forest vegetation in the upper and middle reaches of the river and the weak ecological function (Zhuang 2001). Since then, Natural Forest Protection Project (NFPP) has been implemented to protect and restore the natural forests by the government (Sun et al. 2015).

The NFPP was launched in 1998 to protect natural forests, covering an area of 45 million ha in China (Zhang et al. 2000). Since then, evaluations have been assessed in land use and land cover change (Shi et al. 2016), and carbon stocks and overall forest quality (Dai et al. 2017; Hua 2017), indicating sharp declines in timber harvest with increasing forest area and slow increases in biomass stocks in northeast (NE) China (Wang 2004). Forest ecosystem function improved significantly. The net increase in forest area is 1614 thousand ha. The protection of forest resources is more than 33 million ha. The forest coverage rate increases by 4.1%, and the net increase in stock volume is 273 million m^3. Biodiversity has been effectively protected; the amount of wild animals and plants has increased significantly under national protection. These results are closely related to the power management measures of the first phase of the NFPP from 2000 to 2010. Since implementing the protection project, strict logging management has been carried out to restrict excessive logging resolutely, and resource consumption is strictly controlled.

With the natural protection project, the requirements for improving forest quality and ecosystem functions are gradually increasing. More demand for the synergetic improvement of forest structure, species diversity, and ecosystem functions is urgent, and more reliable scientific support and forest tending management measures are also needed. However, there is a lack of detailed information about species composition and diversity alternations and forest structure of plant size and forest density at different vertical layers, owing to practical design difficulty (Wang et al. 2020).

18.2 Materials and Methods

18.2.1 Experimental Design, Field Investigation and Data Collection

The study sites were in the Liangshui National Natural Reserve and adjacent region in the central Lesser Khingan Mountains region (128°47′25″ ~ 128°58′58″ E,47°07′07″ ~ 47°15′58″ N) (Fig. 18.1). The typical hilly terrain is surrounded by complex mountainous topography, with most north-south mountains. The average slope is 10–15 degrees. The altitude is from 280 to 707 m, with an average of 400 m (the relative altitude is 80 to 300 m). The mean annual air temperature is −0.3 °C, accompanying a short frost-free period of 100–120 days and a mean annual precipitation of 676.0 mm. The outcrop rocks are Hercynian granite and granite phenocrysts, with a few of Archean granitic gneiss. The main soil types are dark brown forest soils (Wang et al. 2019, 2020).

In this study, the sampling plots were located inside and outside the national nature reserve. Plot sizes for the tree layer survey were 30 m × 30 m, and in each tree plot, two 5 m × 5 m shrub subplots and five 1 m × 1 m herb subplots were surveyed, respectively, to sample the shrub and herb layers. In the experimental design, 120 sampling plots were surveyed, including 60 plots in the Reserve and 60 outside the reserve. There were 20 plots in the core zone, buffer zone, and experimental zone

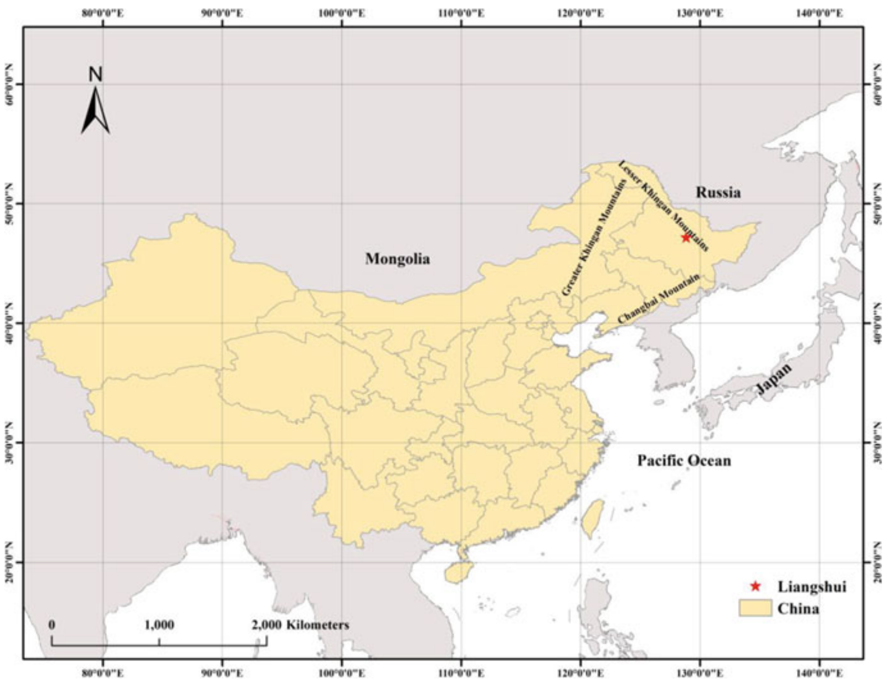

Fig. 18.1 The relative location of the study site in China

in reserve, respectively (a total of 60 plots in the Reserve). The plot locations outside the reserve were within about 30 km from the edge of the reserve in our study (Fig. 18.1). This sampling distance in studying the conservation effects ranged from 2 to 70 km in previous references (Khan et al. 2019; Xu et al. 2019; Yang et al. 2019).

In the survey, plant species names of all trees, shrubs, and herb layer species in the plots and tree sizes and community traits of the forests were recorded in detail. For trees, the diameters at breast height (dbh), tree height (th), and tree density (td) were measured. Shrub surveyed items included shrub density (sd), shrub height (sh), and shrub coverage (sc). In the case of the herb layers, relative coverage of each species (hc) and herb height (hh) was recorded. The coverage of herbs was measured as the proportion of the area of the surveyed species to the total surveyed area in percentage. Tree, shrub, and herb densities were calculated as the number of individuals divided by the plot area. We also recorded the altitude, slope aspect (sunny, shade, and half-sunny-shade slope), slope position (upper, middle, bottom of the slope or flat), slope gradient in degrees, and latitude and longitude of each sampling plot in the survey (Wang et al. 2020).

18.2.2 Species Diversity

Species diversity was calculated with the field survey data, as richness index (18.1), diversity indices (18.2) and (18.3), and evenness indices (18.4) (Ma et al. 1997; Wang et al. 2020).

$$\text{Richness index}: R = S \tag{18.1}$$

$$\text{Diversity indices}: \text{Shannon} - \text{Wiener index } H' = -\sum P_i \ln P_i \tag{18.2}$$

$$\text{Simpson index}: D = 1 - \sum P_i^2 \tag{18.3}$$

$$\text{Pielou evenness indices}: \text{Jsw} = \left(-\sum P_i \ln P_i\right) / \ln S \tag{18.4}$$

P_i is the proportion of the number of species i to the total number of the species, and S is the total of species i in the sampling plot.

18.2.3 Structural Traits

All the structural characteristics of the species were averaged in the plot. Several community structural parameters were used: tree diameter at breast height (dbh), tree height (th), tree density (td), shrub density (sd), shrub height (sh), shrub coverage (sc), relative coverage of each herb species (hc), and herb height (hh). Tree dbh and the height of trees, shrubs, and herbs were calculated using the formulas outlined below (18.5) and (18.6). Tree and shrub density are referred to in Formula (18.7), and shrub and herb coverages are referred to in Formula (18.8) (Wang et al. 2020).

$$\mathrm{DBH} = \left(\sum_{i=1}^{m}\sum_{i=1}^{n} D_{ij}\right) / \sum_{i=1}^{m} n \tag{18.5}$$

$$\mathrm{Height} = \left(\sum_{i=1}^{m}\sum_{j=1}^{n} H_{ij}\right) / \sum_{i=1}^{m} n \tag{18.6}$$

$$\mathrm{Density} = \sum_{i=1}^{m} n/A \tag{18.7}$$

$$\mathrm{Coverage} = \left(\sum_{i=1}^{m} C_i\right) / m \tag{18.8}$$

where D_{ij} and H_{ij} are the dbh and height of the jth tree in the ith species, respectively; m is total species number; n is the measured tree for each species, C_i is the coverage of ith species, and A is the area of the plot.

18.2.4 Dominant Species Abundance

Dominant species in the tree, shrub, and herb layers were first recognized by ranking all the species of the pooled data for all plots inside and outside the reserve. All species names and their quantity were listed, and the top three kinds of species inside and outside the reserve were defined as dominant species in the tree, shrub, and herb layers.

After that, the relative abundance of dominant species, genera, and families (as recognized above) in each plot, inside and outside the reserve, was calculated as the mean value of the ratio of the individual number of the species and the total individual number of all recorded species in each sampling plot (Wang et al. 2020).

18.2.5 Macrofungal Survey for Taxonomic and Functional Group

The species name, the total number of each macrofungus in each plot, and growing habitats (soil, litter, living tree, deadwood) were recorded in detail by at least three times cross-line checking in the plots (30 m × 30 m in size). Macrofungi were identified by traditional phenological observation with the help of microscope observation. In phenological observation, naked eyes or magnifying lenses were used to check the color, shape, ancilla features of the hypophyll, pileus, mediotrastum, collarium, stipe, volva, and rhizomorph on-site, and also at least 5–8 digital photos were taken for later checks. For some fungi, spore print from sporocarp was also collected, and Melzer's reagent was also used to test amyloid (from blue to black) and dextrinoid (brown to red-brown). All photos were taken from different angles, and simple anatomy, the photos obtained are named according to the sample number, convenient for later laboratory recognition. The identification, both in the field and in the laboratory, was carried out by referring to relevant literature and handbook (Chen et al. 2013; Huang 1998; Liu 2004; Mao 2000; Nature-Museum-Editorial-Board 2014; Shao and Xiang 2017; Xiang 2005; Yu et al. 2005). A reconfirmation of the identification was also achieved via the help from a famous macrofungi expert in this region (Prof. Cunti Xiang retired from Northeast Forestry University with two famous macro-fungal books of Xiang (2005) and Shao (1997). The fungi were finally checked in the tenth edition of the fungus dictionary (Wirk et al. 2008), and the Index Fungorum online database (www.indexfungorum.org and www.speciesfungorum.org) was used for the classification, with final grouping all species into genus, family, and order for later analysis.

Many people utilize macrofungi as a livelihood in this region (Bau and Li 2010; Minter et al. 2012; Wu et al. 2019). Considering human or ecosystem utilization possibility will favor macrofungi conservation in the future. After the species recognition, all these macrofungi were divided into five utilization-related functional groups (edible fungi, medicinal fungi, toxic fungi, wood-rot fungi, unknown-function fungi) (Bau and Li 2010; Bau et al. 2019; Wu et al. 2019) and five habitat-related functional groups (living tree fungi, dead wood fungi, soil-based fungi, litter-based fungi, and Ectomycorrhizal fungi) (Shao 1997; Xiang 2005).

18.2.6 Aboveground Carbon Storage and Its Stability

We used carbon stability and carbon stocks to quantify aboveground carbon sequestration capacities. The aboveground biomass of each tree was estimated from dbh and height using species-specific allometric equations. The summation of individual aboveground biomass of all trees was used to obtain total aboveground biomass within each plot (Fan et al. 2011; Hu et al. 2015; Wang et al. 2005). We multiplied aboveground biomass by a factor of 0.5 to derive the aboveground C storage for each plot (Guo et al. 2010). Carbon stocks were calculated by total carbon storage per unit area in each plot (Mg C/ha).

We calculated two stability parameters of recalcitrant stability (RS) to anti-decomposability and environmental stability (ES) to future climatic adaptability by Eqs. (18.9) and (18.10). RS was calculated by six traits related to tree life span and their organic decomposition rates, including the content of cellulose, lignin, and organic carbon, wood density, wood durability to decomposition. ES was calculated by shade tolerance, drought tolerance, waterlogging tolerance, fire tolerance, pollution tolerance, and warming tolerance. The properties functional trait data from the TRY Plant Trait Database (http://www.try-db.org) (Kattge et al. 2011), professional books and literature, and life span was determined by an expert questionnaire survey.

We have adopted a similar soil quality index computation (Mandal et al. 2008; Paz-Kagan et al. 2016) to compute the ES and RS value to assess the carbon stability to decomposition and environment changes. The datasets for RS and ES were selected based on previous publications (as mentioned above), and to integrate the indicator score into an ES and RS as the following. Firstly, we standardized each component parameter by Eq. (18.9).

$$M_{ij} = \frac{t_{ij} - t_{ij\,\min}}{t_{ij\,\max} - t_{ij\,\min}} \tag{18.9}$$

M_{ij} is the standardized process for the no. *j*th traits for no. *i* species. t_{ij} is the no. *j*th trait value of the *i*th species; $t_{ij\min}$ is the minimum value of the no. *j*th trait of no. *i*th species and $t_{ij\max}$ is the maximum value of the no. *j*th trait of no. *i*th species.

Secondly, Pearson correlation–based weights integrated the parameters as an overall assessment index as Eq. (18.10). The Pearson correlation coefficient-related weights have been a reliable prediction (Thakkar and Patel 2021; Zhang et al. 2015).

$$S_C = \sum_{i=1}^{S} \left(p_i \sum_{j=1}^{T} w_j M_{ij} \right) \tag{18.10}$$

$$\mathrm{ST} = \mathrm{RS} + \mathrm{ES} \tag{18.11}$$

S_c is the RS or ES of aboveground carbon sequestration; T is the total number of traits used in S_c calculation; j is the no. *j*th traits used in the calculation. S is the total number of species in a plot, and i is the no. *i*th species in the plot; p_i is the proportion of the carbon stocks of species i to the total carbon stocks of the sampling plot. The weighting coefficient of *j*th trait (w_j) was calculated by the relative importance of the mean Pearson correlation coefficients of the *j*th trait with all other selected parameters. ST is the total stability of carbon sequestration to decomposition and environmental adaptation.

18.3 Plant Species

18.3.1 Species Abundance

In the arbor layer, our survey found 33 tree species belonging to 22 genera from 14 different families in the natural reserve and 37 tree species belonging to 20 genera from 14 different families outside of the natural reserve. Pooled data statistics showed that the most abundant tree species in the natural reserve is *Betula platyphylla*, taking 14% of total trees, followed by *Acer pictum* (12%) and *Picea koraiensis* (12%). There are nearly 9% for *Pinus koraiensis* and *Ulmus davidiana*, respectively. The most abundant genus is *Betula* (17%), followed by *Acer* (15%) and *Picea* (12%). In the case of family, the most abundant family is Pinaceae (35%), followed by Betulaceae (18%) and Aceraceae (15%), all these 3 families took about 68% of total observations. The most abundant tree species out of the natural reserve were *Larix gmelinii* (22%), *Betula platyphylla* (16%), *Picea koraiensis* (9%). The most abundant genus was *Larix* (22%), followed by *Betula* (18%), *Pinus,* and *Acer* (10%). The three most abundant family outside was Pinaceae (44%), Betulaceae (20%), and Aceraceae (10%). The same as in the Reserve area (Fig. 18.2). The

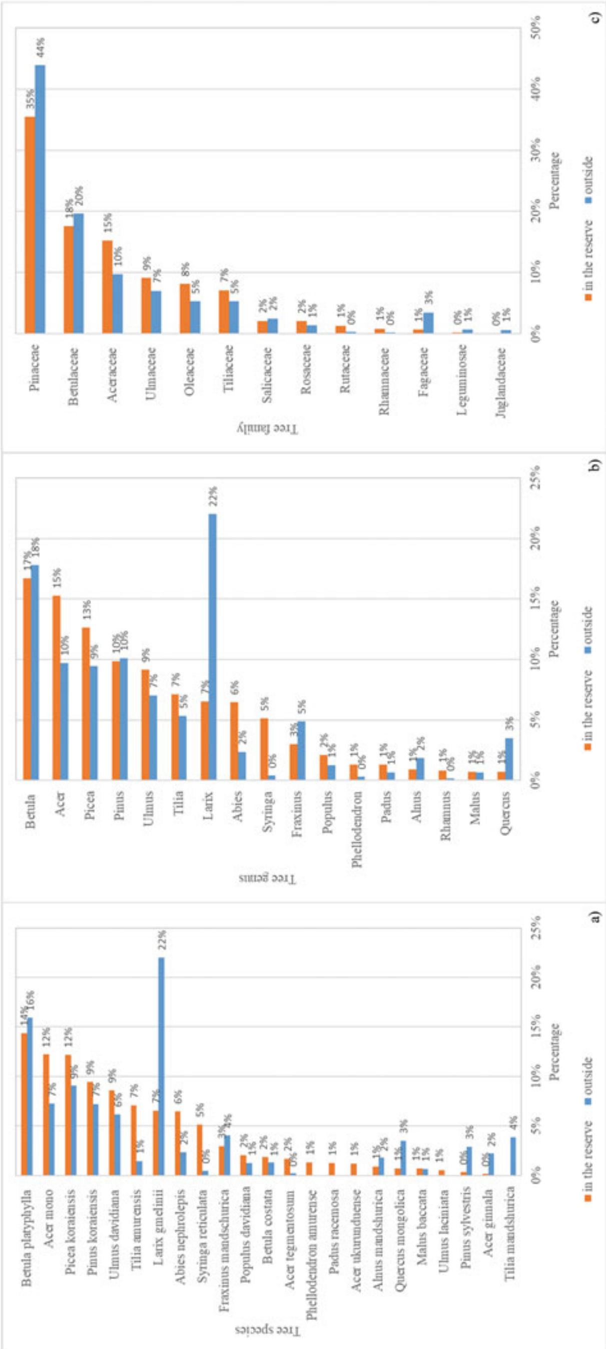

Fig. 18.2 Relative abundance of species (**a**), genus (**b**), and family (**c**) of the arbor layer inside and outside the reserve

dominant arbor species was *Betula platyphylla*, *Picea koraiensis*, *Acer mono*, and *Larix gmelinii* (Fig. 18.2; Plate 18.1). Dominant genus was *Betula*, *Acer*, *Picea*, *Larix,* and *Pinus*; Dominant family was Pinaceae, Betulaceae, and Aceraceae.

In the shrub layer, 29 shrub species belonging to 22 genera from 16 different families were found in the Reserve, and 40 shrub species belonging to 23 genera from 16 different families outside. The most abundant shrub species in the Reserve is *Corylus mandshurica*, taking 31% of total shrubs, followed by *Spiraea salicifolia* (12%) and *Eleutherococcus senticosus* (11%) (Fig. 18.3; Plate 18.1).

The most abundant genus is *Corylus* (37%), followed by *Spiraea* (13%) and *Eleutherococcus* (11%). In the case of family, the most abundant family is Betulaceae (37%), followed by Saxifragaceae (16%) and Rosaceae (14%). The most abundant shrub out of the natural reserve is *Spiraea salicifolia* (24%), followed by *Corylus mandshurica* (12%) and *Philadelphus schrenkii* (10%). The most abundant genus is *Spiraea* (30%), *Corylus* (15%) followed, *Syringa* and *Lonicera* accounted for 11%. In the case of family, the most abundant families are Rosaceae (33%), Betulaceae (15%), and Saxifragaceae (14%) (Fig. 18.3). The dominant shrub species was *Corylus mandshurica*, *Spiraea salicifolia*, *Eleutherococcus senticosus*, and *Philadelphus schrenkii* (Fig. 18.3). Dominant shrub genus was *Corylus*, *Spiraea*, *Eleutherococcus*, *Lonicera*, *Syringa,* and the dominant shrub family was Betulaceae, Saxifragaceae (abbreviation as Saxifragac) and Rosaceae.

In the herb layer, 104 herb species belonging to 79 genera from 40 different families and 176 herb species belonging to 111 genera from 49 different families outsides were found. The sorts of herb outside were significantly more affluent than in the Reserve. The top three abundant herb species in the Reserve are *Aegopodium alpestre* (15%), *Carex pilosa* (8%), and *Oxalis corniculata* (8%). As for out of the reserve, the rank is *Filipendula palmata* (11%), *Athyrium brevifrons* (7%), and *Aegopodium alpestre* (6%). The top three abundant genera are *Aegopodium* (15%), *Carex* (12%), and *Oxalis* (8%). In the case of outsides, *Carex* (14%) firstly, followed by *Filipendula* (11%), and *Athyrium* (7%). The top three abundant families are Cyperaceae (17%), Umbelliferae (16%), and Oxalidaceae (8%). In the case of outsides, the sort is Cyperaceae (14%), Rosaceae (13%), Athyriaceae (11%) (Fig. 18.4; Plate 18.1). The dominant herb species are *Aegopodium alpestre*, *Carex pilosa*, *Oxalis corniculata*, *Filipendula palmata*, *Athyrium brevifrons* (Fig. 18.4). The dominant genera are *Aegopodium*, *Carex*, *Oxalis*, *Filipendula,* and *Athyrium*. The families are Cyperaceae, Umbelliferae, Oxalidaceae, Rosaceae, and Athyriaceae.

18.3.2 Plant Structural Characteristics

The measured trees out of the reserve had tree height (th) shorter than 10 m, which were higher in occurrence than inside, the maximum tree height in the Reserve was higher than outside, more trees (65% of the total) had height from 12 m to 16 m in the Reserve than outside (33%). The proportion of trees with a diameter at breast height (dbh) more than 15 cm in the natural reserve was significantly larger than outside.

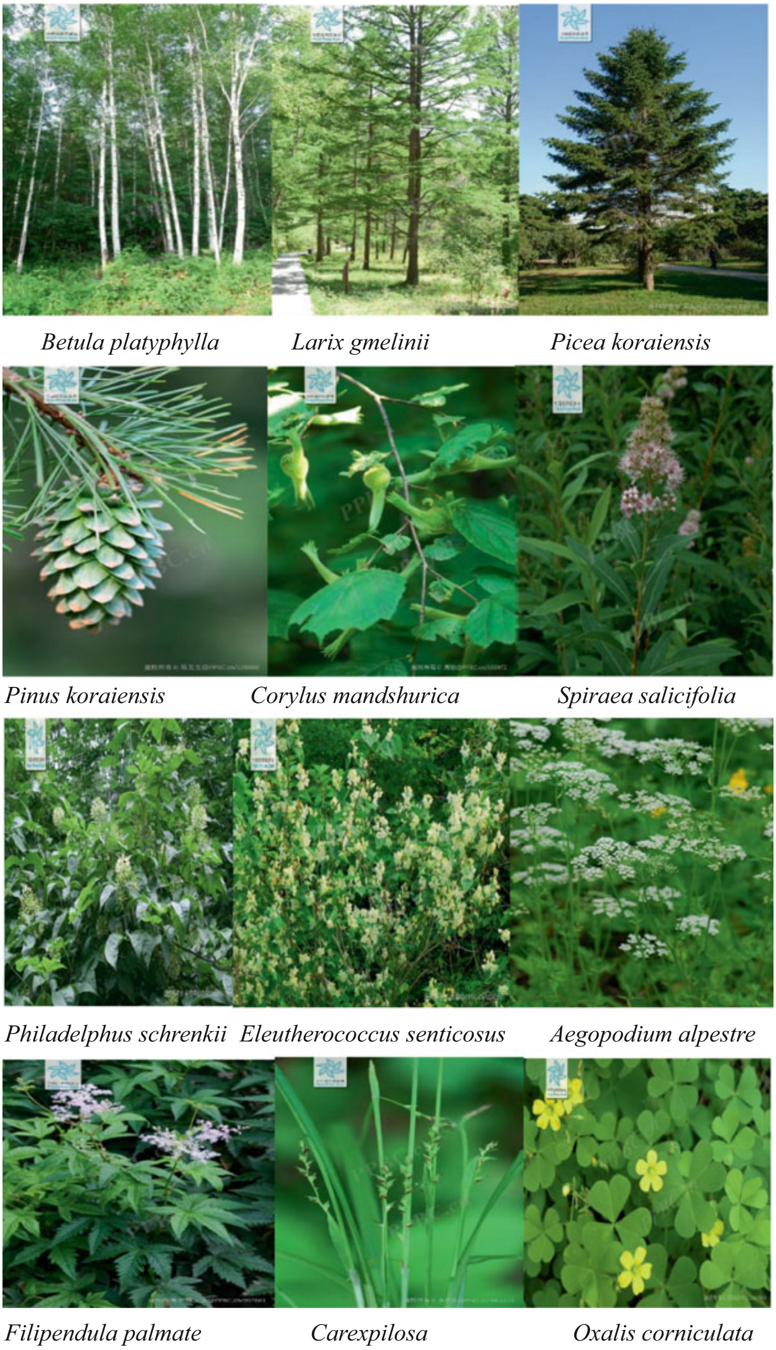

Plate 18.1 Pictures of dominant plant species (pictures are from http://ppbc.iplant.cn/)

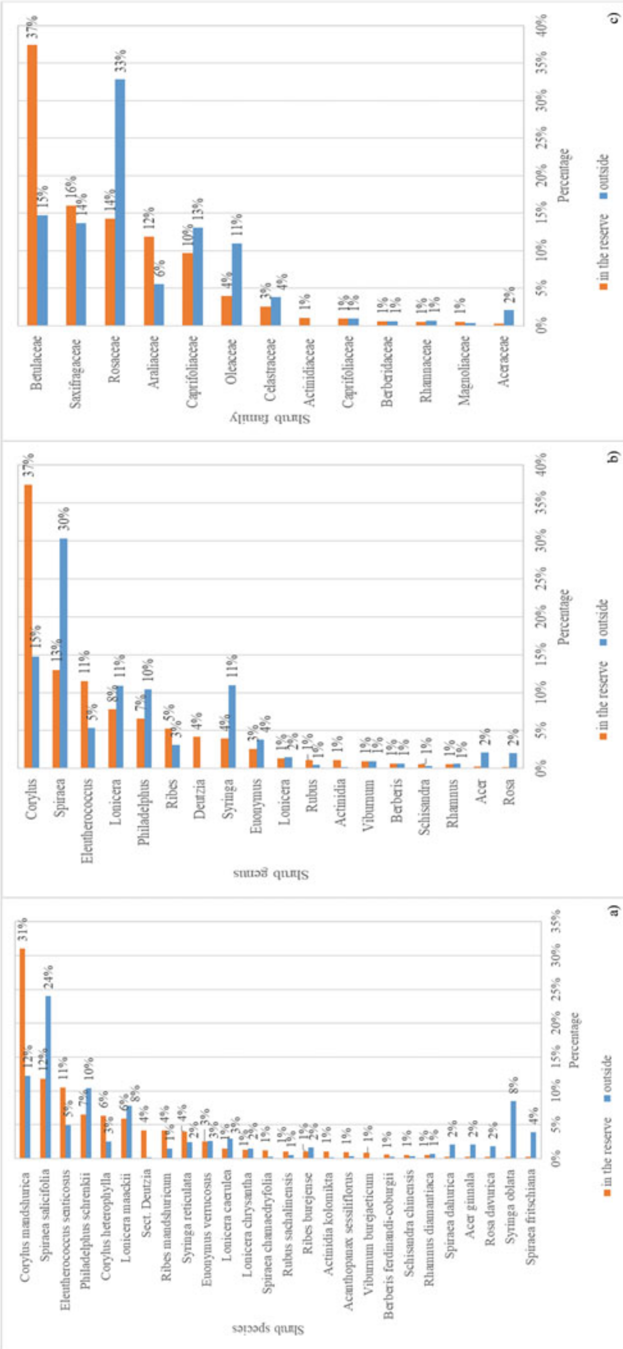

Fig. 18.3 Relative abundance of species (**a**), genus (**b**), and family (**c**) of the shrub layer inside and outside the reserve

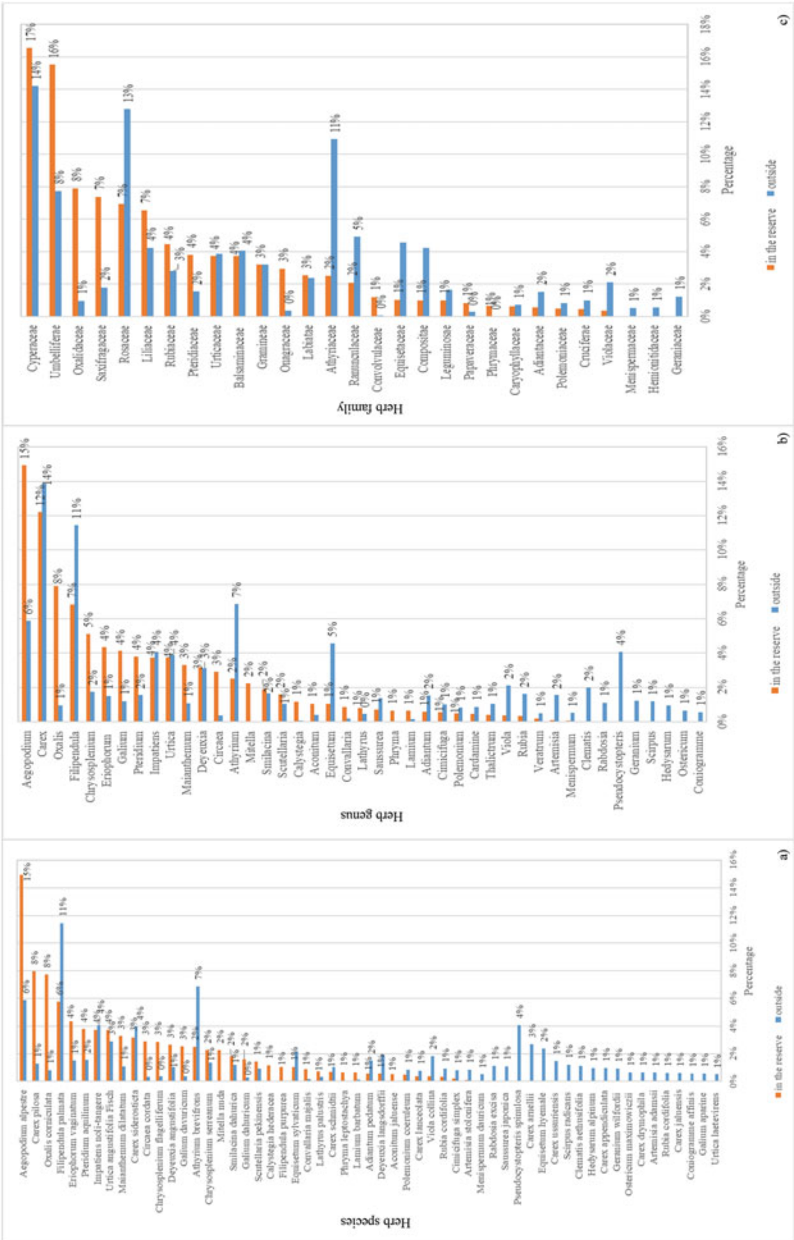

Fig. 18.4 Relative abundance of species (**a**), genus (**b**), and family (**c**) of the herb layer inside and outside the reserve

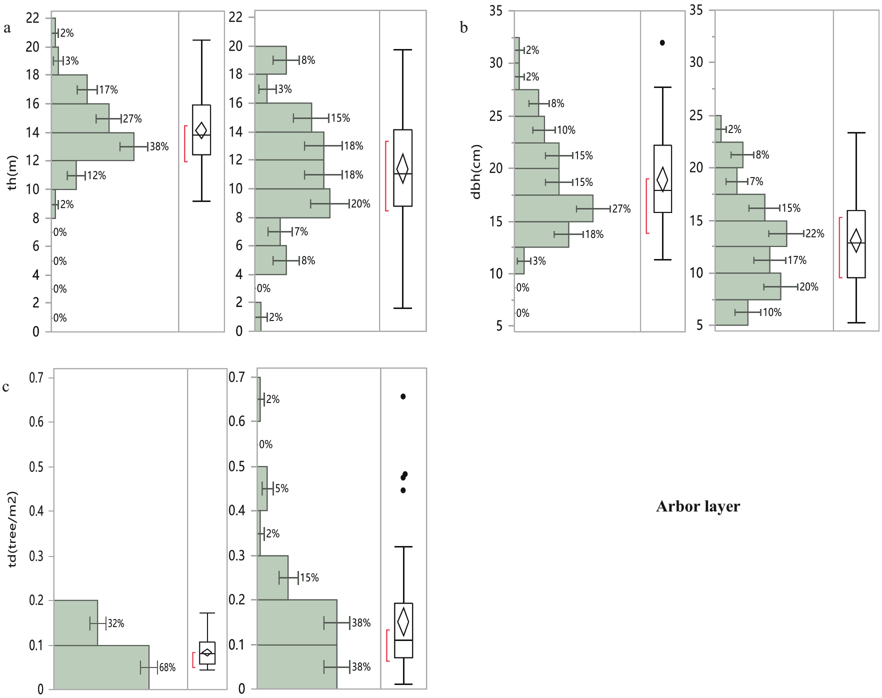

Fig. 18.5 The structural characteristics in the natural reserve (left) and outside the natural reserve (right), arbor layer: th (tree height, unit: m, **a**); dbh (diameter at breast height, unit: cm, **b**); td (tree density, unit: tree/m^2, **c**). shrub layer: sh (shrub height, unit: m, **d**); sc (shrub coverage, unit: %, **e**); sd (shrub density, unit: shrub/m^2, **f**). Herb layer: hc (herb coverage, unit: %, **g**); hh (herb height, unit: m, **h**)

The distribution of tree density (td) more than 0.2 out of the reserve was larger than inside (Fig. 18.5a, b, c). Different from outside, the distribution of shrub height (sh), shrub coverage (sc), and shrub density (sd) in the Reserve had the largest proportion around the average value, and usually had a single peak in the frequency distribution. The shrub height above average (especially 1.25–1.75 m) in the Reserve accounted more than outside. The broader coverage (> 10%) and denser (> 0.75/m^2) of shrubs were distributed outside than in the Reserve (Fig. 18.5d, e, f). The higher level of herb height (hh) and herb coverage (hc) (hh > 0.4 m and hc > 8%) accounted less in the Reserve than outside (Fig. 18.5g, h).

Nature conservation resulted in significant changes in tree structural factors, such as nearly half decreases of tree density, followed by 45.2% and 24.1% increase in dbh and tree height ($p < 0.05$) in the Reserve. In the case of the shrub layer, no significant changes were found in shrub height and shrub coverage, while a 33.3% decrease was recorded in shrub density ($p < 0.05$) in the Reserve. Herb height outside the reserve was one-quarter higher than that in the Reserve ($p < 0.05$), while no evident changes were found in herb coverage ($p > 0.05$). In general, natural forest protection resulted in the appearance of larger-sized trees, shorter herbs but relative sparse forest both for trees and shrubs (Table 18.1) (Wang et al. 2020).

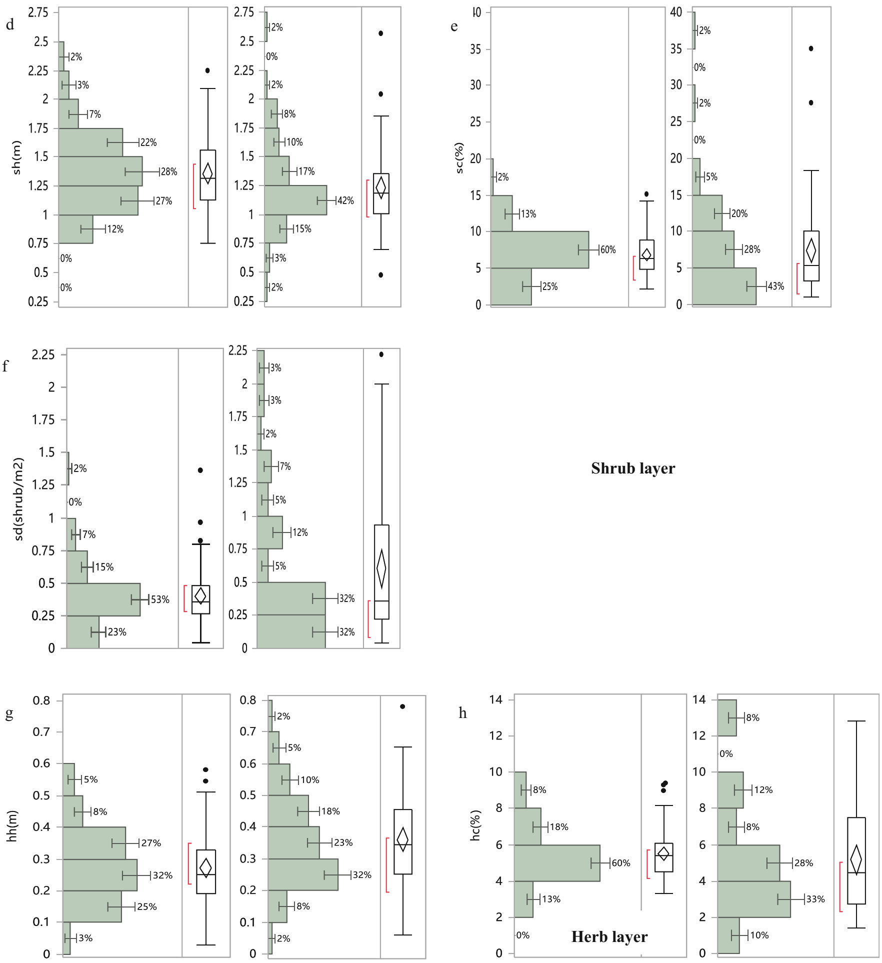

Fig. 18.5 (continued)

18.3.3 Plant Diversity Traits

For tree diversity, the percentage above average (TR > 10, TD > 0.6, TH > 1.25, TJsw > 0.7) in the Reserve was higher than outside. The mean values of tree diversity indices and evenness index in the natural reserve were significantly higher than those outside the reserve. Only tree richness showed a single peak in the frequency distribution (Fig. 18.6). The average shrub diversity indices and evenness index in the natural reserve were higher than those outside the reserve. Shrub richness inside and outside the reserve was generally between 3 and 6. Different from outside, the percentage of low shrub diversity indices (Simpson index <0.3 and Shannon-wiener index <0.5) in the Reserve were low (Fig. 18.7). The mean values

Table 18.1 Differences in structural features inside and outside the reserve (Wang et al. 2020)

Parameters	Inside reserve	Outside reserve	Improvement (%)
Tree height (in m)	14.14 (0.28)a	11.39(0.51)b	24.1
Diameter (in cm)	18.94(0.58)a	13.04(0.55)b	45.2
Tree density (tree/m^2)	0.08(0.01)a	0.15(0.02)b	−46.7
Shrub height (in m)	1.36(0.04)a	1.23(0.05)a	10.6
Shrub coverage (%)	6.84(0.4)a	7.37(0.8)a	−7.2
Shrub density (shrub/m^2)	0.4(0.03)a	0.6(0.07)b	−33.3
Herb height (in m)	0.27(0.01)a	0.36(0.02)b	−25.0
Herb coverage (%)	5.49(0.18)a	5.17(0.4)a	6.2

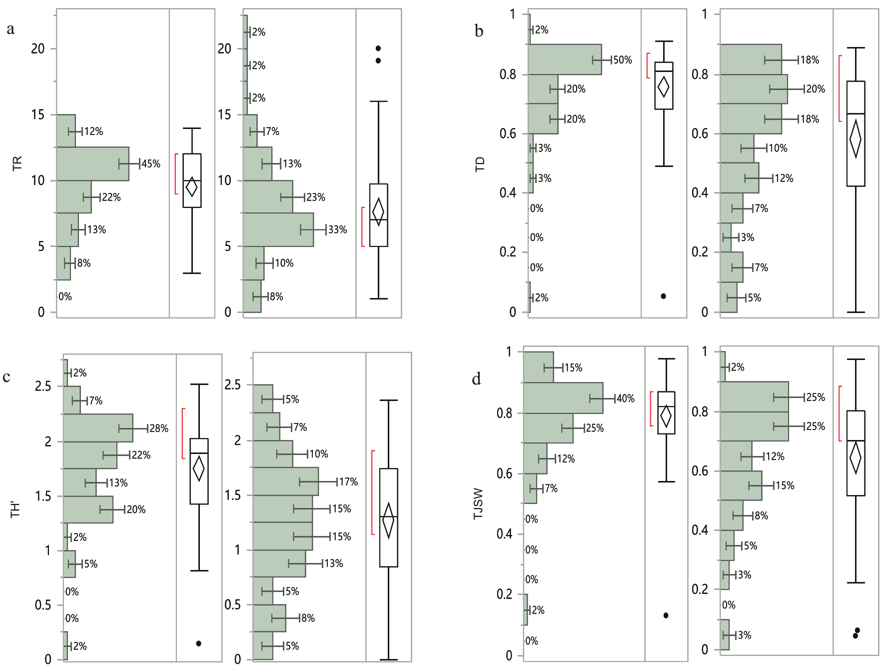

Fig. 18.6 Tree diversity in the natural reserve (left) and outside the natural reserve (right), TR, TD, TH', and TJsw are the abundance index, Simpson index, Shannon-wiener index, Pielou evenness index Jsw of tree layer (**a**, **b**, **c**, **d**)

of herb diversity index and evenness index in the natural reserve were lower than those outside the reserve. The herb diversity and evenness (except for richness) showed a concentrated region average and had a single peak in the frequency distribution (Fig. 18.8).

The tree diversity and evenness were significantly higher in the Reserve than outside the reserve, improving 23.4–37.8%. While no significant changes were

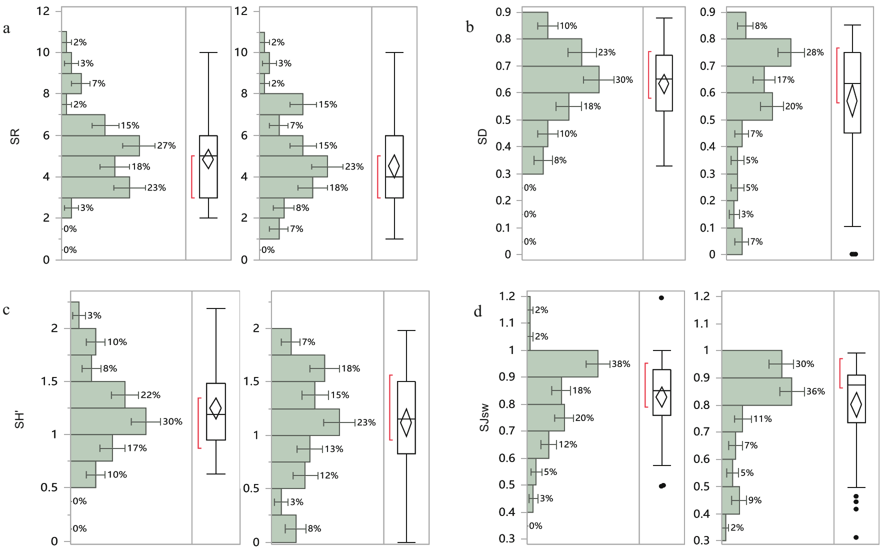

Fig. 18.7 Shrub diversity in the natural reserve (left) and outside the natural reserve (right), SR, SD, SH', and SJsw are the abundance index, Simpson index, Shannon-wiener index, Pielou evenness index Jsw of shrub layer (**a**, **b**, **c**, **d**)

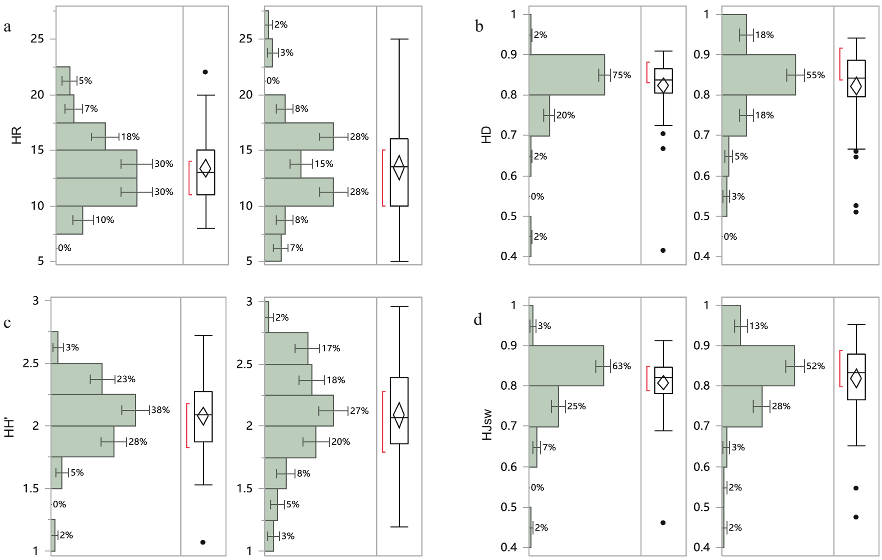

Fig. 18.8 Herb diversity in the natural reserve (left) and outside the natural reserve(right), HR, HD, HH', and HJsw are the abundance index, Simpson index, Shannon-wiener index, Pielou evenness index Jsw of herb layer (**a**, **b**, **c**, **d**)

Table 18.2 Average and significant difference of diversity indices inside and outside reserve (Wang et al. 2020)

Diversity indices	Inside reserve	Outside reserve	Improvement (%)
Tree richness	9.52(0.36)[*]a	7.62(0.51)b	24.9
Tree Simpson	0.76(0.02)[a]	0.58(0.03)b	31.0
Tree Shannon-winner	1.75(0.06)[a]	1.27(0.08)b	37.8
Tree evenness	0.79(0.02)a	0.64(0.03)b	23.4
Shrub richness	4.85(0.23)a	4.52(0.27)a	7.3
Shrub Simpson	0.63(0.02)a	0.57(0.03)a	10.5
Shrub Shannon-winner	1.25(0.05)a	1.12(0.07)a	11.6
Shrub evenness	0.83(0.02)a	0.8(0.02)a	3.7
Herb richness	13.35(0.4)a	13.43(0.54)a	−0.6
Herb Simpson	0.82(0.01)a	0.82(0.01)a	0.0
Herb Shannon-winner	2.08(0.04)a	2.09(0.05)a	−0.5
Herb evenness	0.81(0.01)a	0.82(0.01)a	−1.2

[*]Standard error in the bracket

found in the shrub and herb layers, the diversity and evenness of shrub in the Reserve were higher than outside, and the herb layer was opposite. Furthermore, inside and outside the reserve, the herb diversity index (Richness, Simpson, and Shannon-Wiener) was the highest, followed by the tree, and shrub diversity was the lowest. The evenness of shrubs and herbs was higher than that of the trees (Table 18.2) (Wang et al. 2020).

18.4 Macrofungi Species

We found 142 species from 30 families, nine orders, four classes, and two subdivisions (Table 18.3). Hymenomyceles was the most abundant class (accounted for 56% of the whole order number and 80% of the whole families) with 132 species, accounting for 93% of total recorded species. Pyrenomycetes was the least abundant class with only one order, one family, and one species found in this class (Table 18.4). We further divided the fungi into different utilization and habitat groups. In the utilization-dependent group, 73 species were edible, accounted for more than half of the total documented species; edible fungus mainly included *Hericium erinaceus*, *Hericium coralloides*, *Agaricus silvaticus*, etc. Medicinal fungi documented was 67 species (47.2% of total documented), such as *Elfving applanatum*, *Coriolus versicolor*, and *Fuscoporia oblique*. The toxic species were the least (10 species, 7%), like *Amanita miscaria* and *Amanita pantherina*. Other 19 species were unknown-function fungi, accounting for 13.4%. The unknown-function fungi mainly included *Mycena leptocephala* and *Mycena haematopus* (Tables 18.3 and 18.4).

Table 18.3 Macrofungi species, habitat, and functional description (Du et al. 2017; Sun et al. 2020)

Sn	Class, order, family, species	Habitat and functional description
Basidiomycotina-Hymenomyceles-Aphyllophorales-Hydnaceae		
1	*Hydnum repandum*	In broad leaves forests, edible fungi
	Polypraceae	
2	*Coriolus versicolor*	Dead-wood fungi, medicinal fungi
3	*Coriolus hirsutus*	Dead-wood, living-wood, medicinal fungi
4	*Cerrrena unicoloer*	Broad leaves trees and dead-wood, medicinal fungi
5	*Bjerkandera adusta*	Dead-wood fungi, medicinal fungi
6	*Microporus flabelliformis*	Dead-wood fungi, wood-rot
7	*Inonotus cuticularis*	Wood-rot, medicinal fungi
8	*Tramatesius alasis*	Lignicolous, medicinal fungi
9	*Pycnoporus coccineus*	Lignicolous, medicinal fungi
10	*Trametes orientalis*	Dead-wood fungi, wood-rot, medicinal fungi
11	*Elfving applanatum*	Wood-rot, medicinal fungi
12	*Spongipellis spumeus*	Lignicolous, wood-rot
13	*Fomitopsis ulmaria*	Lignicolous, medicinal fungi
14	*Fomitopsis pinicola*	Dead-wood fungi, medicinal fungi
15	*Hirschioporus pargamenus*	Lignicolous, wood-rot
16	*Hirschioporus abietinus*	Dead-wood fungi, medicinal fungi
17	*Phellinus igniarius*	Lignicolous, medicinal fungi
18	*Phellinus linteus*	Lignicolous, medicinal fungi
19	*Lenzitesbetulina*	Broad-leaved tree, wood-rot, medicinal fungi
20	*Lenzites tricolor*	Lignicolous
21	*Tyromyces fissilis*	Lignicolous, wood-rot
22	*Polyporus picies*	Lignicolous
23	*Polyporellus picies*	Soil-based fungi
24	*Fuscoporia oblique*	Birch living-tree fungi, medicinal fungi
25	*Favolus alveolaris*	Wood-rot, medicinal fungi
26	*Fomes fomentarius*	Lignicolous, medicinal fungi
27	*Piptoporus betulinus*	Lignicolous, medicinal fungi, edible fungi
28	*Phellinus pini*	Needle-leaced tree, lignicolous, medicinal, wood-rot
29	*Phellinus igniarius*	Lignicolous, medicinal fungi
30	*Lenzites acuta*	Dead-wood fungi, wood-rot
	Corticiaceae	
31	*Plicatura crispa*	Dead-wood fungi, wood-rot
	Thelephoraceae	
32	*Sterum lobatum*	Dead-wood fungi
33	*Stereum hirsutum*	Dead-wood fungi, medicinal fungi
34	*Sterum affine*	Wood-rot
35	*Hymenochaetebadio-ferruginea*	Dead-wood fungi, wood-rot
	Ganodermataceae	
36	*Ganoderma densizonmatum*	Lignicolous, medicinal fungi
37	*Ganoderma Lucidum*	Dead-wood fungi, medicinal fungi
	Stereaceae	

(continued)

Table 18.3 (continued)

Sn	Class, order, family, species	Habitat and functional description
38	*Stereum purpuren*	Lignicolous
39	*Stereum ostrea*	Dead-wood fungi, wood-rot
40	*Stereum hirsutum*	Living-wood, dead-wood, medicinal fungi
	Ramariaceae	
41	*Clavicorona pyxidata*	Soil-based fungi
	Meruliaceae	
42	*Ischnoderma resinousm*	Lignicolous, edible fungi, medicinal fungi
43	*Merulius tremellusus*	Dead-wood, wood-rot, edible, medicinal fungi
	Hericiaceae	
44	*Hericium erinaceus*	*Quercus mongolica*, dead-wood, edible, medicinal
45	*Hericium coralloides*	Fir, spruce, dead-wood fungi, edible fungi
Agaricales: Phallaceae		
46	*Armillariella mellea*	Dead-wood fungi, edible fungi
47	*Armillariella cepistipes*	Wood-rot
48	*Campanella junghuhnii*	Dead-wood fungi, edible fungi, medicinal fungi
49	*Cliloeybe sillopica*	Soil-based fungi, edible fungi
50	*Clitocybe catinus*	Edible fungi
51	*Clitocybe dealbata*	Soil-based fungi
52	*Clitocybe expallens*	Soil-based fungi, edible fungi
53	*Clitocybe geotropa*	Soil-based fungi, edible fungi, medicinal fungi
54	*Clitocybe infundibuliformis*	Litter-decaying, edible, medicinal fungi
55	*Clitocybe maxima*	Soil-based fungi, edible fungi
56	*Clitocybeodera*	Soil-based fungi
57	*Clitopilus prunulus*	Soil-based fungi
58	*Collybia acervata*	Broad-leaved forest, wood-rot, edible fungi
59	*Collybia confluens*	Soil-based fungi, edible fungi
60	*Collybia dryophila*	Litter fungi, edible fungi
61	*Collybia maculate*	Wood-rot, soil-based fungi, edible fungi
62	*Cystoderma amianthinum*	Soil-based fungi, edible fungi
63	*Flammulina velutipes*	Mycorrhizal fungi, edible fungi
64	*Laccaria proxima*	Soil-based fungi, edible fungi
65	*Laccaria laccata*	Wood-rot, edible fungi, medicinal fungi
66	*Laccaria laccata*	Soil-based, litter, edible, medicinal fungi
67	*Laccaria tortilis*	Mixed forest, edible fungi, medicinal fungi
68	*Lepista nuda*	Soil-based fungi, edible fungi, medicinal fungi
69	*Marasmiellus androsaceus*	Broad-leaved tree, wood-rot, medicinal fungi
70	*Marasmius dryophilus*	Soil-based fungi, edible fungi
71	*Marasmius siccus*	Broad-leaved tree litter, edible fungi
72	*Marmmius maximus*	Wood-rot, edible fungi
73	*Mycena epipterygia*	Moss woodland
74	*Mycena haematopus*	Wood-rot
75	*Mycena leptocephala*	Soil-based fungi
76	*Mycena pura*	Soil-based fungi, edible fungi

(continued)

Table 18.3 (continued)

Sn	Class, order, family, species	Habitat and functional description
77	*Oudemansiella mucida*	Wood-rot, edible fungi, medicinal fungi
78	*Oudemansiella mucida*	Dead-wood fungi, wood-rot, edible fungi
79	*Panuslepideus*	Needle-leaved tree, wood-rot, medicinal fungi
80	*Ripartitella brasiliensis*	Wood-rot
81	*Xeromphalina campanella*	Lignicolous, medicinal fungi
	Pleurotaceae	
82	*Lentinus imilis*	Dead-wood fungi, edible fungi
83	*Lentinus lecomtei*	Wood-rot, medicinal fungi
84	*Lentinus ramasii*	Soil-based fungi
85	*Panellusstypicus*	Wood-rot, medicinal fungi
86	*Pleurotus anserinus*	Soil-based fungi, edible fungi, medicinal fungi
87	*Pleurotus ostreatus*	Dead broad-leaved tree, edible, medicinal fungi
88	*Pleurotus pulmonarius*	Dead broad-leaved tree, edible fungi
89	*Pleurotus ulmarius*	Lignicolous, medicinal fungi
	Amanitaceae	
90	*Amanita miscaria*	Soil-based fungi, ectomycorrhizal, toxic fungi
91	*Amanita nivalis*	Broad-leaved and mixed forest
92	*Amanita pantherina*	Soil-based fungi, edible and toxic fungi
93	*Amanita citrina*	Soil-based fungi
	Pluteaceae	
94	*Volvariella bombycina*	Wood-rot, edible fungi
	Copricaceae	
95	*Agaricussilvicola*	Soil-based fungi, edible fungi
96	*Coprinellus disseminates*	Edible fungi
97	*Coprinus patouillardi*	Soil-based fungi
98	*Hypholoma appendiculatum*	Soil-based fungi, ectomycorrhiza, edible fungi
99	*Psathyrella candolleana*	Soil-based fungi, edible fungi, medicinal fungi
100	*Psathyrella lactobrunnescens*	Wood-rot
101	*Rhodophyllus speculus*	Soil-based fungi
	Russulaceae	
102	*Lactarius deliciosus*	Soil-based fungi, edible fungi, medicinal fungi
103	*Lactarius uvidus*	Mixed forest, edible fungi
104	*Russula decolorans*	Soil-based fungi, ectomycorrhiza, edible fungi
105	*Russula delica*	Soil-based fungi, edible fungi, medicinal fungi
106	*Russulafotens*	Pine and broad-leaved forest, edible fungi
107	*Russula integra*	Soil-based fungi, medicinal fungi
108	*Russula lilacea*	Mixed forest, edible fungi, medicinal fungi
109	*Russula mustelina*	Soil-based fungi, ectomycorrhiza
110	*Russula paludosa*	Ectomycorrhiza, edible fungi
111	*Russula sardonia*	Soil-based fungi
112	*Russula subdepallens*	Mixed forest, edible fungi
	Hygrophoracea	
113	*Hygrophorus eburneus*	Lignicolous

(continued)

Table 18.3 (continued)

Sn	Class, order, family, species	Habitat and functional description
114	*Hygrophorus ceraceus*	Soil-based fungi, edible fungi
115	*Hygrophorus virgineus*	Broad-leaved forest, edible fungi
116	*Hygrophorouspudorinus*	Moss land, toxic fungi
117	*Hygrophorus miniatus*	Soil-based fungi
	Schizophyllaceae	
118	*Schizophyllum commne*	Dead-wood fungi, medicinal fungi
	Agaricaceae	
119	*Cystoderma cinnabarinum*	Soil-based fungi, edible fungi
120	*Lepiota clypeolaria*	Soil-based fungi, toxic fungi
121	*Agaricus silvaticus*	Soil-based fungi, edible fungi
	Boletaceae	
122	*Suillus luteus*	Mixed forest, edible fungi, medicinal fungi
123	*Xerocomus subtomentosus*	Soil-based fungi, edible fungi
	Strophariaceae	
124	*Pholiota squarrosa*	Lignicolous, edible fungi
125	*Pholiota squarrosoides*	Wood-rot, edible fungi
126	*Pholiota nameko*	Aspen forest, edible fungi
	Marasmiaceae	
127	*Marasmius oreades*	Soil-based fungi, edible fungi, medicinal fungi
Heterobasidio-mycetes-Auriculariales-Auriculariaceae		
128	*Auricularia polytrcha*	Lignicolous, medicinal fungi
Dacrymycetales: Dacrymycetaceae		
129	*Calocera cornea*	Moss covered wood-rot in conifer forests, edible
Tremellales: Tremellaceae		
130	*Tremella foliacea*	Broad-leaved tree wood-rot, edible fungi
131	*Phlogiotis helvelloides*	Soil-based fungi, edible fungi, medicinal fungi
Gasteromycetes-Phallaes-Phallaceae		
132	*Dictyophora duplicata*	Soil-based fungi, edible fungi, medicinal fungi
Lycoperdales: Geastraceae		
133	*Geastrum saccatum*	Soil-based fungi, medicinal fungi
	Lycoperdaceae	
134	*Lycoperdon wrightii*	Wood-rot, medicinal fungi, edible fungi
135	*Lycoperdon pyriforme*	Wood-rot, soil-based fungi, edible, medicinal fungi
136	*Lycoperdon perlatum*	Soil-based fungi, wood-rot, medicinal fungi
137	*Lycoperdon pyriforme*	Wood-rot, edible, medicinal fungi
Ascomycotina-Pyrenomycetes-Sphaeriaceae		
138	*Daldinia conccentrica*	Broad-leaved tree wood-rot, medicinal fungi
Discomydetes-Pezizales-Helvellaceae		
139	*Helvella crispa*	Soil-based fungi, edible fungi
	Pezizaceae	
140	*Peziza vesiculosa*	Soil-based fungi, coprophilous, edible fungi
141	*Peziza sylvestris*	Soil-based fungi, edible fungi

Table 18.4 Number of macrofungi with different classification (Du et al. 2017)

Classification	Order number	Family number	Species number
Hymenomyceles	5(56%)	24(80%)	132(93%)
Gasteromycetes	2(22%)	3(10%)	6(4.2%)
Discomydetes	1(11%)	2(6.6%)	4(2.8%)
Pyrenomycetes	1(11%)	1(3.3%)	1(0.7%)
Utilization-dependent groups		**Species number**	**Percentage (%)**
Edible fungi		73	51.4
Medicinal fungi		67	47.2
Toxic fungi		10	7.0
Unknown-function fungi		19	13.4
Habitat-related groups			
Soil-based fungi		71	50.0
Dead-wood fungi		50	35.2
Living-wood fungi		29	20.4
Litter-decaying fungi		6	4.2

Note: The per cent in parentheses represents the proportion of each class in the total

Four types of fungi were classified as habitat-related groups (living-wood fungi, dead-wood fungi, soil-decaying fungi, and litter-decaying fungi). Half of the species (71 species) were soil-based fungi, mainly from Tricholomataceae, and most of them were edible along with some highly toxic fungi. Fifty species were dead-wood fungi, which accounted for 35.2% of the total species, mainly belonging to the Tricholomataceae, Polyporaceae, and Thelephoraceae. Twenty-nine species (20.4%) were living-wood fungi, and most of them were Polyporaceae and Thelephoraceae, with the possible function of wood rot and medicinal values. Six litter-decaying species accounted for only 4.2%, mainly from Tricholomataceae with medicinal and decomposable function (Tables 18.3 and 18.4). Pictorial representation of some main species is given in Plate 18.2.

18.5 Carbon Stock and Stability

18.5.1 Carbon Sink Function Differences

The recalcitrant stability and carbon stocks improved with natural protection. Among these, carbon storage increased 1.3-fold, recalcitrant stability increased 4% (but nonsignificance), while environmental stability decreased 3% (Table 18.5).

18.5.2 Association Decoupling

From the results of the simple effect of the redundant analysis, it can be seen that the tree height has the most substantial impact on the carbon sink function outside the

Plate 18.2 Pictures of dominant macrofungi species (Du 2018)

Collybia acervata *Pleurotus ostreatus* *Amanita pantherina*

Xerocomus subtomentosus *Pholiota squarrosoide* *Tremella foliacea*

Hericium erinaceus *Collybia confluens* *Suillus luteus*

Stereum hirsutum *Russula delica* *Russula lilacea*

Plate 18.2 (continued)

reserve (27.7%). With increasing conservation, the big trees in the community become the main reason that affects the carbon sink function with the percentage of 52.6%, tree height, and diameter at breast height have a positive effect on carbon

Table 18.5 Differences of the carbon sink function inside and outside the reserve

Parameters	Inside reserve	Outside reserve	Improvement (%)
Recalcitrant stability	0.51a	0.49a	4
Environmental stability	0.39a	0.4a	−3
Carbon stocks (t/hm^2)	121a	51.99b	133

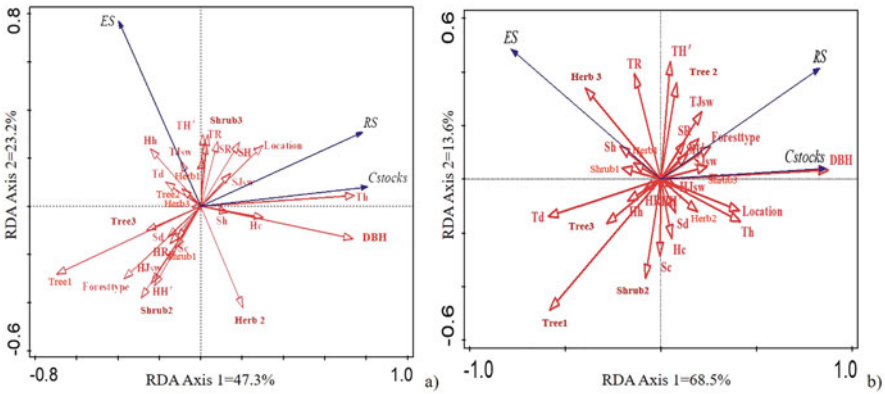

Fig. 18.9 The redundancy ordination (RDA) of the complex association among forest elements, abiotic variations, and carbon sink function inside and outside the reserve. (**a**): the result of outside the reserve, (**b**): inside the reserve. Forest type: plantation 1, secondary forest 2, original forest 3; Location: outside the reserve 1, edge area 2, in the Reserve 3. Arbor 1 = 0.28 *Betula* + 0.27 *Betula platyphylla*, Arbor2 = 0.31 *Acer* mono+0.3 *Acer* + 0.3 Aceraceae, Arbor3 = 0.44 *Picea* + 0.44 *Picea koraiensis*; Shrub1 = 0.32 Betulaceae+0.32 *Corylus* + 0.31 *Corylus mandshurica*, Shrub2 = 0.37 *Spiraea* + 0.35 *Spiraea salicifolia* + 0.31 Rosaceae, Shrub3 = 0.48 *Acanthopanax* + 0.48 *Acanthopanax senticosus*; Herb1 = 0.34 *Aegopodium* + 0.34 *Aegopodium alpestre*+0.33 Umbelliferae 60%, Herb2 = 0.34 *Oxalis corniculata* + 0.34 *Oxalis* + 0.34 Oxalidaceae, Herb3 = 0.35 *Filipendula palmata* + 0.35 *Filipendula* + 0.34 Rosaceae

storage and recalcitrant stability (RS) but are negatively correlated with environmental stability (ES). However, the decrease in the abundance of tree 1 (*Betula* spp.) has an essential effect on the improvement of ES. The lower herb diversity, fewer herb 2 (*Oxalis*), and shrub 2 (*Spiraea*) are more conducive to the elevation of carbon sink function. The location of the sampling points has a significant influence on the carbon sink function both inside and outside the reserve. The amount of carbon sequestration and RS increased with protection. Denser tree 3 (*Picea koraiensis*), more herb 3 (*Filipendula palmata*) led to higher ES, which is negatively correlated with carbon storage and RS (Fig. 18.9, Table 18.6).

Considering the effects of collinearity, the contribution rate of the shrub layer increases with protection. For example, the carbon storage and RS were raised with the denser shrub but lower coverage and distributed more uniformly. Tree diversity and evenness have a positive relationship with carbon stability. It is worth noting that

Table 18.6 The comparison of the simple effect of RDA between inside (on right) and outside (on left) the reserve

Name	Explains (%)	*P*	Name	Explains (%)	*P*
Th	27.7	0.002	DBH	52.6	0.002
Tree1	27.5	0.002	Tree1	27.1	0.002
DBH	26.4	0.002	Td	25.2	0.002
Forest type	9.6	0.002	Herb3	13.1	0.002
Location	7.9	0.012	Th	12.5	0.006
Shrub2	7.3	0.014	Location	11.9	0.002
Herb 2	6.2	0.032	Tree3	6.1	0.032
HJsw	5.3	0.048	Forest type	4.8	0.05
HH'	5.2	0.042	TR	4.6	0.074
Hc	4.4	0.074	Shrub3	4.4	0.072
Hh	4.2	0.086	TJsw	4.2	0.086
SH'	3.7	0.138	SH'	3.7	0.11
Shrub3	3.6	0.112	TH'	3.6	0.102
Tree3	3.5	0.128	Tree2	3.4	0.15
SR	2.6	0.24	Sh	3.4	0.14
Sd	2.5	0.238	Hh	3	0.16
TH'	2.3	0.296	Shrub1	2.9	0.198
TR	2.2	0.328	Herb2	2.8	0.2
Td	1.7	0.454	Shrub2	2.6	0.228
Sc	1.6	0.438	SR	2	0.28
HR	1.6	0.438	Herb1	1.5	0.396
Shrub1	1.5	0.468	Sc	1.5	0.428
SJsw	1.5	0.508	SJsw	1.5	0.424
TJsw	1.3	0.52	Hc	0.9	0.552
Herb1	1.1	0.628	Sd	0.8	0.636
Sh	0.9	0.686	HR	0.6	0.752
Tree2	0.5	0.804	HJsw	0.5	0.786
Herb3	0.2	0.97	HH'	<0.1	0.996

higher tree diversity and denser trees in the community are conducive to ES (Fig. 18.9, Table 18.7).

18.6 Conclusion

Nature conservation in NE China could strongly alter the vegetation-dominant composition in the tree, shrub, and herb layers. Compared with the outer region, the inside of the reserve usually has a much better forest structure with more giant trees (tree height and dbh) but lower tree and shrub density. Tree diversity and evenness increased 31% and 23.4% inside the reserve, while no significant impacts were observed in the shrub and herb layers. The carbon storage and recalcitrant

Table 18.7 The comparison of conditional effect of RDA between inside (on right) and outside (on left) the reserve

Name	Explains (%)	*P*	Name	Explains (%)	*P*
Th	27.7	0.002	DBH	52.6	0.002
Tree1	16.8	0.002	Tree1	6.7	0.002
Herb2	5.5	0.006	Herb3	5	0.002
HJsw	4.4	0.008	Tree3	3.4	0.004
DBH	2.8	0.036	TH'	2.7	0.01
Td	3.1	0.034	Td	2.8	0.004
Shrub3	2.6	0.03	Sc	2.3	0.014
SR	2.4	0.052	SJsw	2.2	0.012
Location	2	0.064	Th	2.2	0.004
Hc	1.7	0.058	Location	1.7	0.01
Forest type	2	0.038	TJsw	1.6	0.012
Tree2	1.5	0.086	Shrub2	1	0.046
Herb3	1.2	0.148	Herb1	1	0.034
Hh	1.6	0.07	Sd	1	0.036
Tree3	1	0.194	Hh	0.7	0.068
HH'	0.9	0.236	HR	0.5	0.186
Shrub2	0.6	0.374	TR	0.4	0.234
Sh	0.5	0.508	HH'	0.6	0.126
Sc	0.5	0.452	Shrub3	0.5	0.16
Sd	0.8	0.256	SR	0.3	0.362
SH'	0.5	0.438	Sh	0.2	0.476
TR	0.4	0.592	Shrub1	0.2	0.53
TJsw	0.6	0.39	Herb2	0.2	0.492
TH'	1.4	0.11	Hc	0.2	0.656
SJsw	0.6	0.424	Forest type	0.2	0.54
HR	0.4	0.522	SH'	0.1	0.772
Herb1	0.5	0.45	HJsw	<0.1	0.902
Shrub1	0.2	0.828	Tree2	<0.1	0.89

stability increased with protection, but a more vulnerable response to climate change. In the central Lesser Khingan Mountains, edible and medicinal fungi accounted for 51.4% and 47.2%, and half of the fungi species were soil-based fungi. More big-sized trees, more Acer and Larix, denser small shrubs led to higher carbon storage and recalcitrant stability, and diverse tree species positively affected carbon sequestration and carbon stability. Our findings provide essential data for evaluating the effect of nature protection on plant species, forest structure, and carbon sink function and provided knowledge for further implementations of the NFPP.

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Urban Forest Resources: A Strategy for Achieving Land Degradation Neutrality

19

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Annpurna Devi, and Ghanshyam

Abstract

Urban forest plays a vital role in conserving diversity and maintaining the forest cover outside the forest. In modern times, development challenges urban planning, economy, ecosystem, environment, and human health. Conservation of biodiversity and forest resources in an urban area is a major challenge and has become the global need to overcome the problem faced by cities due to urbanization. Urban greenery affects the surrounding landscape in direct and indirect ways. Cities with green forest cover help in mitigating the climate change impact and it also offers various ecological, environmental, and ecosystem services. Rapid urbanization leads to an increase in deforestation rate, which harms the biosphere and human-built environment. Minimizing deforestation is a great topic of concern to adapt and minimize the climate change impacts on the ecosystem and environment. The development of urban forestry and greenery in these areas improve the microclimate, aesthetic value of the landscape as well enhance the floral and faunal diversity in an urban area. Climate change and destruction of habitat due to deforestation lead to threatening biodiversity. Urban forest plays a crucial role in a sustainable agroecosystem and provides many products and services. The management strategies and effective policy are needed

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to be properly implemented to enhance the green cover and lead toward sustainable cities and development.

Keywords

Biodiversity · Urban green space · Land degradation · Climate change

19.1 Introduction

Urban forestry and urban green space are one of the most important resources for sustainable urban infrastructure and cities. This has a potentially positive impact on the urban environment with wider dimensions. The urban forest creates a relationship between society and the environment and leads to harmony between natural processes and human civilization (Khan et al. 2020a, b). Urban forest resources include trees in urban space, parks, garden areas, green space, etc., in cities. These urban forest resources facilitate various ecological services and conserve and improve the biodiversity of the region (Khan et al. 2022; Nowak 2018).

Rapid urbanization is a major challenge for sustainable cities and development along with urban forest cover and resources (Banerjee et al. 2020). Building and construction work in an urban area is rapidly decreasing the vegetation cover in cities and causing various eco-environmental impacts. The importance of urban forestry toward the sustainable and eco-cities by environmentalists and urban designers made them work and applied implementation of urban forestry concept across the world. In cities, urban vegetation controls various forms of pollution (Escobedo et al. 2011). Trees and vegetation in cities also help in providing shelter and habitat to different faunas, which in turn conserve the biodiversity. Urban tree resources offer various ecosystem services including air purification, noise control, microclimate regulation, groundwater recharge, carbon (C) capture, carbon sequestration ($C_{seq.}$), etc. (Ascari et al. 2015; Khan et al. 2022). In this perspective, many evergreen and broad leaf species show good results in reducing noise and air pollution and also providing shade and shelter to biota and human beings. Urban forest resources include a cluster of park trees, gardens with trees, and any green spaces including rooftops, riparian corridors, city parks, and urban forests >0.5 ha (Endreny 2018).

Urban forest helps in mitigating climate change and its negative impact. Urban cities are prone to various environmental problems and land-use changes caused by climatic and anthropogenic perturbations. In this context, urban forest resources help in mitigating change and social consequences of urban sprawl to make cities more resilient to these changes. Urban forest resources improve the quality of cities life, providing food, supporting pollination, regulating temperature, improving health, providing recreational and spiritual benefits, and human well-being (Cheisura 2004).

The urban greenery/forest resources are considered as a lung of city that help in the construction of the high-quality human settlement, eco-design of cities, and human-built environment. Therefore, urban forestry besides its functions and services enhances the forest cover of the nation. The forest resources in developing

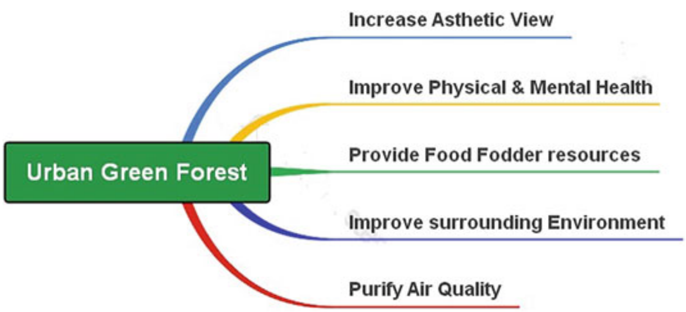

Fig. 19.1 Urban green forest and their roles in human civilization (Compiled: Khan et al. 2022; Nowak 2000, Nowak 2018)

countries are depleting, which is creating pressure on the natural ecosystems and their processes and functions (Raj and Jhariya 2021a, b). Thus, plantation schemes in degraded land, wasteland, and urban areas and their proximities can meet the objective of the nation's goal of increasing the forest cover (Khan et al. 2021a, b). In this context, government of India has launched various schemes and programs to enhance the vegetation cover as forest and tree outside forest (TOF). Recently, Indian government has launched the Nagar Van Project intending to create urban green space in 200 Indian cities in the coming 5 years. Sustainable cities can be designed by opting for eco-friendly technologies in various spheres of human habitation and the surrounding landscape. This only can lead toward the overall prosperity of human civilization and sustainable development (Fig. 19.1). In this context, this chapter deals with the urban forest resources and forest cover and their role in overall eco-environmental services and development.

19.2 Urban Forest Resources

Forests and other tree components including woodland and plantations are an integral part of urban areas. Urban forest resources comprise all diverse types of plant life forms that entirely intermingle and ensure many ecosystem services. These resources provide various tangible and intangible services for a better urban environment and people's health. Therefore, urban forest resources ensure environmental sustainability and ecological stability through promising food-soil-climate security. However, forest resource assessment is quite important for understanding tree covers and related services in urban areas. Ground inventory and geographic information system-based assessment are good strategies that require better planning and management for urban forest and green space assessments (Hoang and Tran 2021). However, analyzing dendrometric parameters in forest resource assessments is also influenced by water quality and soil types under prevailing climatic conditions (Sanesi et al. 2006).

These resources provide various services that can ensure urban sustainability at ecological, social, and economic dimensions. Urban forest resources can provide a variety of plants and ample green space that regulate other natural resources like soil, water, and air, which maintains ecological stability (Nowak et al. 2006). Thus, the function of forest resources would be critical due to population variations in urban areas. Moreover, forest-based resources ensure biomass and energy productions along with shading provision to buildings and paved surfaces in urban cities (Yu and Hien 2006). However, several biotic disturbances and climate change-mediated insect pests and disease outbreaks affect these forest resources in urban cities (Zhang and Brack 2021). For example, fungal-endophyte-mediated complex disease syndromes have declined plant vigor losses in various tree species, for example, *Quercus rubra*, *Acer pseudoplatanus*, *Quercus robur*, and *Alnus cordata* in urban cities of Parco Nord regions. Declining tree vigor due to several diseases like chlorosis, necrosis, tree dieback, leaf-wilt, and bark cracks was observed in tree species under urban setup. Thus, adopting scientific management practices would be a viable tool to protect the forest species from various biotic and climatic disturbances (Turco et al. 2006). In this context, smart urban forest and its management can effectively manage all forest resources for the welfare of humans and the environment (Prebble et al. 2021). A management-oriented effective policy along with good governance is required to protect forest resources that enhance biodiversity and intensify ecosystem services for a better sustainable urban world.

19.3 Multifunction of Urban Forestry

Urban forests in cities perform various functions for the environment and human beings. The urban forest in the cities connects the people with the environment as ecology and the natural balance of the planet are influenced by anthropogenic activities. Urban forest cover provides shelter, maintains ecological functions, and provides many opportunities to enhance ecosystem services. Urban forest-based ecosystem services across the globe are shown in Table 19.1 (Koricho et al. 2020).

Rapid urbanization and expansion create many challenges in urban areas such as environmental problems, soil health, and habitat destruction of many flora and fauna, which lead to biodiversity loss (Jhariya and Singh 2021a, b, c; Raj et al. 2018). Green infrastructure in urban areas plays a vital role in coping with climate change and its negative impact on the ecosystem. Urban forest resources are very important to safeguard the environment in cities for maintaining a healthy and pure environment. Urban green resources (e.g., trees and vegetation) help in cooling the air temperature, reduce the wind speed, provide shade and shelter, reduce soil loss, control pollution, improve biodiversity, moderate climate change, and play a significant role through providing multifunctional services to urban ecosystem, human and other living organisms that leads to sustainable development and urban sustainability (Fig. 19.2).

Urban forest facilitates various direct and indirect benefits to human society. These forests are capable to produce diversified goods and services for human civilization. In developing countries, urban forests are an important source of

Table 19.1 Urban forest-based ecosystem services across the globe

Regions	TD	CS	CS	PR
Adama city in Ethiopia	96.0	21.3	1.5	0.02
Perth city in Australia	83.0	15.0	0.3	0.2
Barcelona city in Spain	141.0	11.2	0.5	0.10
Urban region of London	35.0	15.0	0.5	0.12
Beijing city in China	79.0	7.4	0.4	0.3
Toronto city in Canada	160.0	19.3	0.8	0.07
Urban region of Atlanta	275.0	39.3	1.3	0.11
Los Angeles	48.0	10.4	0.4	0.04
Washington city in U.S.	121.0	32.9	1.01	0.06
Oakville city in Canada	192.0	14.8	0.66	0.03
Syracuse city in New York	167.0	25.4	0.84	0.04
Woodbridge town New Jersey	164.0	26.7	0.93	0.08
San Francisco city	55.0	16.3	0.42	0.03

TD tree density (ha^{-1}), *CS* carbon sink ($t\ ha^{-1}$), *CS* carbon sequestration ($t\ ha^{-1}\ year^{-1}$), *PR* pollution removal ($t\ ha^{-1}\ year^{-1}$)
Modified from Koricho et al. (2020)

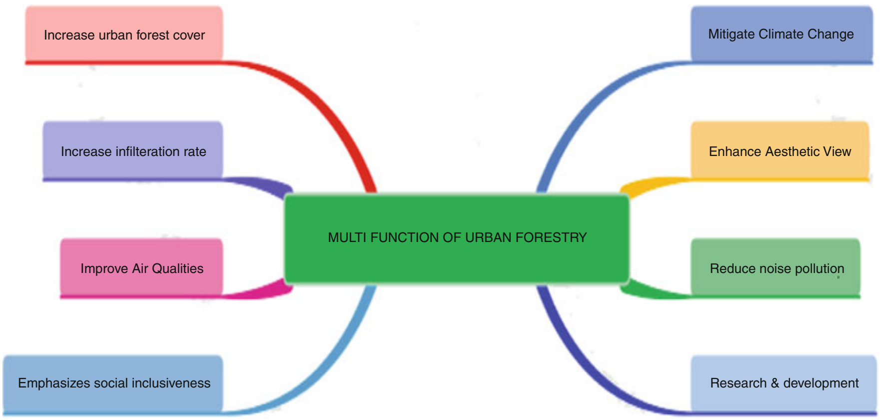

Fig. 19.2 Multifunction of urban forest resources (Khan et al. 2022; Koricho et al. 2020)

wood for construction work and fuelwood. Fruit trees and some medicinal plants in gardens, streets, and residential areas help urban dwellers to make use of the product. Planting and growing trees in urban areas strengthen the economy and multifunctional nature of urban agriculture. Species like *Syzygium cumini*, *Mangifera indica*, and other fruit tree species in urban areas facilitated nutrition and economic gains. Urban agriculture improves the availability of food for local people and shortens thesupply chain that supports food security (Raj et al. 2020). Urban agriculture helps to contribute as C sink in an urban area; along with the productive function, they also play a protective role by reducing environmental pollution and managing the urban ecosystem.

19.4 Ecosystem Service of Urban Forest

Urban trees and green space improve the urban environment and community health. The health of an urban ecosystem can be measured by tree cover and the status of vegetation in that area. An ecological system such as soil, air, and water is supported by vegetation and their intricate relationship in an urban landscape. High tree cover provides more and healthy ecosystem services to an urban area in the form of reducing water runoff, $C_{seq.}$, heat reduction, soil and water conservation, biodiversity improvement, climate change mitigation (Parsa et al. 2020; Yan et al. 2018). Trees found near residence/building provide shade and help in cooling air and reduce solar exposure. Estimating ecosystem services and their annual value (in money) makes a clear understanding of urban forest resources and related services for managing biodiversity and environmental health. In this context, the annual value (million $) of various ecosystem services from Gainesville's urban forest resources is depicted in Fig.19.3 (Andreu et al. 2019). The total annual monetary benefits from forest ecosystem services are 24.5 million US dollar. Ecosystem services as carbon sequestration contributed second rank (5.9 million US $) after energy-saving services as 7.7 million US dollar. These creates awareness among the people about the importance of urban forest resources and thus helps to strengthen ecosystem services for a better urban environment.

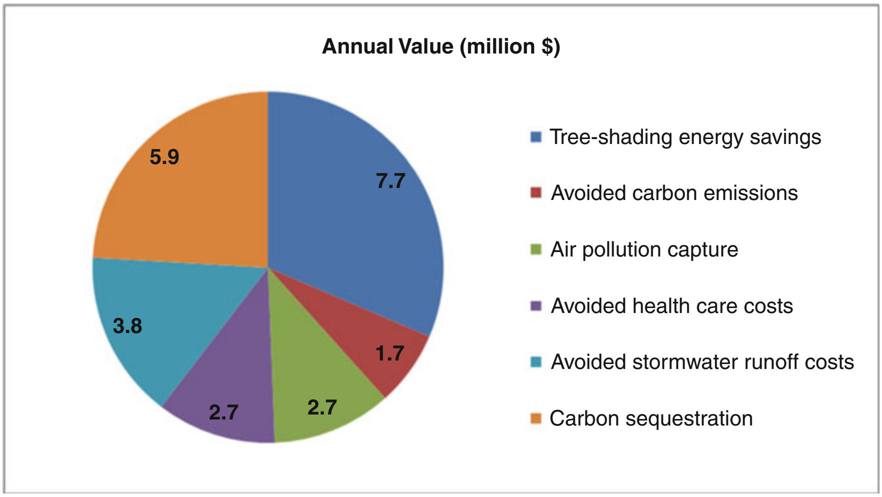

Fig. 19.3 Annual value of ecosystem services provided by urban forest resources in Gainesville's, Florida (Andreu et al. 2019)

19.4.1 Water Conservation and Runoff Reduction

Water scarcity in urban areas is the major problem due to population pressure, utilization, and lowering of groundwater table day by day followed by global warming and climate change phenomenon. In most of the regions of the world, especially in a developing country, the availability of fresh water is becoming a scarce resource at present time. This will worsen in the coming future if proper steps toward judicious conservation and management of water resources are not given due consideration. The urban forest cover helps in reducing runoff intensity and increases the water-holding capacity of soil, which helps in increasing groundwater recharge. The different component of a tree helps in reducing the storm-water flow by rainwater interception through various tree components such as leaves, stems, branches, etc. Moreover, applying organic mulch helps in soil-water conservation (Mechergui et al. 2021) along with run-off reduction in urban forest areas. For example, in an arid urban region, a mulch application with a range of 0.25–0.50 kg/m^2 enhanced soil water content along with runoff amount reductions by 28–83%, respectively (Wang et al. 2021). Tree roots help in absorbing water and also help to hold the soil particle and prevent runoff, which manages the runoff amount in urban areas. Trees in urban space also reduce the cost of constructing storm water control infrastructure and are cost-effective techniques to manage the trinity of soil-water-environment (Jhariya et al. 2019a, b).

19.4.2 Air Quality in Urban Area

With increased urbanization and pollution rate due to many anthropogenic activities, air quality in the urban area gets polluted. Urban forest helps in controlling pollution levels in urban cities. Different tree species have different absorbing/removal tendencies of pollutants and other contaminants from the atmosphere. In this context, tree species for removing pollutant for improving air quality is depicted in Table 19.2 (Nowak 2000). Urban forest cover is the sink to store C from the atmosphere. Urban forest trees produce oxygen for 18 people per tree on daily basis. Cities are moving toward green cities to reduce the impact of pollution in urban areas. Urban forest cover can work as efficient air cleaning machines. Broad leaf species help in intercepting particulate matters and pollutants from the air. Trees in urban areas help in improving the health issues caused by poor air quality. Trees are a very important component in urban cities and the loss of trees in the urban area increases the heating effect due to loss of shade and evaporation. Trees help in reducing temperature levels in an urban atmosphere.

19.4.3 Carbon Reduction by Urban Trees

Urban forest plays a key role in C management by enhancing C sink and reducing GHGs emissions that minimize C footprints and climate change issues globally

Table 19.2 Tree species for removing pollutant for improving air quality

Scientific name	Common name	O_3	CO	SO_2/NO_2	PM
Ulmus procera	Common elm	√	√	√	√
Ulmus rubra	Indian elm		√		
Tilia europaea	British isles	√		√	√
Tilia euchlora	Caucasian linden		√		
Tilia tomentosa	Silver linden		√		
Fagus grandifolia	American beech	√	√	√	
Betula alleghaniensis	Yellow birch	√	√	√	
Liriodendron tulipifera	American tulip tree	√	√	√	
Tilia americana	American linden	√	√		
Fagus sylvatica	Common beech	√	√		
Tilia platyphyllos	Large-leaf lime	√			
Betula papyrifera	Paper birch	√			
Ginkgo biloba	Ginkgo		√		
Platanus x acerifolia	London plane tree			√	√
Cupresso cyparis x leylandii	Leyland cypress				√
Juglans nigra	Black walnut			√	√
Abies alba	Silver fir				√
Larix decidua	Common larch				√
Picea rubens	Red spruce				√
Populus deltoides	Poplar			√	

PM particulate matter
Modified from Nowak (2000)

(Banerjee et al. 2021a, b, c, d; Buzási et al. 2021; Zhang and Brack 2021).Trees have a great ability to store C from the atmosphere, reduce greenhouse gases (GHGs), and contribute to minimizing the negative consequence of global warming. Trees components (above/below) help in storing C into biomass and sequester CO_2 from the environment. An older tree can conserve more C than the young trees depending upon the site quality and inherent characteristics of the species. Climate change in the addition of destruction and degradation of forest resources leads to a problem through increasing C levels in the environment (Meena et al. 2022; Roy et al. 2022; Yadav et al. 2022). Thus, the urban forest plays a vital role in improving and mitigating the climate change impact on the biosphere.

19.4.4 Trees and Energy Conservation

The tree tends to conserve energy and thus benefits urban cities from direct shading. Trees improve the microclimate of the region and save money on energy costs and also reduce various forms of GHGs and air pollution (Hwang et al. 2017). During summer seasons, urban cities experience more heat as urban areas absorb more heat waves due to less vegetation resulting in warmer air temperature as compared to an area having good vegetation and trees. Trees increase the albedo effect by reflecting the short waves and providing shade to urban infrastructure, thus lowering the temperature level in an urban environment.

19.4.5 Maintaining and Enhancing Wildlife Habitats and Corridors

Urban forest resources maintain biodiversity and provide shelter to many wild animals, which ensure balance in the urban ecosystem. Biodiversity conservation is very important for a balanced ecosystem. In urban regions, environment gets harsh due to faulty practices; thus, greenery in this landscape often is the symbol of nature and life. The urban tree helps in providing food for the fauna and bird species; in turn, they play the role of pollinator in urban area and its proximity. Anthropogenic activities affect the resources of the earth and beautiful landscapes; thus, trees and vegetation in an urban area help in minimizing the negative outcomes caused by anthropogenic activities. Biodiversity and wildlife conservation in an urban area also included with sensory stimulation and help in connecting the human with the natural landscapes and help in improving the ecosystems and human health that leads to the overall prosperity of the biosphere (Honda et al. 2018; Silva-Rodríguez et al. 2021).

19.4.6 Urban Forest Cover and Climate Change

Trees in the urban area act as C sink for carbon dioxide (CO_2) fixation and mitigation during photosynthesis and store C into vegetation biomass. Urban forest resources help to store C in above and below biomass and sequester CO_2. Thus, increasing green cover in urban area helps in the accumulation of C that leads to mitigating climate change. Anthropogenic activities such as deforestation, burning of coal, and management activities such as crown thinning also resulted in increment of CO_2 in the atmosphere. Urban forest cover is a key to improving C storage and sequestration in the cities. C sequestration and storage is key ecosystem services delivered by urban forest resources. Thus, the greater the urban forest cover greater will be the C sequestration and mitigation potential of CO_2. As per Zhao et al. (2010), C storage values were reported as 11.74 Tg and 30.25 t ha^{-1} as compared to 166.5 ton year^{-1} and 1.66 ton ha^{-1} year^{-1}, respectively, in Hangzhou's urban forests. Moreover, better management of urban forests offsets 18.6% of C emitted by anthropogenic industrial activities in the city. For sustainably managing the urban environment, the integrated management approach is needed and can be a good solution under changing climatic perspective. Integrated management of resources tackled in urban ecosystem practices aims to address the linkage between ecosystem components and urban cities. Changing land use into eco-friendly approaches may help in improving water, air, soil quality, and reducing the overexploitation of these precious resources, and building the ecosystem resilience. Urban green space reduces GHGs. C in a tree is measured in two ways: storage in tree biomass and sequestration per year. Trees' ages also affect the rate of absorption rate; different aged trees have different capacities of storage intensity. Urban vegetations are very helpful in maintaining environmental attributes viz., temperature, relative humidity, evapotranspiration, etc., and have a substantial impact on weather and climate change.

The health of community ecology can be measured by tree health. Trees are a good indicator of urban ecosystem health; cities with good forest cover may face fewer ecosystem problems than the cities with the less forested area. Good urban forest cover with less impervious surface helps in reducing the storm water runoff, storing and sequestering the atmospheric C, and reducing the energy consumption of urban infrastructure. The urban tree also helps in maintaining the water conservation and management in the watershed region and helps in resource conservation across the world. Community forestry and social forestry by private and public sectors also helps in mitigating climate change in urban cities. Trees in urban areas have the potential to work as C sink, good pollution controllers. The TOF plays a vital role in cycling global C, TOF includes roadside planting, gardens, residential areas various institutional or academic landscapes. Urban vegetation has a high potential in mitigating environmental degradation due to rapid urbanization through ecosystem services.

19.4.7 Tree and Sustainable Cities

Trees are an important component in an urban ecosystem as they play a vital role in maintaining the diversity and services in the ecosystem. Trees in the urban area provide nonpriced benefits like controlling pollution, mitigating climate change, C sequestration, improving aesthetic view, and many functions for improving urban life. The relationship between society and the environment is very much altered by urbanization and activities and process during urbanization that affects the ecosystem services, environment, sustainability, and resilience. Urban forest resources are the most important contributor and play a significant role in the sustainable development of cities. Sustainable development includes the interdisciplinary and integrative approaches for the management and improvement of existing facilities and services provided by urban forest resources (Khalaim et al. 2021). Trees around the urban centers provide goods and services to people. Many environmental services such as green infrastructures in cities benefit to climate, the people living in the cities, and contribute to sustainable development goals. Urban forest and vegetation help in the management of water by improving groundwater recharge. Sustainable supply of water is a major task as the increasing population and demand for water in urban cities are getting high. Thus, these urban forest resources help in recharging the groundwater under the urban setup. The presence of urban green space and urban resources are an asset to urban cities for sustainable growth and development of healthy life.

19.5 Impact of Deforestation on Urban Forest Cover

The global forest faces various problems leading to the degradation of these valuable resources to a great extent. Among all the deforestation is more devastating and degrading the resources directly beside their indirect huge losses in various spheres related to the environment and ecology (Fig. 19.4) (Zipperer et al. 2012).

Urban green space includes diverse life forms of flora facilitating various ecosystem balance, which hampers due to anthropogenic influence. Deforestation activities alter the vegetation dynamics and associated ecological functions and processes and associated ecosystem. The developmental process and land-use changes have negative impacts on urban green space and vegetation cover in an urban setup.

19.5.1 Factors Affecting Urban Vegetation Development

- Lesser availability of the area for urban greening.
- Deprived soil health and quality due to biotic interference to affect the overall health and development of the urban vegetation and plantation affords.
- Hostile environmental conditions for invasive, alien species, which affect the indigenous biota.
- Frequent expansion of infrastructure setup in the urban area alters the tree cover and population dynamics.
- More stress and drought due to pollution and other factors affecting the ecological amplitude of the species.
- Lack of proper planning, developmental activities as well as governmental initiatives with the people participation toward the awareness of urban forestry programs.

The deforestation activities in the urban landscape can be minimized through campaigning regarding environmental justice, promotion of urban forestry, and protection measure to check the negative consequences of climate change and global warming (Hwang et al. 2017). The vision-related to urban forestry and its development must be addressed in the working and development plan of the city. Further, community transformation and participation toward conservation of nature instead

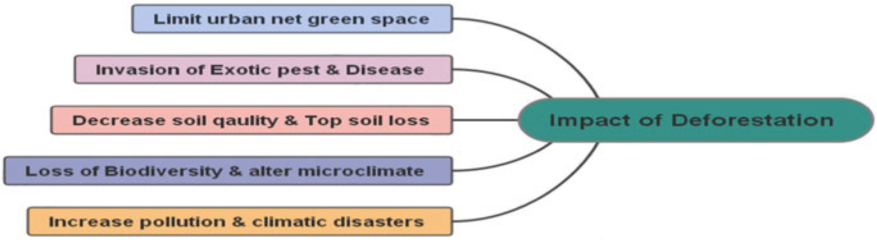

Fig. 19.4 Deforestation impacts on environmental segments. (Modified: Zipperer et al. 2012)

of destruction of vegetation need to be promoted followed by plantation, community stewardship, and technological intervention.

19.6 Prospects of Urban Forestry and Development

Urban forestry practices are rapidly increasing in the present time due to global and regional efforts toward sustainable cities and improving the green cover in the urban setup. The prospect of urban forestry is wider to link the human being with nature and get more ecological benefits from forest resources on a sustainable basis (Khan et al. 2021a, b, 2022). This is a growing concept with the urban science and its scientific design, management, and socio-ecological context to move forward for sustainability. This not only fulfills and satisfies the needs of human society but also advances the ecosystem conservation affords as well as an adaptive mechanism to natural alterations. The urban forestry opportunities integrate the urban free space areas for restoration, utilization, eco-socio-environmental development, green infrastructure, and design perspectives, climatic adaptive and mitigation strategy, eco-environmental resilience, and many more. The success of urban forestry depends upon the people's participation, awareness regarding eco-environmental functions of urban forestry resources, the establishment of various green spaces, green infrastructure and designing, proper policies instruments, and planning for sustainable urban development (Fig. 19.5).

Moreover, integrated urban forestry development and planning must be implemented through joint participation of people along with the government/cities authorities for successful execution of the schemes. In addition to this, proper monitoring and mapping of urban forest resource need to be explored on a

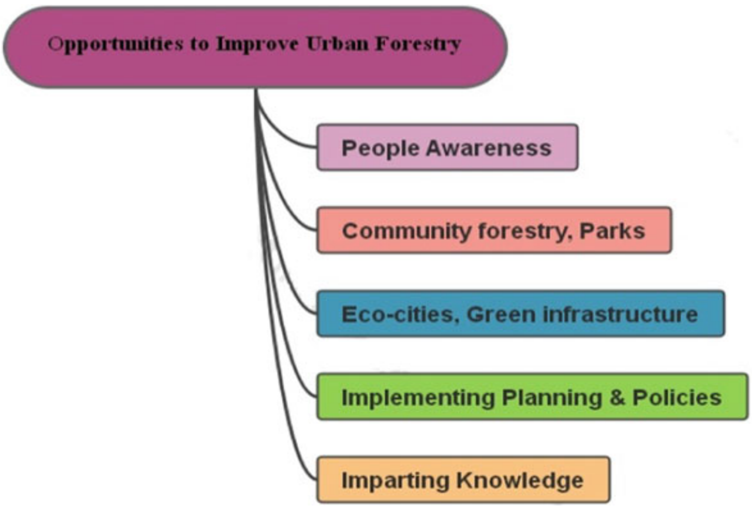

Fig. 19.5 Prospects and opportunities of urban forestry

time-to-time basis toward risk assessment, environmental perception, and analysis of other related aspects. Urban forestry schemes and programs link the people with nature and natural resources. This leads to social progress through the environment stewardship integrating the ecology, environment, economics, and social dimensions. This often attracts and influences people's perception, participation, and behaviour regarding their natural resource conservation concerns.

19.7 Management Aspects

Management aspects are an important consideration for the success of any schemes and programs. Developing a proper management plan for urban forestry includes the goal of management, changes on urban and periurban green cover, urban forest resource management plan toward optimizing green covers in precise duration (Jhariya et al. 2019a). Further, monitoring the changes and alterations in an urban area and its proximity due to biotic pressure must be well defined in the management action plan to meet the desired goal of management. This requires accurate data base by the forest managers to tackle the urban forest resources and the services it offers to human beings (Khan 2018). Further, the ecological services provided to the ecosystem by the urban forest resources can be improved through decision-making tools, which are essential roadmap to guide regarding the management and policies context. Well-planned and well-managed urban forest resources are more effective toward climate change adaptation and mitigation, resilient and sustainable in the various spheres. Therefore, planting trees is precious followed by their proper care, maintenance, and management for increasing the forest cover and achieving the sustainable goal.

19.8 Research and Development of Urban Forest Resources

The urban forest resource assessment, monitoring, evaluation through research and development activities are the building blocks of ecosystem management. Research and development help for proper and efficient planning, execution, and management toward urban forest resource development (Khan et al. 2019a, b, 2020a, b). The research and development must be aligned with the climate change scenario and other disturbance regimes, because urban landscapes have more biotic alteration of systems as well as harsh growing environment to the plants. Thus, the screenings of potential species with diversified environmental, ecological, and socio-economic outputs having wider ecological amplitude must be done through careful and applied research and development plans. Urban vegetation and landscape database quantification should be taken for strengthening the improvement of urban green space and sorting out the constraints and hurdles faced during the past. Moreover, inclusive, logical, and scientific databases and information are obtained from quality research and developmental activities related to urban forest resources.

19.9 Policies and Legal Framework

Non-judicious use of resources, human greed, population explosion, and lacunae in the policies and legal framework leads to an unsustainable and unhealthy urban environment. In this context, human civilization and development need to redefine and rethink to balance harmony with nature. Sustainable urban development depends upon the proper planning, policies, and strategic roadmap to conserve and enhance the urban forest cover. In this perspective, collaboration and execution of sustainability aspects of the urban landscape need to align with local, national, and international levels. The conservative approach of urban vegetation improves the life of the city, enhances the ecology and sustainability of the urban landscape (Khan 2018). The technological intervention and upgradation of science have few pessimistic consequences as environmental quality degradation and pollution loads, which are threatening the human being. Thus, new initiatives need to be implemented for increasing urban forest cover toward sustainable cities through offsetting the carbon emission and reduction through vegetation and soil carbon pools (Lal and Stewart 2017).

19.10 Future Thrust

The urban planning and development under changing climate context need to be linked and well-aligned with the compatible policies framework as well as future directions to manage the urban landscape in sustainable ways (Khan et al. 2019a, b). The climate-related policies for the urban area need to be given due consideration for C management strategies (Jhariya et al. 2021a, b, 2022). Under this perspective proper assessment of forest structure (physical attributes of vegetation), vegetation modelling for urban area and its proximity for deriving optimum output, framing appropriate management plan followed by proper evaluation and monitoring of these landscapes are essential toward overall prosperity and well-being of human civilization and ecosystem (Fig. 19.6) (Nowak 2018).

For the effective management plan of the urban forest resources, the databank of emission and reduction followed by strategies to combat these issues in the current climatic context will surely move toward a sustainable world (Raj et al. 2021, 2022). Further, time-to-time monitoring along with technological and methodological validation is essential for the prediction of future changes. The greenery programs in the urban setup can be enhanced to generate awareness and motivation toward conservation of nature through urban forestry, afforestation; reforestation, social forestry, aesthetic forestry, home garden, Oxygen Park, botanical parks, and garden, as well as plantation activities improve the resilience of human-built environment (Khan et al. 2022).

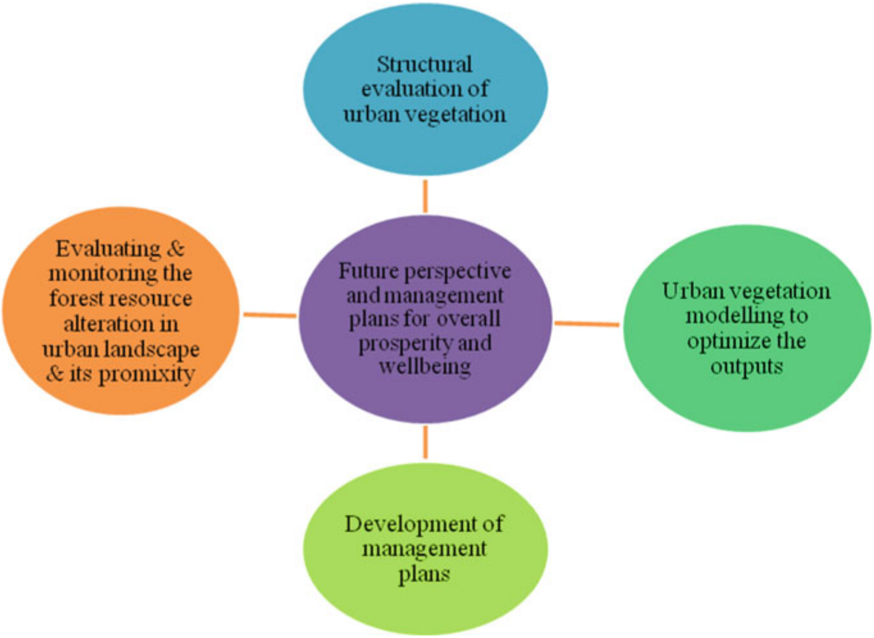

Fig. 19.6 The future perspective for management and implication for future wellbeing. (Modified: Nowak 2018)

19.11 Conclusion

Urban development is critical for changing climate worldwide, because the urban landscape has a substantial part of the world's C cycle. After all, it possesses significant C flux and C alteration as compared to other land-use or ecosystems. This landscape was mainly altered by the human-built environment and became a source of biotic climate change. The information related to urban vegetation, characterization of source and sink of C is essential toward management, conservation of these floras for sustainable planning and development of urban ecosystems. The idea and database on the urban region are important for C monitoring, fluxes, and for adapting pollution and climate mitigation framework and policy development and formulation. Screening of site-specific species having higher ecological adaptation and amplitude is needed for moving forward to emission reduction strategy.

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Soil Nitrogen Dynamics and Management in Agroforestry Systems for Ecological Sustainability

20

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and Arvind Bijalwan

Abstract

The apparent benefits of improving soil health and providing ecosystem services associated with agroforestry systems have led to the attraction of practicing agroforestry in tropical as well as temperate regions for decades. The agroforestry systems usually require low inputs in terms of capital; provide economic benefits by various forest products including fodder; reduce soil erosion; conserve water; and help to improve soil fertility by maintaining nutrients in soil. However, soil health management is unarguably one of the most important criteria for sustenance of food production and other ecosystem services in these land uses. Like other terrestrial ecosystems, maximum amount of nitrogen in soil-plant system is linked with soil and majorly in organic form. The availability of nitrogen to plants after mineralization of organic compounds is the key factor determining the production potential of agroforestry sites. In these systems specifically nitrogen-fixing tree species provide nitrogen inputs by biologically fixing nitrogen and other tree species also help in recycling nitrogen in the soil. Moreover, under the symbiotic association, nitrogen fixation can be affected due to other soil parameters like soil pH, the toxicity of aluminum and manganese, deficiency of nutrients like calcium, magnesium and phosphorus, water stress, soil texture and type. The contribution of agroforestry land uses toward sustainable economic

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production is often constrained owing to these limitations related to nitrogen cycling. Since the agroforestry systems extract more nitrogen from soil as compared to conventional agriculture fields, balance in nitrogen input and loses is required to maintain ecological sustainability of these systems. Keeping these facts into consideration, the proposed chapter aims to manifest dynamics of nitrogen in agroforestry systems and present a conclusive outlook on practices followed worldwide for efficient nitrogen management in different agroforestry land use patterns on the basis of available literature.

Keywords

Agroforestry systems · Soil · Nitrogen · Sustainability

20.1 Introduction

In the Indian subcontinent, agroforestry has a long history. Raising, caring for, and loving trees are deeply woven into the socio-religious fabric of the people of the subcontinent. According to the agro-climatic and other local characteristics, trees are widely incorporated into the region's agriculture and livestock production systems. Sustainable agriculture should entail the sustainable management of agricultural resources to meet the increasing human demand along with retaining or recuperating the quality of environment and conserving the natural resources (Nyberg 2009). Agroforestry's goal is to maximize beneficial exchange between different components in order to give more fruitful, sustainable, or diverse outcome from the land than is possible with other land uses (Handa et al. 2020). Agroforestry has emerged as having an approaching role to play because of its inherent, inclusive, and multidisciplinary approach, its optimal rather than component-maximizing purpose, and the current degree of interest and inclination of farmers in it (Lundgren 1987). More than a century back, various experimental trials based on tree-crop interactions in tea estates, scientific investigations on silvopastoralism, intercropping experimentation with plantation crops, and sequential studies in ravines started agroforestry research in India more than a century ago (Handa et al. 2020). The nature and pact of the components, as well as the ecological and socioeconomic circumstances under which such systems are followed, vary widely. Multifunctional enhanced fallows, plantation crop-based mixed species production systems, home gardens, woodlots, alley cropping, orchards, live fences, windbreaks, and shifting cultivation are some of the most common approaches. However, in recent years, agroforestry for livelihood and environmental security has become a very popular slogan around the world as a result of various extreme disaster scenarios such as floods, droughts, heat and cold waves, and global warming forcing us to adopt woody perennial systems to maintain farm production and livelihood (Garrity et al. 2006). It is an essential component of practically all terrestrial ecosystems (Handa et al. 2020).

Despite substantial scientific and technological developments in agroforestry over the last few decades, the lack of knowledge about how smallholder farmers

Table 20.1 Agroforestry techniques practiced throughout the world

Agroforestry systems	Definition
Agrisilvicultural	The concurrent growing of crops along with trees on the same piece of ground.
Silvopastural	The type of agroforestry system that includes forage production, livestock, and forest tree species on the same land-management unit (Kaur et al. 2000).
Boundary planting	Trees planted to serve as delineation between two farms, a buffer between highways and farms, and to provide lumber, poles, fruits, fuelwood, and other services such as wind breaks and soil erosion management. *Grevillea Robusta*, *Markhamia lutea*, *eucalyptus* spp., and *Alnus acuminate* are widely distributed species utilized in border planting systems, depending on the agroforestry systems.
Improved fallows	Leaving land fallow allows impoverished soil to recoup some of the fertility it has lost due to repeated cultivation with little or no fertilizer application. When compared to natural fallow, improved fallow consists of growing trees, primarily legume tree species, in order to nourish the soil in a shorter amount of time.
Shallow systems	Combination of tea, or cocoa, coffee shrubs with multipurpose shade species in an agroforestry practice.
Homegardens	On tiny plots of land surrounding homesteads, incorporated tree-crop-animal production systems are formed. It consists of a diverse range of woody species coexisting in a multilayered relationship with annual and perennial crops, herbs, and livestock, which are all controlled on the same piece of ground.
Woodlots	Many woodlots are found on farms or as buffers and emergent area between properties such as residential complexes, industrial forests, and public lands. A rotating woodlot is an agroforestry option that tries to replicate the traditional fallow system in shifting agriculture, in which trees help to maintain fertility of soil by cycling of nutrients during the fallow period. Gyroscopic woodlots include crop production and methods of forest management to provide a variety of goods. The technology entails growing trees and crops in three stages: (i) initial installation of tree, which combines intercropping trees with crops; (ii) tree fallow; and (iii) cropping after the harvest of tree.

Reclassified by Feliciano et al. (2018)

in developing countries care and value trees, as well as the barriers they experience in embracing tree culture, is thought to be a crucial factor. Several agroforestry adoption studies have been conducted in various areas in recent years (Franzel et al. 2001). The different agroforestry systems practiced in the world in present times are grouped into 7 categories and listed in Table 20.1 (Feliciano et al. 2018).

Agroforestry has enormous potential for providing long-term agricultural benefits. Agroforestry is practiced by approximately 1.2 billion people around the world in some form or another (World Bank 2004). According to Dixon (1995), the area suitable for agroforestry worldwide is 585–1215 million hectares; however Nair et al. (2009) estimated the agroforestry area to be 823 million hectares. According to remote sensing data, at least 10% tree cover covered 43% of all agricultural land globally in 2010, a rise of 2% over the preceding 10 years (Zomer et al. 2016). In

India, (Dhyani 2014; Rizvi et al. 2013; Zomer et al. 2006) all provided varied figures on agroforestry acreage. Based on data from CAFRI, Jhansi, and Bhuvan LISS III, Chavan et al. (2015) estimated that the agroforestry area was 13.75 million hectares. However, the Forest Survey of India assessed the size to be 11.54 million hectares, or 3.39% of the country's total land area. In our country, raising crop output to fulfill rising food demands while preserving natural resources is a huge task. By increasing soil productivity, high fertile soils contribute significantly to the country's food output. Agriculture intensification causes soil fertility to be depleted due to overuse of resources. Tree, agricultural, and pasture land use patterns have an essential role in enhancing soil fertility and quality in a variety of ways. Agroforestry has the potential to increase agricultural production while also restoring and sustaining soil fertility. The importance of perennial woody tree species in agroforestry systems cannot be overstated (Sarvade et al. 2014). Despite various ecosystem services associated with the agroforestry land use, the limiting nitrogen in the soil may adversely affect the associated outputs. Moreover; high mobility of nitrogen in soil and plant makes it susceptible to various losses and influences the dynamics of nitrogen. The selection of acceptable, usable tree species is the most important component in the success of agroforestry for increasing soil nitrogen (Prabhu et al. 2015). Nitrogen-fixing tree species are most likely the paramount alternative because of their capability to actively fix nitrogen and thus contribute significantly to improving the soil's nitrogen condition (Nyberg 2009). Soil nitrogen content can also be improved through nutrient cycling where nutrients from lower levels of soil profile are extracted by trees and brought to surface through leaf litter and root decay (Bayala and Ouedraogo 2008; Nair et al. 2009).

According to Lal and Miller (1989), total soil organic C and N concentrations were found to be lower in alley cropping than in plough-till solo cropping, but the turndown was at par under lane cropping and no-till sole cropping. Total nitrogen in soil and microbial biomass improved in maize alley-cropped with Cassia compared to sole-cropped maize, according to Yamoah et al. (1986), but did not alter in *Gliricidia* and *Flemingia* alley cropping. The amount of nitrogen in mulch created by cutting trees in alley cropping might be as high as 200 kg per hectare per year (Young 1989). Yamoah et al. (1986) found that the nitrogen released from *Flemingia* and *Cassia* pruning was equivalent to 25% and 75% of the maize's N need, respectively. Mulongoy and Meersch (1988) discovered that leaving the pruning from a Leucaena fallow on the ground boosted maize N uptake by 37% compared to removing the pruning. Despite this, the increase in N intake caused by the pruning only accounted for 3.2–9.4% of the N released by the pruning.

20.2 Nutrient Cycling in Tree-Based Ecosystems

As it is evident, the agroforestry is a land-use approach that includes the deliberate preservation, introduction, or amalgamation of trees in crop or animal production in order to profit from its consequent ecological and economic interactions. It is economically beneficial and environmentally oriented natural resource management strategies that expand and uphold output for better social, financial, and ecological rewards by the interaction with trees on farms and in the agricultural land uses. According to Anderson and Sincair (1993), agroforestry systems are customized environment and cannot be considered as natural systems. However; they represent diversion from the noticeably artificial systems of monoculture production toward imitating the features of natural ecosystem, with more stress on diversification of species and on conservation of natural resources. In agroforestry system, both socioeconomic and ecological interactions occur between different components, which implies that.

(i) Agroforestry systems occupy two or more species of plants or/and animals, among which at least one should be a woody perennial species.
(ii) The outputs from an agroforestry system are always dual or more.
(iii) Two or more years are required to complete the cycle of an agroforestry system.

The key purpose of agroforestry is to take full advantage of positive outcomes of the system, thus improving the productivity along with conserving the natural resources. The agroforestry holds potential for marginal, slopping lands with constraints associated with soil fertility/productivity owing to the ability of trees to grow up under unfavorable climate and soil conditions along with the possibility for conservation of soil. The agroforestry systems comprises agri-silivicultural systems (tree + crops), agri-silvipastoral systems (tree + livestock + crop) silvipastoral systems (combination of multiuse fodder trees on farmlands, living boundary markers of fodder hedges and shrubs, pasture trees and shrubs, combined production of animals and wood products, etc.), trees along with aquaculture, multipurpose trees, etc. (Kumar et al. 2021; Nair 1985). Agroforestry systems can restore degraded land and ultimately may improve both fertility of soil and biological diversity. In terms of management, the agricultural and environmental aims of agroforestry are to maintain ecological balance, provide sustainable yield, biologically facilitated fertility of soil, natural means of pest control by varying agroecosystems and the use technologies with low input (Gliessman 1998). The agroforestry systems utilize the interactions and synergisms led by a range of combinations of crops, tree, and animals in spatial and temporal engagements (Altieri 1994). According to Young (1997), the agroforestry systems use the following ways to perform ecological functions of soils:

(i) Making the ways for the use of marginal lands.
(ii) By retrieving and restoring the degraded areas.
(iii) Germplasm may be developed to generate improved plant varieties, which can acclimatize to different soil constraints.
(iv) Soil organic matter and biological activities are maintained, which benefits the soil physical features along with balancing the nutrient supply.
(v) Improvement of nutrient use efficiency and cycling of nutrients in agroecosystems.

(vi) Use of fertilizers and other external inputs may be moderated and tactical use to overcome nutrient deficiencies.
(vii) Betterment in water-use effectiveness.

The high soil fertility level and closed nutrient cycling capacity of trees to maintain or improve soils is shown under natural forest, the reinstatement of fertility in forest fallow under shifting cultivation practice, and with the evidences of reclamation forestry and agroforestry (Young 1989). The trees are known to sustain or improve soil fertility by following ways:

(i) By fixing atmospheric carbon by photosynthesis and transferring it to the soil through root decay and litter.
(ii) By fixing the atmospheric nitrogen by leguminous trees and a few nonleguminous tree species like Alder and Casuarinas, etc.
(iii) Enhanced nutrient recovery from lower horizons by tree roots; also through mycorrhiza.
(iv) The input of nutrients from rainfall and dust is facilitated.
(v) The combination of tree cover and barrier helps to control the soil.
(vi) Reducing the leaching loses by root uptake of nutrients.
(vii) Owing to the root action and maintenance of soil organic matter, the soils below trees possess better structure and water-holding capacity.
(viii) Availability of varied variety of plant litter, herbaceous, and woody, plant growth-promoting substance.
(ix) The frequent release of nutrients from litter in relative synchronization with management of pruning and crop demand.
(x) Microclimate affected by tree shade.

A unique characteristic of most tree-based ecosystems is addition of large amount of organic matter in soil through periodic litter fall of leaves, fruits, branches, and bark. This residue contains large quantity of nutrients detached annually from the trees. The dead vegetation decomposes and consequently releases nitrogen to be reused by the standing crop or trees itself. Apart from that addition of nitrogen into the ecosystem is also contributed by biological fixation or weathering of parent rocks. The losses of nitrogen can also be attributed by crop uptake and harvesting, surface removal, leaching, and burning. Thus, a dynamic and complex system of geological, chemical, and biological cycling of nitrogen ensures the continued productivity of a tree-based ecosystem. In tree-based ecosystems, the transfer of nitrogen into and out of the system is a continuous process. Generally, two major nutrient cycles have been recognized in tree-based ecosystems viz. geochemical cycle (external) and biological cycle (internal).

20.2.1 Geochemical Nutrient Cycling

The geochemical nutrient cycling engages cycling of nutrient elements into or out of the ecosystem (Fig. 20.1). The amount of nutrient added or lost by the system is mainly influenced by the soil properties, climatic conditions, vegetation type, etc.

20.2.1.1 Inputs Under Geochemical Nutrient Cycle

(i) *Atmospheric inputs*: The atmospheric inputs include precipitation and dust and amount of such inputs depends upon location, season dust, and lightning activity. Atmosphere acts as a long-term source of nitrogen for soil, plant, and trees.

(ii) *Biological N fixation*: The most vital pathway of nitrogen to enter into the soil and plant system is biological N fixation by symbiotic or free-living organisms. In most of the tree-based ecosystems, the nonsymbiotic N_2 fixation by blue-green algae and some free-living bacteria (*Clostridium* and *Beijerinckia*) is not very much. Symbiotic N_2 fixation by *Rhizobium* in leguminous tree species and also by *Streptomyces* and other unidentified organisms in nonleguminous tree species also imports atmospheric N into the system.

(iii) *Weathering of parent rocks:* One of the most significant ways of restoring nutrient reserves in tree-based systems is geological weathering of parent rocks. The rate of weathering of these parent materials depends upon climate, topography, vegetation, and type of parent material. Although exact quantification of this input is not available. Unlike other plant essential nutrients viz. K, P, Mg, Ca, etc., the N input from weathering of parent rocks is very negligible.

(iv) *Contribution through added fertilizers.*

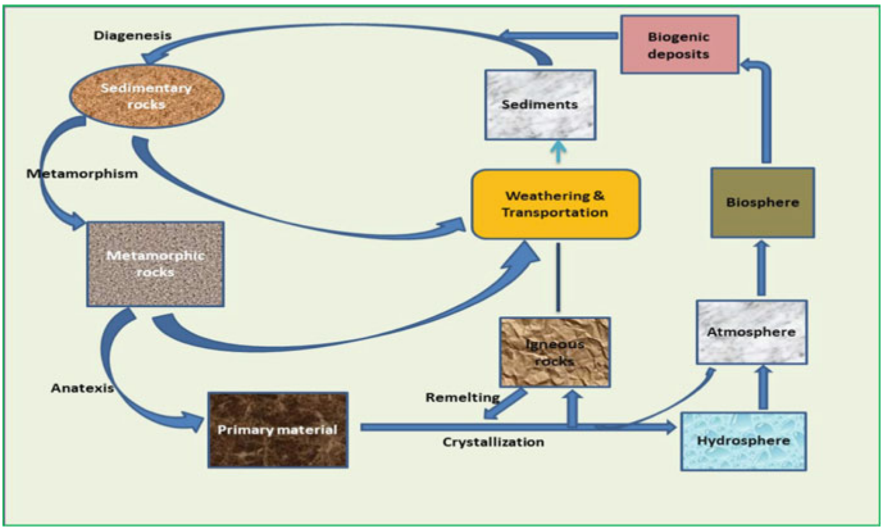

Fig. 20.1 Geochemical nutrient cycling

Application of inorganic fertilizers accelerates the rate of nutrient cycling and increases nutrient availability in soil in nutrient-deficient areas. The limiting nitrogen plays key role in nutrient dynamics owing to immobilization stimulated by high C:N ratio of litter or residue.

Where in case, the nutrients released by soil are not absorbed by crop/tress or retained or recycled by the organisms in soil, these nutrients generally get removed from the soil either to the atmosphere or to the subsurface or ground water.

20.2.1.2 Outputs (Losses) Under Geochemical Nutrient Cycle

(i) *Leaching and run off:* The leaching losses depend upon the soil type, slope, surface vegetation etc. As compared to cultivated lands, the leaching and run off loses are considerably low in undisturbed forest ecosystems.
(ii) *Harvest:* The amount of nutrient removed through harvest and litter removal in agroforestry depends upon the tree species, age, site and type of crop.
(iii) *Volatilization:* Under alkaline conditions, N may be volatilized from soils as NH_3 and under acidic conditions as nitrous oxide owing to chemical decomposition without the involvement of enzymes. However; the loses of N in higher trees-based systems is not very substantial due to prevailing conditions of these soils which do not endorse the formation of gaseous form of N. Whereas; the forest fire seems to have significant effect on gaseous losses of N from soil (Rawat et al. 2020a, b).

20.2.2 Biological Nutrient Cycling

The biological nutrient cycling involves transfer of nutrients between the soil and associated plant and organism communities. The major components of this cycle are uptake, retention and distribution, restitution or return and internal transfer of the nutrients.

(i) *Nutrient uptake:* The type and age of agroforestry tree species, vegetation cover, crop geometry, soil type and climatic factors affects the nutrient uptake in agroforestry land use types. Relatively more amount of nutrients are absorbed by the trees is gradually returned to the soil or translocated within the tree and smaller portion is retained in an annual accretion of biomass.
(ii) *Nutrient retention and distribution:* The different between nutrients returned to the soil system and nutrient uptake accounts for the net annual nutrient accumulation. During the early development stage, it increases linearly or exponentially and at a diminishing rate as the stand attains maturity, depending upon the tree species and management practices. The nitrogen concentration reported in the foliage of some agroforestry tree species is presented in Table 20.2.
(i) *Nutrient returns or restitution:* In agroforestry systems, a major portion of the nutrients is taken up by the above ground biomass of the trees and is returned to the soil in the form of litter fall. The contribution of return diverges with tree species, site, age of trees, etc. In general, copiously growing trees return

Table 20.2 Nitrogen concentration in foliage of some agroforestry tree species

Sn	Tree	N % in foliage/leaf litter	Reference
1.	*Albizia coriaria*	2.2	Ssebulime et al. (2018)
2.	*Artocarpus heterophyllus*	3.7	Ssebulime et al. (2018)
3.	*Ficus natalensis*	2.4	Ssebulime et al. (2018)
4.	*Mangifera indica*	1.6	Ssebulime et al. (2018)
5.	Grewia	2.91	Kaushal and Verma (2003)
6.	Morus	2.24	Kaushal and Verma (2003)
7.	Toona	2.14	Kaushal and Verma (2003)
8.	Populus	1.93	Kaushal and Verma (2003)
9.	*G. sepium*	3.30–3.96	Melchor et al. (2005)
10.	*Albizia julibrissin*	3.3	Misra (2011)

comparatively higher proportion of nutrients as compared to trees growing in deficient conditions.

(ii) *Internal transfer:* In trees the transfer and translocation of nutrients takes place from the senescent organs to the actively growing parts. The newer and growing leaves generally always contain high amount of N, P, and K but lower Ca than older leaves owing to high mobility of N, P, and K in plant. The concentration of nitrogen, phosphorus, and potassium decreases steadily during active growth stage and attains a steady state when the leaves are completely developed.

(iii) *Biochemical cycle:* The internal transfer of nutrients within the ecosystem is generally termed as biochemical cycle. The movement of nutrients involving biological organisms and geological (atmosphere or lithosphere) environment is collectively referred to as biogeochemical cycles. It wheels the associations between available and unavailable forms of nutrients in soil.

20.3 Nitrogen Cycling in Agroforestry

The supply of N present in atmosphere is in dynamic equilibrium with certain fixed forms of N in soil as certain microbial and chemical processes release back elemental N to the atmosphere. Cycling of N in the soil-plant-atmospheric system is facilitated by various transformation of N between organic and inorganic forms. Except for industrial and combustion fixation, all these transformations occur naturally. However; the soil and crop management activities can influence these transformations enabling the human interference. As depicted in Fig. 20.2, the nitrogen cycle can also be divided into: N inputs and N outputs/losses.

The Nitrogen fixation, ammonification, nitrification, and denitrification are the major significant steps of N cycle. There are majorly four comprehensive processes that regulate nitrogen and other cycling of nutrients in agroforestry systems. These are

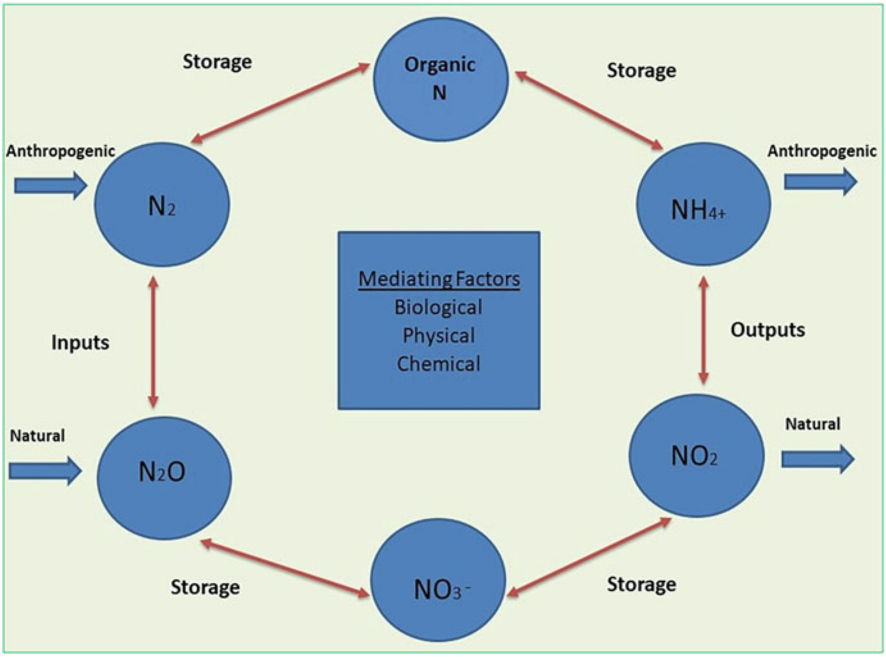

Fig. 20.2 Nitrogen cycle

(a) Biological fixation of atmospheric nitrogen.
(b) Biomass production and decomposition.
(c) Deep capture of nutrients (Nair et al. 1999).
(d) Erosion induced losses of nutrients (Sileshi et al. 2014).

The main processes are briefly described below:

(i) *Nitrogen inputs:* Biological nitrogen fixation is the dominant source of nitrogen input in soil under agroforestry systems. Among the nitrogen fixed by cultivated systems, major portion of N is contributed by leguminous crops such as soybean, cowpea, etc. Nitrogen input through addition of fertilizers also contributes toward the input of N in soil under agroforestry.
(ii) *Nitrogen outputs:* The N output in agroforestry systems includes leaching, run off, volatilization losses, and uptake by trees and crops.

In the terrestrial ecosystem, the nutrients move under an internal and external cycle. The external cycle encompasses the input and output of nutrients from the ecosystems (Mishra et al. 2017). One of the main inputs of N in agroforestry system is biological N fixation. Among the two symbiotic N fixing phenomena, the *Rhizobia* legume and Frankia-nonlegume symbioses play key roles. Around 320 genera of legume plant species fix atmospheric N by symbiotic association with *Rhizobia* and about 200 species under eight families of flowering plants fix the atmospheric N by association with Frankia (Franche and Lindström 2009; Obertello et al. 2004; Russo 2005). N-fixing potential and the affiliation of particular bacteria capable of colonizing tree root nodules; N-fixing tree species play an important role in agroforestry systems. This symbiotic relationship is widely known for improving soil fertility and nitrogen status. Though quantifying the exact scale of biological nitrogen fixation is methodologically difficult, general rates of N fixation for both leguminous and non-leguminous range trees range from 20 to 300 kg N ha^{-1} $year^{-1}$. The N fixed by trees is commonly equal to 20 to 120 Kg N ha^{-1} N fertilizer. Franche and Lindström (2009) opined that the rates of N fixation by Frankia-non legume symbiosis are also equivalent to the N fixed by legume Rhizobium symbiosis. According to Nygren et al. (2012) the agroforestry trees provide low-cost N input by fixing approximately 250 (56–675) kg N ha^{-1} $year^{-1}$. The litter fall by N-fixing tree species also stream substantial amount of nitrogen to crops. Apart from the biological nitrogen fixation the input trough the domestic animals as dung and urine, birds living on the trees and other soil microorganisms also exist but is not as much studied and quantified. However; the role of trees in facilitating the N input in soil is not only limited to biological fixation. The deep nutrient capture and storing it in biomass by trees also retains N and indirectly supply it to the soil and associated crop.

The uptake of nutrients by roots of trees at the depth beyond the reach of crop roots is referred to as deep nutrient capture. Deep root capture retains the quantity of nitrogen that would otherwise drain down into the subsurface soil layers. As a result, nutrient input under agroforestry systems has an extra advantage over conventional cropping systems. Also, the decomposition of litter and tree roots release absorbed primary, secondary and micronutrients into the soil (Sanchez and Palm 1996). The production of organic matter through litter and prevention of soil erosion under tree-based cultivation also retain the nutrients in soil. The conversion of nutrient to labile forms of soil organic matter ultimately enhances the nutrient availability in soil. The process of decomposition assists the mineralization of organic forms of nutrients present in the plant residues into easily absorbed inorganic forms. Due to several interactions such as tree-tree, tree-crop, tree-symbiotic microorganisms, crop-soil microbes, and between soil microbes, the cycling of nutrients in an agroforestry ecosystem includes certain belowground complexity. Unlike the open nutrient cycling in conventional agriculture the forest ecosystem maintains a closed cycling of nutrients, Nair et al. (1999) suggested that the nutrient cycling in agroforestry systems falls in between the open and closed nutrient cycling of agriculture fields and forests, respectively. The use of fertilizers in agroforestry is one of the foremost influxes of nitrogen along with biological N fixation and slightly less input via litter fall. The nutrient cycling processes between ecosystem pools also includes losses of nutrients through leaching and soil erosion (Sileshi et al. 2014). The major losses of N from the soil include leaching losses (Nair et al. 1999), and plant uptake and minor volatilization losses by N-emission. Kass et al. (1999) approved that N_2O produced in the coffee farms under shaded conditions does not create greenhouse gas issue.

20.4 Nitrogen Management in Agroforestry

The agroforestry system has been well known for having wide prospective to preserve and improve nutrients of soil and soil fertility status, which is a significant factor for sustainability of ecosystem and biodiversity (Kumar et al. 2021; Rawat et al. 2021). However, the limiting nitrogen affects productivity of agriculture/agroforestry systems. Inefficient restoration of soil nitrogen removed by crop uptake gradually depletes it in the soil, thus reducing the production potential of the system. To improve the crop yield, incorporation of chemical or organic fertilizers is a common practice followed by the farmers. Commonly farmers use less than 10 Kg of inorganic N ha^{-1} (Vitousek et al. 2009) in fields where agroforestry is practiced and the issues related to accessibility and availability of labor negatively affects the use of inorganic fertilizers as well. The limited use of external sources of nitrogen in agroforestry methods causes soil degradation in these locations, jeopardizing food security and agroforestry-based land use development. Non-judicial excess use of N fertilizers, on the other hand, results in unfavorable environmental conditions, threatening biodiversity and groundwater quality in addition to climate change and global warming. The movement of nutrients from decomposing litter to the soil and then back to the plants, as covered in the preceding sections of this chapter, is critical to the system's nutrient cycle. This study involving the use of 15 N also pointed out that the maize grown with these trees and in unavailability of the mulch contained 3–15% less N at the stage of maturity and conclusive of the fact that the N_2-fixing trees affirmatively affect the on- going transfer of nutrient in alley cropping. In the similar investigation, Snoeck et al. (2000) recorded a range of 13–42% of N transfer in terms of total N fixed by the N_2-fixing tree to the tree-crop under coffee plantation. In the rotational fallows, incorporating leguminous biomass from the trees, decomposition of roots and nutrient transfer to the crops plays a key role in nutrient cycling. Chirwa et al. (2003) and Sileshi et al. (2008) reported that the mixed species fallows influence the soil N cycling and organism more effectively than the single species fallow rotations in eastern Zambia. They opined that mingling the shallow-rooted species with deep-rooted species may have the potential to augment the nutrient uptake and soil-water region in the profile of soil.

Isaac and Nair (2006) conducted the analysis of decomposing litter in agroforestry-based system and demonstrated a rapid loss/release of N at initial 6 months of the experiment followed by the improving concentration in the subsequent months. The authors were of the opinion that the leaching of soluble form of N must have led to the initial losses and the later enhancement in N content was attributed to the immobilization of N facilitated by the microbial population enhanced by the availability of litter. Isaac et al. (2005) found negative net nitrogen mineralization rate over 60 days incubation period of recomposing litter. However, the nitrate production enhanced over 2-year-old and 25-year-old treatments, which led the authors to the thought that the possible nitrification of initial ammonium directed the decreased nitrate production under incubation studies. The soil in 2-year-old treatment had 13.8 Kg ha^{-1}/60 days nitrification rate, whereas the

15 year old treatment recorded 21.4 Kg N ha^{-1}/60 days. The effect of various factors on soil N under varying agroforestry systems is depicted in Table 20.2.

20.4.1 Nitrogen Management Under Non-N-Fixing Trees–Based Agroforestry

In India, owing to its fast-growing capacity, the Poplar has become immensely widespread among the farmers and forest product-based industries and enterprises (Plate 20.1.) in the plain areas of north India.

Nitrogen application in Poplar helps in attaining enhanced height and girth of the tree. It is recommended to apply N fertilizer in May (1/3rd) after harvesting of the intercrop, in July (1/third N), and the rest in remaining in September (1/third N) for the soils having moderate levels of available nitrogen. Also, more productivity of clonal planting material of *Eucalyptus* has also attracted farmers to adopt the block plantations of it in the agriculture fields. It has been advised to apply whole DAP/SSP, MOP 1/third of Urea in the month of July and the left urea dose (1/third N) in the month of October for *Eucalyptus* (Doherty et al. 2017). Mishra

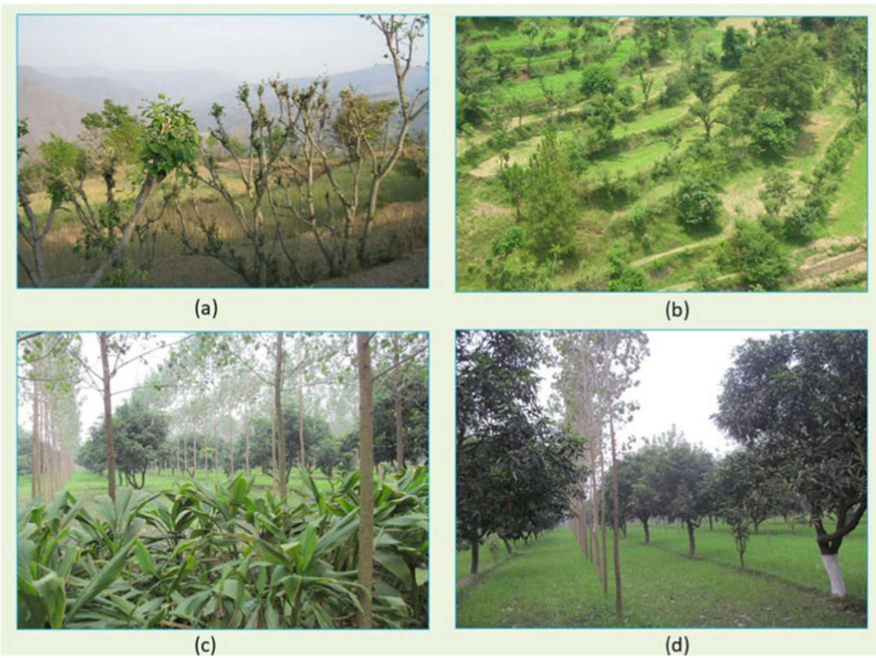

Plate 20.1 Different agroforestry systems in India: (**a**) *Grewia optiva* and wheat; (**b**) Traditional agroforestry system in hills; (**c**) Intercropping of turmeric with poplar and mango trees; and (**d**) Wheat crop under poplar and mango

(2014) documented the high uptake nutrient (N, P, K) potential of Guava trees from the soil and thus, advised for higher rate of application of N, under Mango + Guava + Paddy agri-horticultural system. Magill et al. (1997) exhibited that the nitrogen concentration in foliage improved around 25% with application of nitrogen fertilizers in *Betula lenta, Fagus grandifolia, Quercus velutina*, and *Acer rubrum* grown under agroforestry practices and 67% enhancement was observed in *Pinus resinosa* (Debnath et al. 2016). The release of nutrients from decomposing roots is an important alleyway of nutrient flux under tree-based agriculture practices. Debnath et al. (2016) indicated toward high nitrogen biomass in fine roots of poplar on surface layers, which further increased with N and P fertilizer applications. This trend was found to be more prominent in summer and rainy season as compared to winter and spring. Keeping this in view it can be concluded that the poplar roots will provide higher competition for nutrients in summer season crops, therefore suggesting higher demand of N application for the system in summer/rainy season. Oijen et al. (2010) revealed the higher leaching losses of N in coffee-based agroforestry systems and recommended the reduction of using N fertilizers into the system. They also opined that although the rate of N fixed by legumes in the system's nutrient budget is minor but is well enough for the sustainable productivity of the system. According to their observations, the coffee-based agroforestry contributes not much to the greenhouse gas emission even with the use of N fertilizers. Li et al. (2020) documented the stock of total N at 0–40 and 0–10 cm depth being significantly more in *C. sinensis* and *C. liberica* than in monoculture of rubber. Confirming the opinion of Devi et al. (2015), they also suggested that the surface layer in agroforestry systems is more responsive than the subsurface layers.

Various free nitrogen-fixing soil microorganisms have also been identified to increase the available nitrogen in agriculture-based land use systems. Aasfar et al. (2021) pointed out on the importance of Nitrogen-fixing *Azotobacter* species as impending soil microbial organisms for crop nutrition and yield stability. They suggested for the scientific exploration of specific characteristics like resistance to environmental stress by cyst formation for the greatest intend of research and develop specific formulations of *Azotobacter* biofertilizers. Nevertheless the soils with low organic matter content and antagonistic connection with other soil microorganism negatively influence the population of *Azotobacter* (Debnath et al. 2019). Another paradigm under nutrient transfer in agroforestry land use practices encompasses the "mycorrhiza," which is known to augment the nutrient availability in tree based ecosystems. The general mycorrhizal network is characterized by the ability of transferring nitrogen between various species in differing ecosystems and agroforestry systems as well. According to Jalonen et al. (2009), the Arbuscular mycorrhizal fungi can associate with 80% terrestrial plants in which the list is dominated by tropical tree and crop plants like cacao and coffee (Kähkölä et al. 2012). They are also known to facilitate the transfer of N from N-fixing trees species to the non-N-fixing trees in an ecosystem (Moyer-Henry et al. 2006).

Table 20.3 N_2-fixing potential of some common plant species in agroforestry systems

Sn	Species	Nitrogen fixed (Kg N/ha/year)
1.	*Acacia mearnsii*	200
2.	*Casurina equisetifolia*	60–110
3.	*Erythrina poeppigiana*	60
4.	*Gliricidia sepium*	13
5.	*Inga jincicuil*	34–50
6.	*Leucaena leucocephala*	100–500
7.	*Vicia faba*	68–88
8.	*Alnus acuminata (A. jorullensis)*	279
9.	*Alnus glutinosa*	40–53
10.	*Alnus rubra*	85–320
11.	*Casuarina equisetifolia*	12–110
12.	*Coriaria arborea*	192
13.	*Ceanothus velutinus*	4–100
14.	*Purshia tridentata*	1

Source: Misra (2011), Russo (2005)

20.4.2 Management under N-Fixing Trees-Based Agroforestry Systems

The capacity of nitrogen fixation differs among species of trees (Table 20.3; Giller 2001). There are about 515 leguminous species among the worldwide known 650 woody N_2-fixing species and the agroforestry in tropical regions is primarily dominated by leguminous species along with some actinorhizal tree species like *Alnus* and *Casuarina* (Nair et al. 1999).

As per the suggestion of Nygren et al. (Nygren et al. 2012), nitrogen fixation by plants is efficient of including tens to hundred kilograms of nitrogen/ha to an agroforestry land use system. The nitrogen-fixing capacity of trees also varies among the agroforestry systems of various regions owing to the varying climate, fertilizer application, soil type, pruning intensity or frequency, tree physiology and other management factors. Bala et al. (2003) mentioned that the *Erythrina spp., Acacia spp., Gliricidia spp., Leucena spp. and Inga spp.,* are some N-fixing trees of tropical agroforestry systems, which are known for their symbiotic association with a range of N-fixing bacteria. The legume-based agroforestry provides miscellaneous arrangement of farming including intercropping, multistrata agroforestry, and improved fallows. The integrated use of leguminous trees along with traditional cropping system allows natural enhancement of N input in soil instead of using the chemical fertilizers, which ultimately increase the input cost. The biologically fixed nitrogen ultimately reaches to the growing crops after the decomposition of legume residues. The capacity of nitrogen fixation by legumes varies greatly depending upon species and the status of N in soil and ranged between 5 and >300 kg N Kg^{-1} ha^{-1} $year^{-1}$ (Ajayi 2011; Vanlauwe and Giller 2006). The addition of N into this system from external sources like legume plants also has certain environmental impacts. Since the fixed nitrogen by legumes is converted into the mineral nitrogen in the soil, it is also prone to the same pathways of leaching and volatilization losses. Some researchers have risen concerned over this problem of potential increase of nitrous oxide emission from these systems, which eventually contribute to the greenhouse effect (Cadisch et al. 2005; Verchot et al. 2007). Verchot et al. (2008) presented over the thought that magnitude of change in soil nitrogen with the incorporation of legumes into the system may not always be substantial. Unlike the traditional agriculture systems, agroforestry provide large variable of ecosystem functions including addition of organic matter to the soil, facilitating the biodiversity, providing fuel/fodder, and retaining N in soil (Harmand et al. 2007; Tscharntke et al. 2011). Rosenstock et al. (2014) pointed out towards the N_2O emission from agroforestry systems. However, they were of the opinion that this is not an issue of concern owing to the following facts:

1. The N fluxes in the legume-based agroforestry systems and the traditional agroforestry systems where inorganic fertilizers are being used are relatively similar.
2. Some potential legume-based agroforestry systems on the other hand may act as a major sink for greenhouse gases owing to the affirmative impact of legume trees on biomass carbon and soil carbon sequestration.
3. Potential enhancement in the yield of crops due to addition of N through legume trees.

Despite all these facts the intensification of N into the system can still have smaller or larger adverse environmental effects. Tully et al. 2013 reported elevations in NO_3 concentration in soil and water due to decomposition of high-quality leguminous biomass. Transportation of leached NO_3 from soil into the ground water may contaminate the drinking water supply in some cases. Recha et al. (2013) revealed that NO_3 incorporated in ground water may retain for decades and may increase over time creating health hazards to plant and animals. However, some researchers put forward the fact that instead of shallow rooted annual trees, the leguminous trees are capable of scavenging nitrogen that passes through the depths below crop roots (Chintu et al. 2004; Taylor et al. 2011). Thus, although legume-based agroforestry systems increase the surface soil NO_3, there are fewer chances of leaching losses from the soil. Instead, legumes are helpful for achieving high yield targets. Sileshi et al. 2008 suggested the use of *Gliricidia sepium* under intercropping or in improved fallows to enhance the yield of maize (*Zea mays*) in comparison to the current farming practices used in the sub-Sahara, Africa. However, the reported yield seems to differ across the soil types, rate and method of fertilizer application, and climatic conditions (Sileshi et al. 2010). Lal and Miller (1989) reported the importance of tree hedges as their roots protect the soil against erosion and surface runoff. The hedges of nitrogen fixing trees may serve this purpose in addition with increasing the overall nutrient input and improving the rate of nutrient cycling (Kang et al. 1993). Mulch obtained from tree leaves of hedge species provides around 100–200 Kg N ha^{-1} to alley cropping systems (Sanchez and Palm 1996). Legumes like *Leucaena leucocephala, Sesbania sesban, Gliricidia sepium* containing high N concentration and low lignin and phenol release more than half of the N in their leaf with 2 weeks of pruning (Oglesby and Fownes 1992). The N added into the soil by legume trees is not only beneficial for the crop but direct transfer of nitrogen fixed by legume tree to the nonlegumes in the soil by root exudates and mycorrhizal networks has also been reported by several researchers (Nygren et al. 2012; Sierra and Nygren 2006). According to Sharma et al. (2016), nitrogen incorporated into the soil by *Alnus* and *Albizia* was relatively higher in cardamom (95–116 Kg ha^{-1} $year^{-1}$) based agroforestry system as compared to noncardamom-based system (6–-22 kg ha^{-1} $year^{-1}$). As reported by Snoeck et al. 2000, in coffee-based agroforestry, *Leucaena, Calliandra*, and *Erythrina* fix about 30% of N proficiently. Jayasundara et al. (1997) have also documented the fact that in Sri Lanka up to 21% nitrogen in grasses is derivative from the nitrogen transferred by *Gliricidia and Leucaena.*

20.4.3 Sustainable Practices for N Management in Agroforestry Under Problematic Soils

The land use practice with agroforestry system not only imparts more efficient nutrient cycling in soil plant atmosphere continuum but also helps in restoration of degraded land. However, planting trees in such areas is associated with many challenges. One of such challenges includes poor survival rate of trees in such land owing to adverse physicochemical constraints and considering suitable tree species suitable for these specific soil conditions is a prerequisite. No specific critical limits of soil degradation processes have been identified as they depend on inherent soil characteristics, which are based on the quality of soil (Rawat et al. 2020a, b). Nitrogen-fixing tree species are able to grow and sustain in soil with low nitrogen availability. However; limited availability of P and moisture stress in degraded areas of dry land can also limit the growth of such N-fixing trees (Sileshi et al. 2014**).** For example, application of P under *Faidherbia* seedlings with indigenous AMF has been found to enhance its growth in dryland regions (HaileMariam et al. 2018**).**

Habte (2006) reported low nodule formation in *Leucaena* owing to low P in soil, which further improved with inoculation of AMF. The problem of soil acidity has also been a constraint for organization of tree species in agroforestry systems. The soil acidity has been well known to reduce the symbiotic nitrogen fixation, pessimistically influencing the legumes yield and growth (Ferreira et al. 2016). The strongly acidic soils having $pH < 5.5$ contains low levels of plant available calcium and phosphorus and also suffer from aluminum and manganese toxicity (Srivastava et al. 2015). Due to such factors, many leguminous agroforestry species do not grow and sustain in these soils indicating toward the need of inoculating effective nitrogen-fixing bacteria and AMF to improve their growth and establishment under slightly to highly acidic soils. The AMF have potential to counter the deficiencies of P and thereby stimulating the nodulation and N fixation owing to their effect on enhanced levels of available zinc, copper, iron, calcium, and phosphorus to the legume trees (Habte 2006; Srivastava et al. 2015). However, access and selection of the right strains of N-fixing bacteria and AMF is more important. On the other hand, the role of N-fixing species in the remediation of soil in low fertility and high salinity drylands has been extensively documented (Peoples and Craswell 1992).

Moreover, the addition of inorganic nitrogen in soil has also shown promising results in N-depleted soils. In an agroforestry system consisting of 200 plants/acre, the tree height and girth of *Melia azedarach* were found to be the highest with the application of N. The application of 1/third N during May after harvesting of intercrop, 1/third N in July, and the remaining 1/third N in September was recommended for the soils having medium levels of nitrogen. On the other hand, P application every year was not found to be required for *Melia azedarach* (Doherty et al. 2017). Dhara and Sharma (2015) suggested that hardy and deep-rooted fruit plants like *Mangifera indica, Psidium guajava, and Ziziphus mauritiana* may be planted as high value horticultural crops in degraded waste lands having red and laterite soils in West Bengal and approved that the N increased by 34.3% in mango-based agroforestry systems, that is, *E. tereticornis* + Mango + Pigeon pea and *E. tereticornis* + Mango + Black gram. A few researchers have also focused on using the nitrification inhibitors for improving the nitrogen dynamics and N fertilizer use efficiency. Srivastava et al. (2016) opined that the AM (2-amino 4-chloro 6-methyl pyrimidine) remain efficiently as residue in soil for an adequate duration of time, therefore may be used for improving the efficiency of nitrogenous fertilizers along with defending and controlling the polluted soils in subtropical regions.

20.5 Conclusion

The combinations of trees with crops have potential to affect the supply and availability of nitrogen in the soil. Agroforestry systems are apparently efficient to reduce the nitrogen losses from soil owing to the enhanced nutrient uptake from varying soil depth by tree and crop roots. For enhanced nitrogen supply, capture, and cycling in agroforestry land uses, the ideal tree species are usually fast-growing, N-fixing trees. However, according to the studied literature, the preference of tree species to be planted under various agroforestry systems is subjective to both biophysical and socioeconomic conditions of specific regions. In soils that are rigorously depleted of nitrogen due to different forms of soil degradation, the addition of inorganic fertilizers, manures, biofertilizers, or AMF is capable of increasing the productivity. Moreover, the agroforestry systems endorse improvement of ecosystem services by enhancing organic matter status of soil, biodiversity, soil physicochemical properties along with nitrogen retention. However, it is necessary to recognize and limit the factors encouraging N losses in agroforestry and plan appropriate region-specific management strategies that synchronize nitrogen availability with the crop demand along with sustainability of the ecosystem. Integrated nitrogen management has identified to be able to deliver sufficient nitrogen to sustain crop growth and improve soil condition in various cases. There is also a call for development of perspective approaches for long-term nitrogen management in agroforestry together with dexterous efforts to make them available to the end users.

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Land Degradation Neutrality for Achieving Climate Resilience in Agriculture 21

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Abstract

Land degradation is predicted to damage more than a quarter of the world's land surface, resulting in decreased or lost soil performance owing to physical and chemical degradation, as well as falling biological and economic productivity. Land loss and climate variation are two interrelated routes with biophysical and man-made drivers, consequences, and remedies. Land restoration has an influence on agro-ecological systems' socioeconomic constancy. Changes in the quantity and quality of ecosystem services as a result of climate resilience will have an impact on livelihoods in a variety of businesses. Agriculture adaptation planning should emphasize continuous land restoration, as well as the possibilities that come with restoring degraded land. While some national agricultural adaptation plans recognize the need of soil protection, many still fail to include land restoration as a component of such strategy. Management choices such as changing crop types and animal breeds, as well as adjusting the timing and location of management actions, have been a major emphasis for crop and livestock production systems. In order to achieve land degradation neutrality (LDN), efforts must be made to minimize additional net losses of land-based natural capital as compared to a reference condition, or baseline. Within

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individual land types, where land type is determined by land potential, planning for neutrality entails counterbalancing predicted losses with steps to obtain corresponding benefits. LDN adoption contributes to SDG 15 and other associated targets, providing possibilities for achieving these objectives in a cost-effective and environmentally sound manner at the same time.

Keywords

Agriculture · Climate change · Resilient · Degradation

21.1 Introduction

For millennia, land degradation and climate change have exacerbated difficulties that have harmed global agricultural productivity and human food security (Diamond 2005). Addressing these issues is critical for developing long-term agroecological systems capable of feeding the world's constantly rising population. Although there is a lot of information regarding land degradation and climate alteration as independent facts, there is less information on their interaction in different agro-ecological situation and, more importantly, in what way communities must concurrently adjust to the effects (Reed and Stringer 2016). This is an urgent time to talk on these issues.

Land degradation is predicted to damage more than a quarter of the world's land surface (37.25 million km^2), resulting in decreased or lost soil performance owing to physical and chemical degradation, as well as falling biological and economic productivity (ELD Initiative 2015). Rangelands and pasturelands, silvopasture systems, and croplands are all experiencing these changes (Karamesouti et al. 2015). However, current worldwide estimations of land degradation speeds employ a variety of categories, lack comparability, and are extremely speculative. Around 40% land loss has taken place in emerging nations, expecting to account for 78% of worldwide dryland growth and 50% of populace upsurge by 2100 (Huang et al. 2015).

Alongside, climate variation poses significant threats to agriculture, livelihoods, and biodiversity with few largest threats occurring in emerging dryland areas (IPCC 2014). Managing the rapid effects of climate change is a massive and urgent undertaking, but it may also present chances for land restoration and increased agricultural productivity in some circumstances. It is known that land loss typically spreads the susceptibility and sensitivity of agro-ecologies to environment effects, diminishing resilience and altering land users' adaptive capability, combating land degradation is an important part of agricultural adaptation strategy (Gisladottir and Stocking 2005). However, technical developments in the last century have frequently obscured the influences of soil degradation and climate variation on agriculture (Pingali 2012).

In Australia, for example, soil deterioration has lowered cereal grain yields, resulting in production plateaus that have been concealed by continued farmland development (Turner et al. 2016). Reduced rainfall across Australian croplands is expected to exacerbate the effects of soil degradation on output, posing a threat to food safety (CSIRO and BOM 2015). Land degradation hazards may be significantly larger in pasture systems and places that do not embrace adequate conservation farming. In the Botswana Kalahari, shrub encroachment and wind erosion have made local people more vulnerable to drought than neighboring Namibia and South Africa (Dougill et al. 2010). The ability of land to continue delivering ecosystem services in the face of climate change is directly impacted by how it is maintained. Land degradation can have a negative impact on the efficiency of climate change adaptation.

Novel management and policy approaches can result in "multi-win" results in terms of land degradation, climate change, and biodiversity. These methods are based on existing knowledge of the biophysical, societal, and financial connections between land degradation and climate variation at several spatial and chronological dimensions. They allow for the documentation of major societal and biophysical vulnerabilities, as well as suitable adaptation techniques. Agriculture adaptation planning has been a focus of worldwide science and policy in order to meet climate-change risks and possibilities (Howden et al. 2007). However, widespread and severe land degradation continues to be a significant impediment to successful adaptation (Reed and Stringer 2016). Scientists and leaders may weaken adjustment forces; aggravate food safety threats presented by climate modification, and stop to fulfil much of the Sustainable Development Goals (SDGs) except these comprehensive disputes are handled simultaneously in styles that do not damage biodiversity (United Nations 2015). Recognizing the numerous advantages of slowing and changing land degradation, the notion of "zero net land degradation" was advocated at the 2012 United Nations Conference on Sustainable Development. In the final conclusion paper, "The Future We Want," this was recasted as "strive to achieve a land degradation neutral world," and was later endorsed by the United Nations General Assembly as part of the Sustainable Development Goals (SDGs).

21.1.1 The Concepts and Framework for Land Degradation Neutrality

Land degradation neutrality (LDN) is defined by the United Nations Convention to Combat Desertification (UNCCD) as "a state in which the amount and quality of land resources required to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD 2015). The objective is to preserve or improve the land resource base, that is; the natural capital stocks connected with land resources and the ecosystem services that flow from them. The relevance of ecosystem services in attaining food production sustainability is highlighted in the definition.

LDN's goals are to (a) maintain or improve the long-term delivery of ecosystem services; (b) maintain or improve productivity in order to improve food security; (c) increase the land's and people's resilience; (d) seek synergies with other social, economic, and environmental goals; and (e) reinforce responsible and inclusive land

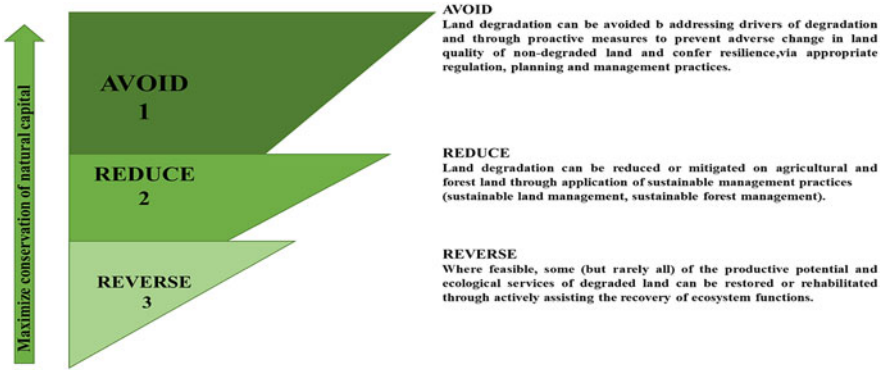

Fig. 21.1 The response hierarchy that promotes avoidance over reduction and ultimately reversal (restoration and rehabilitation) of land degradation

governance. The LDN theoretical outline is intended to be valid to all land and all sorts of land degradation, through a wide range of country circumstances, in order to be implemented in a harmonized manner by all countries that choose to pursue LDN. By defining LDN in operational terms, it helps to link the break between the idea and the real-world execution of LDN via National Action Packages. It is a development program that embodies the idea of what LDN is meant to attain and, on that basis, gives direction on how to assess land degradation, identify suitable management activities, and report on progress toward LDN.

The addition of a factor not previously addressed in land degradation management policy is enclosing and tackling the ecological problem of land degradation. To achieve neutrality, decision-makers must employ a method that allows them to weigh possible benefits and losses in terms of purpose (recording the intended consequences of land use and management choices in a neutral way) and results (evaluating the impact of those decisions). Because LDN is an original tactic to land degradation controlling, and since the land-based communal-ecological structure will be impacted by universal environmental variation, it is serious to incorporate adaptive supervision, based on knowledge, into LDN development, execution, supervising, and explanation. It includes a response hierarchy that prioritizes avoidance of land degradation over reduction and, eventually, reversal (restoration and rehabilitation) (Fig. 21.1). Among scientists and practitioners, this order is universally acknowledged. It is crucial to note, however, that it may not always be suitable owing to a lack of undisturbed area or if the return on investment in reversal (restoration) or decrease is greater than that in degradation prevention.

21.1.2 The Concepts and Framework for Climate Resilience

Climate-Resilient Agriculture (CRA) is a term that expresses the desire to increase agricultural production while also responding to climate change. Its purpose is

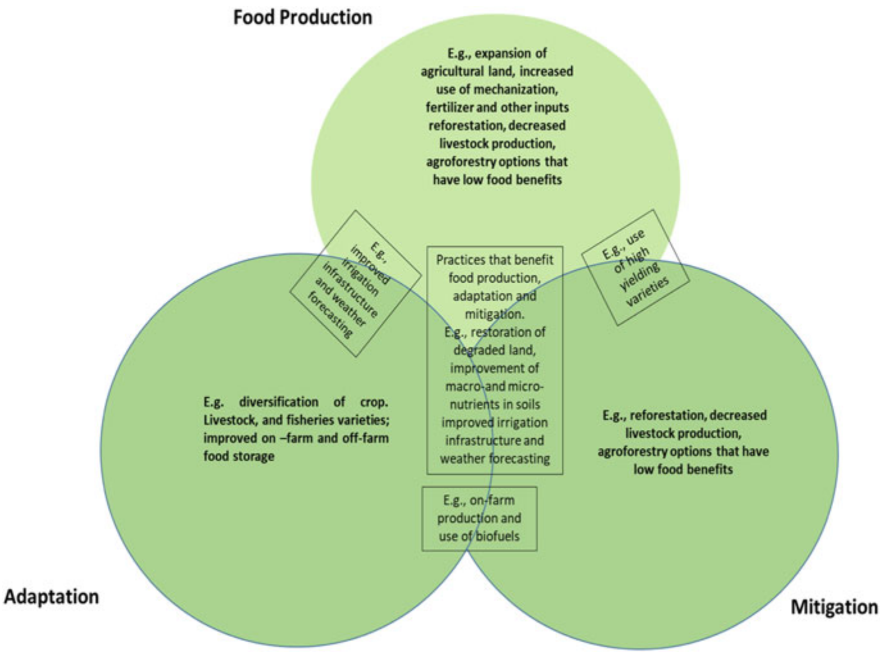

Fig. 21.2 The objectives of climate-resilient agriculture

accomplishing food safety and wider development aims in the face of weather change and rising food requirement. Plant and animal production and resistance are increased, and greenhouse gas (GHG) emissions are reduced due to CRA programs. They do, however, need problem-solving planning and coordination across three pillars: production, adaptation, and mitigation (FAO 2013). The goal of establishing further well-organized, operative, and reasonable food schemes is to solve social, financial, and ecological concerns that reflect the priorities of many countries and stakeholders (Fig. 21.2).

Despite the fact that this idea is new and continually growing, many of the methods that make up the CRA are currently in use by farmers throughout the world to deal with various risks involved with foodstuff production (Grosjean et al. 2017). Administrations in areas at jeopardy of major climate change have taken significant steps to address climate change vulnerability and its consequences through economic, social, and environmental policies, along with an official plan that aims on food safety, disaster risk reduction, and resilience building. Small farmers use various CRA practices in aquaculture (e.g., mangrove restoration and fish stock improvement), animal husbandry (e.g., biogas and composting and alternative feeding systems), vegetable production (adaptive calendars for crops and organic farming), integrated agricultural systems (agroforestry, soil, and water protection), and maize and rice crops (Global Forest Watch 2017). However, in many countries, adoption of CRA procedures remains low, owing to a lack of enhanced seed, a lack of financial resources to pay investment expenses, and a scarcity of service resources.

CRA aims to move the agriculture sector ahead in order to achieve long-term (economic, social, and environmental) growth while also addressing food security and climate problems. It is supported by three pillars (FAO 2013): (1) boosting agricultural output and managing income in a sustainable manner, (2) adapting to and creating resilience to climate change, and (3) decreasing and/or eliminating greenhouse gas emissions (GHGs) whenever practicable. The CRA strategy may be started by including climate change issues into agricultural development planning. CRA does not rely on a particular technology or practice, but rather on site-specific analyses to determine appropriate agricultural technologies and practices (FAO 2013).

21.2 LDN for Climate Resilience

Land loss and climate variation are two interrelated routes with biophysical and man-made drivers, consequences, and remedies (Herrick et al. 2013). Land degradation is defined as a "reduction or loss of biological or economic productivity and complexity of agro-ecological systems as a result of land use, or from one or more processes that may arise from human activities, such as (1) soil erosion by wind and/or water, (2) deterioration of the physical, chemical, biological, or economic properties of soil (e.g., due to salinization), and (3) long-term loss of natural vegetation" (UNCCD 1994). Natural occurrences such as drought, severe rainfall, and fire can accelerate land degradation. Communal, financial, and civil variables that support or enforce land-use burdens while lacking to equilibrium the resource of environment services with agrarian production needs may further affect these processes (D'Odorico et al. 2013). As a result, land degradation can emerge in a variety of ways across agro-ecological systems. Land degradation manifests itself in organizational alterations in tropical forestry canopy shelter and biomass decline (Miettinen et al. 2014), salinization of irrigated drylands (Qadir et al. 2014), and nutrient loss in crop lands (Quinton et al. 2010). The effects may be widespread over landscapes and regions, or they may manifest as hotspots, with significant regional variability. Farming and societal systems that are becoming less resilient can put more strain on natural procedures, guiding to a downward twisting of degradation as lands are exhausted and vegetation societies shift. As systems become powerless to survive with climatic and administration shocks, producers typically lose their adaptive potential (Marshall et al. 2014). Various factors, such as faster soil erosion, higher evapotranspiration rates, drought, and changes in biodiversity, pests, and diseases, can worsen and accelerate land degradation. The size and direction (positive or negative) of climate change impacts on agro-ecological systems may then be influenced further by the legacy of prior land degradation.

Kelly et al. (2015) developed conceptual models to describe the resilience of agricultural systems, which have shown to be useful in achieving LDN on

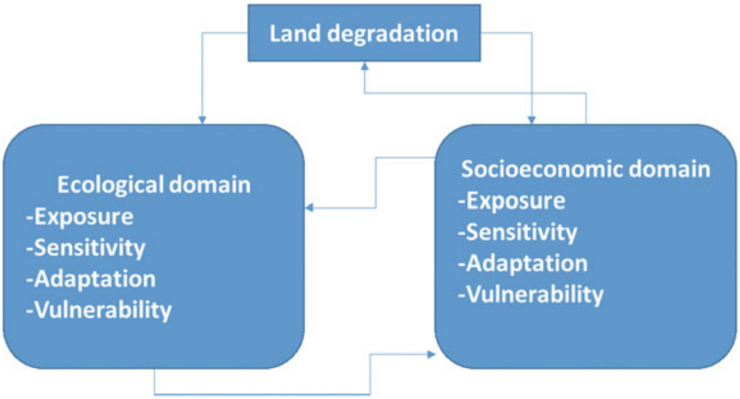

Fig. 21.3 Linkage between land degradation and agricultures sensitivity to climate change across ecological and socio-economic areas

agricultural productivity and the interconnection of those impacts with social and economic systems (Fig. 21.3) (Rist et al. 2014).

Models like these suggest that agro-ecological systems' vulnerability to climate change is determined by their exposure (degree of climate stress), sensitivity (e.g., crop responsiveness to climate change), and adaptive capacity of producers, all of which can be influenced directly or indirectly by land degradation (Fig. 21.2). Land restoration has an influence on agro-ecological systems' socioeconomic constancy. Changes in the quantity and quality of ecosystem services as a result of climate resilience will have an impact on livelihoods in a variety of businesses (from "farm to fork"). Land restoration affects adaptive possibilities even more as a result of such feedbacks (Briske et al. 2015).

Agriculture adaptation planning should emphasize continuous land restoration, as well as the possibilities that come with restoring degraded land. While some national agricultural adaptation plans recognize the need of soil protection, many still fail to include land restoration as a component of such strategy. Management choices such as changing crop types and animal breeds, as well as adjusting the timing and location of management actions, have been a major emphasis for crop and livestock production systems (Howden et al. 2007). However, land restoration can significantly enhance the efficiency of incremental and reactive adaptations, which can provide short-term advantages, whereas long-term and transformational management actions (such as land-use change) are frequently necessary (Kates et al. 2012). As an anticipatory adaptation strategy, addressing land degradation now might be a very effective way to construct productive and resilient agro-ecological systems in the future. To increase agro-ecological systems' resilience and minimize their susceptibility to land degradation and climate change, many solutions are needed at local, regional, and national levels.

21.3 Soil Organic Carbon for LDN and Climate Resilience

It's no surprise that worldwide lands have attracted the consideration of the global scientific society due to their enormous carbon-storing capability. Soils stockpile ~1500 Pg SOC in the 100 cm deep profile (FAO 2015; Lal 2018). In light of these amazing characteristics, there is little question that SOC needs particular worldwide attention in this period of climate resilience and LDN. Canada has the highest SOC reductions in the world followed by Finland Bahamas, Russia, Singapore, and Indonesia (~227.6 t C km^2 $year^{-1}$). In several nations throughout the world, major mean increases in SOC happened at the same time. During the 2001–2015 period, Canada was also the universal hotspot of mean SOC drops per $kilometre^2$ afterward Bahamas, Finland, Singapore, Norway, Russia, and Monaco. As a result, even minor countries are captured as worldwide hotspots of SOC changes by this indicator. This could be crucial for additional effective execution of land restoration and recuperation actions in more than 120 nations that have dedicated to putting LDN goals (Gilbey et al. 2019; UNCCD 2020). More importantly, our results on national SOC balances might be helpful in forging fresh pledges for the 70+ nations who have yet to commit to LDN objectives (UNCCD 2020).

21.4 Smart Agriculture for LDN and Climate Resilience

In order to achieve LDN, efforts must be made to minimize additional net losses of land-based natural capital as compared to a reference condition, or baseline. Within individual land types, where land type is determined by land potential, planning for neutrality entails counterbalancing predicted losses with steps to obtain corresponding benefits. Planning for LDN interventions should be integrated into existing land use planning. Projecting and tracking the expected cumulative consequences of land use and land management actions receives special emphasis. Land management measures that avoid or limit deterioration, as well as initiatives to reverse degradation via restoration or rehabilitation of land that has lost productivity, are all part of the LDN strategy. Avoid > Reduce > Reverse land degradation is the response hierarchy that articulates the priorities in designing LDN solutions. LDN implementation is managed at the landscape scale, taking into account all land units of each land type, as well as their interactions and ecological trajectories, in order to optimize LDN interventions among those land units in order to maintain or surpass no net loss per land type. The balance between the area of gains (significant positive changes in LDN indicators = improvements) and the area of losses (major negative changes in LDN indicators = degradation) within each land type across the landscape will be quantified by monitoring the accomplishment of neutrality. Land cover (land cover change), land productivity (net primary output), and carbon stocks are the LDN indicators (and related measures) (soil organic carbon).

To achieve climate resilience through LDN, measures must be coordinated to (1) avoid healthy land deterioration, (2) lower the amount of land degradation, and (3) repair or rehabilitate degraded land in such a way that the areas of losses and

Table 21.1 Land-use-specific rehabilitation strategy and action measures to achieve LDN

Land use type	Rehabilitation strategy	Action measures	Ecosystem
Rangelands: livestock grazing	Land degradation mechanisms and local environment influence rehabilitation techniques. Land degradation severity and kind, as well as mechanisms and causes, are taken into account.	Reduced grazing intensity; focused human intervention in the form of selected grass planting and artificial seeding, along with ecological and biological rodent population management, to restore "irreversibly" damaged rangelands	Rangeland
Agriculture	Agroecology-based aggradation-conservation agriculture for soil rehabilitation.	Farmers collaborate to design and execute locally adapted conservation agriculture (CA) methods using agro-ecological concepts and soil rehabilitation procedures to restore biomass productivity.	Cultivated semiarid ecosystem
Grazing lands and pastoral livelihood	Range restoration with local community involvement; land is then utilized by the community for income-generating enterprises.	For recovering damaged grazing grounds, participatory techniques include distributing grass seed mixtures and then tearing to break the hard crust ("rip-after-broadcast"). Communities create grazing by-laws that they agree to follow in order to safeguard reseeded areas from grazing.	Semiarid rangelands
Mining: coal, acid mine Drainage (AMD)	Engineers, scientists, and artists collaborate on this project, which is interdisciplinary, community driven, and administered locally.	Transforming a dirty terrain into a beautiful public park that also serves as a water treatment system	Appalachian Mountains, wetlands
Mining: Lignite strip mining	Interdisciplinary: Communal, financial, and ecological issues must be balanced; engineers, landscape architects, and communities should all be involved	Mined landscapes are being rehabilitated, transformed into waterscapes and energy landscapes, and reforestation is being encouraged. Land is also being sold for solar panel and wind turbine fields, and agriculture and tourism are being encouraged	Pine forests, heath-lands and medows

gains are balanced for each land type. Some sector specific remedies are tabulated in Table 21.1.

The UN's 10-point strategy for action over the decade of ecosystem restoration (DER) (2021 to 2030), as indicated by the UN: activate a global movement, create the right incentives, finance restoration on the ground, honor leadership, change behaviors, invest in research, increase capacity, promote a restoration culture, educate the next generation, and pay attention and take notes.

21.5 LDN Toward SDGs

Efforts to achieve LDN should be in support of other SDGs and global commitments (Cowie et al. 2018). However, 12 of the 16 other SDGs, including the ‘No Poverty,’ ‘Zero Hunger,’ and ‘Reduced Inequalities’ targets, have discovered trade-offs with the ‘Life on Land’ goal, of which the LDN’s aim is a component (Pradhan et al. 2017). Understanding the future spatial implications of achieving LDN is important for policies to support local communities and ecosystems in achieving as many SDGs as possible, balancing trade-offs with other SDGs or commitments, protecting local land-tenure, and identifying potential competing land claims. Previous LDN research has primarily focused on the challenges of implementation and social implications of LDN, such as investigating socioeconomic drivers of success (Salvati and Carlucci 2014), local perceptions of restoration measures and beneficiaries (Crossland et al. 2018), the progress of LDN target setting and implementation (Allen et al. 2020), or resilience assessment as a preliminary step toward LDN (Cowie et al. 2019). While LDN has been accepted at the municipal level, nothing is known about how future land use and management patterns would evolve if LDN is implemented nationally. Land use and land management (herein after referred to as land systems) respond to conflicting demands on land resources, and LDN’s implementation as a “no-net-loss” policy will interact with the other pressures on land systems. As a result, attaining LDN contending with many conflicting demands on land resources is a model for accomplishing several SDGs.

The selection of neutrality as a goal is an unusual feature of LDN that sets it apart from prior initiatives to combat land degradation. This is accomplished by combining actions to prevent or mitigate land degradation with steps to reverse previous degradation. The goal is to offset expected losses in land resources with initiatives that provide alternative advantages, such as sustainable land management and land restoration. LDN adoption contributes to SDG 15 and other associated targets (Fig. 21.4). As a result, UNDP considers LDN to be a “SDG Accelerator,” providing possibilities for achieving these objectives in a cost-effective and environmentally sound manner at the same time.

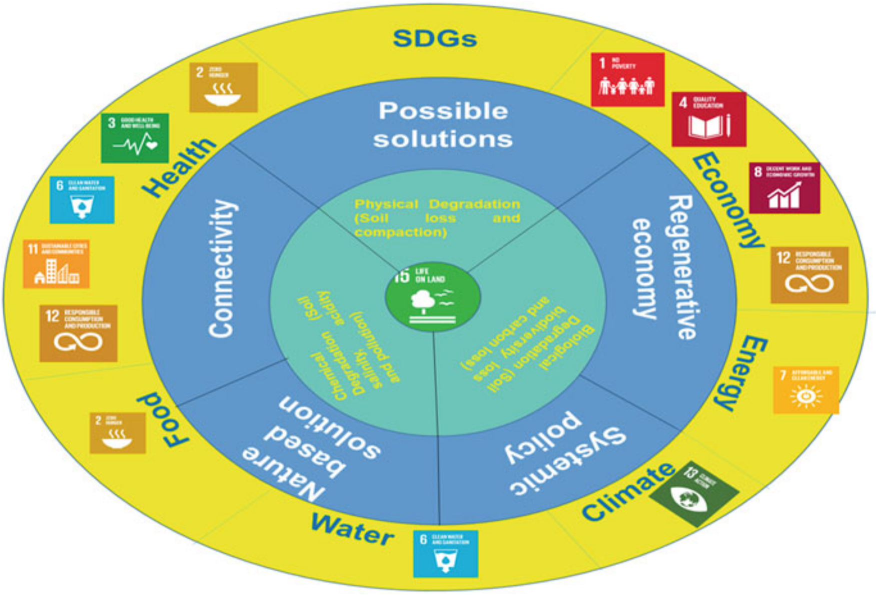

Fig. 21.4 Schematic view of linkages between the sustainable development goals and LDN

21.6 SWOTs of LDN

21.6.1 Strength

- LDN understands the need of putting in place appropriate climate change adaption strategies in order to mitigate the negative consequences.
- In terms of environmental compliance, LDN is closely linked to land management and agricultural policy.
- Monitoring LDN will be an excellent communication tool for boosting awareness among stakeholders and policymakers.

21.6.2 Weakness

- Desertification is not viewed as an issue connected to environmental preservation, due to a lack of political awareness.
- The need to include funding land degradation and desertification as an important area of policy study.
- The need to analyze the costs and benefits of land degradation and desertification measures and the necessity to conduct cost-benefit analyses.

21.6.3 Opportunities

- To reap the benefits arising from the synergies between the integration of the Conventions (UNCDD-UNFCCC-CBD) in terms of financing cross-sectoral actions.
- Developing new IT tools for LDN for collecting quantitative data.
- Promoting sustainability as part of the engagements for implementing Agenda 2030 for sustainable development.

21.6.4 Threats

- Increased land degradation will have an impact on available resources, resulting in insufficient measures for climate change adaptation and mitigation.
- Competing and conflicting potential when it comes to policy implementation on climate change, agriculture, and desertification when it comes to national priorities.
- There aren't enough finances to support cutting-edge integrative research in LDN.

21.7 Conclusion

Land is under growing pressure, and land resources are rapidly deteriorating as a result of poor use, putting even more strain on the remaining land. This necessitates a new, long-term strategy to land use and management. There is a sense of urgency; the LDN (2030) deadline is approaching quickly, especially in terms of environmental concerns. Healthy soils and land are critical for accomplishing many of the SDGs' socioeconomic goals. To achieve sustainable systems, we need wide and integrated environmental, economic, and social methods that span the socio-ecological continuum of the systems we want to preserve against deterioration and manage effectively. A systems approach is required for the SDGs to be implemented and realized successfully. The SGDs aren't 17 independent objectives to be tackled one by one. Instead, they should be viewed as intertwined objectives that can only be realized via careful planning that harnesses the natural and social systems' strength. Systems thinking, connectivity, nature-based solutions, and a regenerative economy are all intertwined in this study. The three others are built on systems thinking, which emphasizes not just feedback loops but also delayed reactions. Their combined usage will result in more robust solutions that are environmentally, societally, and economically sustainable. Long-term landscape vision and planning must include short-term management. To transition from environmental preservation to sustainable use and management, as well as from a dominating economic and function-driven approach to a natural-system-based approach, paradigm changes are required. New business models are required to achieve this, as well as a strategy that incorporates environmental, social, and economic concerns. Only by transitioning to integrated solutions based on a socio-ecological systems analysis and concepts like nature-based solutions will we be able to reverse land degradation.

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NTFP and Homegarden vis-à-vis Land Degradation Neutrality: Sustainable Livelihood and Development

22

Trishala Gurung, Mendup Tamang, Gopal Shukla, Pankaj Panwar, and Sumit Chakravarty

Abstract

Livelihoods and sustainability—both have their importance. In the general interest, the long-term potential for supporting livelihoods must be maintained and enhanced. To reconcile the short-time horizons of the desperately poor and the long-time horizons of the responsible rich, keeping sustainable livelihoods as the central objective is the way to go. Livelihood sustainability is achieved when it shows resilience when faced with external adversities and stresses; they are independent of external added support; its ability to maintain the productivity of natural resources in the long term; and finally, their outlook toward management of the resources for others and the future generations. Approaches for a livelihood that is rights based and security driven are complementary with the same aim of achieving a uniform goal. Empowering and involving the society's most vulnerable have a fundamental aim to strengthen their capacity to achieve stable and secure means of livelihood. Immediate action with a great deal of urgency was recognized in 2012 at Rio + 20 to reverse the state of land degradation and respectively achieve land degradation neutrality (LDN) in the world in the context of sustainable development. The concept of LDN defines the balance between current land degradation and land restoration has to be zero. It also aims to implement many mixtures of designs to avoid, reduce and/or reverse land degradation to achieve a state of no net loss of healthy and productive land. This chapter gives an insight on the socioeconomic capacity building, and empowering through participation of the rural and tribal dwellers via their active

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usage of NTFPs of forest and their day-to-day usage of homegardens. Empowering the rural and indigenous communities happens through various forms, out of which economic contributions through NTFPs are of major importance. The prospect of forests in the era of fast growth, industrialization, and urbanization coupled with climate change has changed from a source of national revenue dominantly from timber to NTFPs as it empowers people at the local level while timber benefits only state treasuries. Homegardens are micro-land-use system offering a way of life and livelihood with pride, and preserving cultural heritage of smallholder producers and indigenous communities of the tropical world from generation to generation. Climate change is the major threat to sustainable development the world is facing today. Conserving the remaining forest while, increasing woody biomass outside forests i.e., in agricultural landscape will viably mitigate climate change. Agroforestry-based REDD+ strategic options are now increasingly adopted around the world for mitigating climate change.

Keywords

Land degradation opportunities · Livelihood · Resilience · Capacity building

22.1 Introduction

"If immediate livelihood is a priority of the poor, sustainability is a priority of the enlightened rich." The rural poor and their priorities are many depending on the time, person, and place. Health may be a luxury form of priority for them, but the very basic and universal priority always remains to be the absolute desire for a reliable and decent form of livelihood (Chambers 1986). Therefore, Livelihood was defined by Chambers, 1986 as "the level of wealth and of stocks and flows of food and cash which provide for physical and social wellbeing and security against becoming poorer." Management of the available resources for a long period so that there is no shortage for the future generations through maintenance and enhancement of productivity is the key to sustainability. Livelihood mostly comprises the elements of material and social resources and all the activities needed for a certain way of living. Hence, livelihood security is the key to ownership and security of such resources including reserves and assets to offset risk, ease shocks, and meet contingencies (Chambers and Conway 1991).

Livelihoods and sustainability—both have their importance. In the general interest, the long-term potential for supporting livelihoods must be maintained and enhanced. To reconcile the short-time horizons of the desperately poor and the long-time horizons of the responsible rich, that is, to achieve the priorities of both together, keeping sustainable livelihoods as the central objective is the way to go (Chambers 1986). Approaches for a livelihood that is rights based and security driven are complementary with the same aim of achieving a uniform goal. Empowering and ensuring participation of poor and vulnerable strengthen the capacity for a dignified life (Chambers and Conway 1991). The argument Chambers made stated that it isn't sustainability, but rather a social vulnerability and security that raised central concerns when formulating the approach toward livelihoods. However, Chambers brilliantly managed to put forth the momentum of the environmental sustainability discussion. Later at its height during the 1992 UN Conference on Environment and Development, sustainability as a matter of vulnerability reduction and promotion of human security was reinterpreted (de Haan and Zoomers 2005).

Sen (1985, 1987), used the term "capability" to refer to the rural poor's ability to perform certain basic functions. He used the term "valued activities" to describe the quality of life and their ability to choose and perform those activities. Within his framework on the subject, he also plays with the terminology of "livelihood capabilities," which mainly includes the ability to find and make maximum use of livelihood opportunities, as well as coping with stress and shocks (i.e., gaining security). Such capabilities are not just reactive, but also proactive and dynamically adaptable. Livelihood sustainability is achieved when it shows resilience when faced with external adversities and stresses; they are independent of external added support; its ability to maintain the productivity of natural resources in the long term and finally their outlook toward management of the resources for others and the future generations (DFID 1999). Regarding the topic of livelihood sustainability, two main questions arise: Is the form of livelihood environmentally sustainable for local and global resources and various other natural assets, and is it socially sustainable? Meaning, ability of the society to cope with stress and shocks while retaining the ability to continue and improve the livelihood opportunities of its nonempowered ones. When viewed in this perspective, livelihood security is an agency-based approach to social vulnerability (Chambers 1986).

22.2 Land Degradation Neutrality

The land is extensive in terms of its availability and the services it provides. Apart from the practical terms of its usage, many view land as an inspirational pathway to their creativity and connectivity to nature. Enriching cultural value and its fruitful provision of resources such as food, fuel, water, waste purification, and various forms of employment are all a part of land utilization. As per a certain point of view, the desired state of land for one purpose might be considered degraded from another side (IUCN 2015). To frame it simply, the land provides soil and soil is a finite resource that is being lost by the value of 24 billion tonnes per year due to agricultural and other activities. Considering the services it provides daily, the soil is an essential basis for human development (Sheals 1969). Hannam (2022) states the importance of healthy soil regarding water filtration and ground water recharge, and its contribution to providing almost 90% of our food.

Land Degradation Neutrality (LDN) was officially recognized by UNCCD in October 2015 by a decision of the twelfth session of the UNCCD Conference of the Parties (COP12). Under Decision 3/COP.12, LDN is defined as "A state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems" (UNCCD 2016). Following the declaration in 2015, the UNCCD developed processes to implement the practices (Bodle et al. 2019). Immediate action with a great deal of urgency was recognized in 2012 at Rio + 20 to reverse the state of land degradation and respectively achieve land degradation neutrality in the world in the context of sustainable development (United Nations 2012). The concept of LDN defines the balance between current land degradation and land restoration has to be zero. It also aims to implement many mixtures of designs to avoid, reduce, and/or reverse land degradation to achieve a state of no net loss of healthy and productive land (UNCCD 2016).

22.2.1 Soil Loss and Land Degradation

UNCCD (1994a, b) has defined land degradation as the "reduction or loss of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes . . . arising from human activities." In a much more classic sense, IUCN (2015) specifies that land degradation is "any form of deterioration of the natural potential of land that affects ecosystem integrity either in terms of reducing its sustainable ecological productivity or in terms of its native biological richness and maintenance of resilience."

Land scarcity and increasing population are the two main characteristics in a particular area that hint at the initial causes of land degradation. Moreover, insecure land rights is also contributing to land degradation (Davies et al. 2016). Immediate responses to halt and reverse land degradation are of the highest priority to achieve sustainable use of soil (Hannam 2022). The ever-increasing pressure on natural resources such as land and soil only further aggravates the degradation process creating a greater amount of pressure on the remaining available land, calling for an urgent need to establish a sustainable approach toward the land-use systems and management (Keesstra et al. 2018).

22.3 LDN for Sustainable Future: Land Use and Improvement

Achieving a land degradation neutral world in the context of sustainable development with an understanding of its ability to catalyze financial resources from a varying degree of private and public sources was the decision of United Nations (2012). When looking from a higher perspective, land degradation includes the degradation of soil resources, vegetation, water, and another biota (Le et al. 2014). Provision of biological, social, and economic services might come to a standstill due to the effects of various levels of degradation of the particular ecosystem (FAO 2011). From the overall land surface of the earth, 60% of it is under the management of humans, and out of the total of this land, almost as much as 60% is under agricultural practices (ELD Initiative 2015). “Desertification” is the term given to a form of land degradation that takes place in arid, semiarid, and dry-subhumid areas where the extent of damage transforms a given dry land into unproductive deserts (UNCCD 1994a, b).

Despite the intensity of this phenomenon, land degradation is a perception-laden concept. The extent of it remains hazy because of the number of different methods that are used to assess the problem and also the types of environments that are included or excluded in definitions. Land degradation now definitely falls under the category of a pervasive problem that is occurring widespread across ecosystems of the managed areas. It has been observed that this phenomenon affects rural, poor areas in developing countries in disproportionate measures. A report on the state of the world’s land and water resources (SOLAW) for food and agriculture states that globally, 25% of the land is highly degraded, 8% is moderately degraded, and 36% is stable or slightly degraded, while land improvement is seen in only 10% of global land (FAO 2011). Another recent estimation states that about 52% of agricultural land worldwide is moderately or severely affected by this (ELD Initiative 2015), which in turn affects 1.5 billion people (Bai et al. 2008). Now, judging by the severe extent and its relationship with conflict risk, land degradation was recently qualified as an underestimated “threat amplifier” (Van Schaik and Dinnissen 2014).

A huge amount of economic exploitation is another aftermath of land degradation apart from the direct ecosystem and livelihood loss. By the total economic value and valuation methods, the Economics of Land Degradation (ELD) Initiative has put forward the calculation that worldwide, “the lower estimate of lost Ecosystem Service Values of USD 6.3 trillion/year is more than five times larger than the entire value of agriculture in the market economy” (ELD Initiative 2015). The estimated economic loss due to LD is US $ 434–720 per hectare and US $ 870–1450 per capita per year (ELD Initiative 2015). The failure of UNCCD to reverse desertification in widely affected countries like Africa is mainly due to reasons such as unreliable scientific evidence and weak research; a poor interrelationship between the guidelines of science and policy; a lack of inclusion of issues related to national strategies for economic growth and public security, poverty alleviation, and overall sustainable development; and a consequent lack of financial support and investment to reverse desertification (UNCCD 2007).

Land rehabilitation or land restoration is the two most studied and approved methods for slowing down the process as per the required context and outcomes. Restoration would include the process of returning the already degraded land to its original state, and rehabilitation is the process of turning the degraded land and turning it to something productive even though it was not similar to its previous functions. Therefore, when it comes to land restoration, it is often dependent on the initial uses and form of degradation of the land for the restoration to work effectively. In these cases, rehabilitation may be preferred over restoration. It is however important to point out that preventing land degradation is more cost-effective than restoration or rehabilitation. As per the SOLAW report (FAO 2011), preventive interventions are successful for 36% of the land that is stable or slightly degraded. The concept of LDN involves

- Prevention as the basic preferred step and/or trying the overall reduction of the degradation level.
- Restoration of partly degraded land that still has potential.
- Reclamation of deserted land (Chasek et al. 2014; World Business Council for Sustainable Development 2015).

Restoration should not be prioritized over balancing the proper form of measurements taken to avoid land degradation in the first place as there may be a tendency to take restoration practices as an easy way of overcoming degradation resulting in neglect that could have been avoided in the first place itself. Chasek et al. (2014) suggest that collective efforts of the local community around the globe are what counts as the saying goes, “think globally, and act locally.” The expectation from the concept of LDN is to advance the effective integration and/or mainstreaming of issues related to the degradation and restoration of terrestrial ecosystems into local, national, and regional strategies for sustainable development. Implementation will be measured and monitored in the context of set targets and indicators.

22.3.1 Drivers of Land Degradation

Achieving LDN is only possible when we understand the different factors that are in play and consequently develop solutions in tackling them. Reducing degradation and increasing land restoration is crucial in maintaining LDN. The main drivers of land degradation (Kiage 2013; Muchena et al. 2005; The Montpellier Panel 2014; Tully et al. 2015; WMO 2005) are as follows:

- Increasing population pressure: The ever-increasing population will create a massive strain on the land as the need for food, shelter, and other uses increases at the same rate, which systematically puts huge pressure on the available arable land. The balance between sustainable intensified crop production and crop expansion is a necessity in order to meet future demand while still conserving natural resources. As crop expansion is inevitable, not only should it focus on expanding into previously uncultivated areas but also include the restoration of suitable degraded areas.
- Poor land management: Lack of knowledge and experience with alternative sustainable practices and technologies on the farmers’ part are driving factors in poor land management decisions and implementation. The high cost of fertilizers and other external inputs as well as the lack of incentives to improve management practices worsens the already degraded land management practices. Small-scale rain-fed farms, especially in Africa and other developing countries in Asia, show the prevalence of such problems.
- Insecure land tenure: Unclear tenure terms, small and fragmented landholdings, and poorly implemented laws limiting people’s ability to mortgage or transfer land disincentivize farmers from investing in sustainable agricultural practices

and technologies due to the risk of limited or no return. Applying such sustainable agricultural practices and technologies is often expensive and hard to find in places where it is needed the most. Statutory and customary land tenure systems are often flawed leading up to insecure land tenure. Especially under customary systems, tenure may be loosely defined, often to the disadvantage of women who play a major role in farming.

- Poor access to markets and services: Markets plays a crucial role as it incentivizes farmers to produce excess, which in turn can be sold for the economic benefit, which further increases resources in their hand, which can be used for land development. Farmers are forced to resort to making subsistence-based management decisions and are therefore unable to utilize their land to its maximum potential, which leads to the allocation of fewer resources for land management practices when markets are poorly developed, missing, or too far away from production sites.
- Climate change: Vegetation production in dryland areas is crucial in the availability of organic matter and as cover to protect the soil. Arid regions are extremely dependent on climatic conditions. In this way, it influences various soil properties and LDN. Rainfall is considered to be the most important factor affecting LD vulnerability, followed by temperature and wind.

22.4 Capacity Building and Empowering Through Participation

Empowering the rural and indigenous communities happens through various forms of participation out of which economic contributions through NTFPs are of major importance. About a quarter of the world's population majority of whom are indigenous forest communities are directly or indirectly dependent upon forests for their day-to-day needs due to their poor economic conditions (Ahuja 2014; Shackleton and Pullanikkatil 2018). About 150–200 million people belonging to indigenous groups in over 70 countries, mostly in the tropics, depend on NTFPs to sustain their way of life, including their culture, religious traditions, and for commercial purposes (Dey and De 2010; Bauri and Mukherjee 2013). India has an indigenous population of 42 million of which some 60% live in forest areas and depends on forests (Yeshodharan and Sujana 2007) and it is estimated that in India, about 800 species are consumed as wild, edible plants, chiefly by these indigenous communities (Bandyopadhyay and Mukherjee 2009).

The prospect of forests in the era of fast growth, industrialization, and urbanization coupled with climate change has changed from a source of national revenue dominantly from timber to NTFPs as it empowers people at the local level, while timber benefits only state treasuries (Peters et al. 1989; Savage 1995). Identification, documentation, and classification of this forest resource along with its associated traditional knowledge was also considered essential for understanding and analyzing human forest interaction, its sustainable utilization, and conservation for now and to be used in near future for the ever-increasing population (Lepcha et al. 2020; Saha et al. 2014).

New views regarding the positive relation among NTFP use, forest conservation, and local livelihoods are needed that focus on a much more location- and product-specific approach, which addresses both ecological characteristics of specific NTFPs and the nature of NTFP management practices along with value chains (Belcher and Schreckenberg 2007; Shackleton et al. 2011) leading to consideration of NTFPs harvest as a strategy for sustainable use and conservation of forests (Masoodi and Sundriyal 2020; Miina et al. 2020). Combining quantitative data on resource productivity with traditional knowledge of NTFP management practices will encourage a participatory resource management process to improve the sustainability of NTFPs (Wimolsakcharoen et al. 2020). Thus, conservation and development of forests can go hand in hand with development along with benefitting the whole country (Masoodi and Sundriyal 2020). Moreover, there lies a conflict between powerful commercial interests and powerless indigenous communities for resources (Chaudhuri 2007).

The poor economic condition of indigenous forest people compels them to depend on forest products (Alex et al. 2016; Emery 1998; Masoodi and Sundriyal 2020). The income that the gatherers receive from the collection and selling of NFTPs helps these rural people in various ways. Be it for their own in-house consumption, as a gap-filling means during times when they do not have enough grains to survive on, and also to raise their household income. Rich households collect NTFPs as an additional source of their income, while poor households collect NTFPs for their subsistence survival (Ahenkan and Boon 2011). The households, which earn profit more from NTFPs, were found with bigger land holdings than those who collect it for mere survival. The rural populace, especially forest dwellers in India, depends on the forests not only to supplement their domestic requirements but also to supplement their incomes by selling part or all of their collection in local markets (Das 2005). Women were prominently involved in NTFP gathering, processing, and commercialization, which indicates its potential in women empowerment to raise their status in the household and in the community at large (Bauri et al. 2015).

Homegardens are distinct ecological and cultural units in agriculture landscapes of moist tropical regions which is linked with socio-cultural dignity of it's owners while, preserving local cultural values and indigenous ecological knowledge of the area as well from generation to generation (Cherry and Di Leonardo 2010; Zerihun et al. 2011). Homegardens can be considered as traditionally and culturally constructed spaces where families and communities exchange and conserve their undocumented biocultural tradition and ethnobotanical knowledge (Eyzaguirre and Linares 2004). Unfortunately, the contribution of cultural and socioeconomic influence on homegarden structure and diversity is yet very less understood (Perales and Brush 2005). Women play a prominent role in homegarden management, expanding and improving the practice like introducing and experimenting with new species (Vogl-Lukasser and Vogl 2004; Akhter et al. 2010) and often are custodians of seeds and knowledge that they transmit to the following generation (Brush 2000; Tonutti 2008). It was reported that women's involvement in home gardening increases and conserves homegarden biodiversity (Schadegan et al. 2013).

The structure and composition of homegardens are profoundly influenced by ecological and socioeconomic conditions, demands, tastes, knowledge, ethnicity, cultural values, customs, tradition, aesthetic preferences, and special experiments of the households (Khoshbakht et al. 2006; Sordi et al. 2008), thus bringing variations among the homegardens even in the same locality (Galluzzi et al. 2010; Agbogidi and Adolor 2013). Crops or their landraces were preferred based on their suitability to the environmental conditions of the location, their capacity to produce stable yields even in unfavorable conditions, field size, and use (Negri 2003, 2009; Andonov and Ivanovska 2004). The more the land held, the larger the homegarden and consequently the more diverse the garden is (Tesfaye et al. 2010; Seta et al. 2013). The owner adopts the management practices for his/her homegarden based on socio-psychological and situational factors, which also indirectly affect the carbon sequestration potential of the homegarden as the decision on homegarden management practice is to meet the household livelihood demand only and not to influence the carbon sequestration *par se* (Saha et al. 2011). Studies also reported a nonsignificant relationship between socioeconomic factors like schooling, household type, and land tenure situation on homegarden production and use (Galluzzi et al. 2010; Agbogidi and Adolor 2013).

In the humid tropics of West Bengal, higher species richness was documented in the village homegardens than in the urban homegardens due to scarcity of land and restriction in the choice of species (Panwar and Chakravarty 2010). Species diversity in urban homegardens was less than in their rural counterparts as the products the species supply are available in the urban market discouraging the owners to maintain the species in their gardens, whereas the unavailability of sustenance products in rural forces the owners to maintain the species in their gardens (Wezel and Ohl 2005). Vegetables, fruits, and timber species were less preferred than ornamentals and medicinal plants in the urban homegardens due to their availability in the urban markets, while vice versa is true for rural homegardens (Christanty et al. 1986; Panwar and Chakravarty 2010). Ornamental plants and commercial fruit trees were preferred over traditional plant species in Mayan homegardens closer to the cities (Rico-Gray et al. 1990). Market opportunities and commercialization providing income opportunities are now threatening the existence of traditional crop varieties and even the practice of home gardening (Azurdia et al. 2001; Birol et al. 2005; Bravi et al. 2002; Negri 2005; Portis et al. 2004; Sordi et al. 2008).

The structure and composition of the home gardens were also reported to be influenced by the interaction among different homegardens characteristics like household features, income, literacy, age of household, labor inputs, time devoted to home gardening, and agrobiodiversity indices (Yongneng et al. 2006; Schadegan et al. 2013). In Sri Lanka, 65% of the total home garden plant diversity was explained by factors like education, management, landholding, household expenditure, and primary conservation practices (Kumari et al. 2009). More specifically management, education, and garden size significantly improve the diversity of edible, medicinal, and commercial plant species in the Sri Lankan homegardens, while special techniques employed significantly increased ornamental and commercial plant species diversity.

Owners of humid tropical home gardens in rural areas of West Bengal preferred more fruit species like *Mangifera indica* and *Musa* spp. over others, while in the urban homegardens, *Cocos nucifera* and *Areca catechu* were more preferred (Panwar and Chakravarty 2010). Urban homegardens have a less available area where palms were preferred due to their small canopy and taller heights, which allow sunlight to understorey species. Village homegardens were preferred with fruit trees to satisfy the nutritional demands of the household or even sold (Panwar and Chakravarty 2010). Homegardens of indigenous residents adjacent to Kaziranga National Park, Assam, though were larger than the home gardens of the immigrants but produced four times lesser than the latter (Shrivastava and Heinen 2005). This was because immigrants who inhabited low-lying areas much closer to the park than the natives were with uncertain land tenureship and were subjected to a higher risk of crop damage by wildlife and floods. These garden owners insured their risk of threat by preferring crops with higher economic returns. This indicates that plant associations in home gardens were designed in relation to climatic/locality and socioeconomic factors to fulfill a variety of complementary functions (Karyono 1990; Linger 2014).

22.5 Carbon Stock in Homegardens

Climate change is the major threat to sustainable development the world is facing today (Salunkhe et al. 2018; Sheikh et al. 2020). Conserving the remaining forest and increasing woody biomass and rotation length through sustainable management both in forest and outside forests will viably mitigate climate change as sink and avoided deforestation (Pandey 2002; Shi et al. 2018). Agroforestry-based REDD+ strategic options are now increasingly adopted around the world for mitigating climate change (Shi et al. 2018).

Agroforestry including home gardens is recognized as a viable option by Kyoto Protocol (article 3.3) not only as a carbon sink but also for its potential in carbon trading (Pala et al. 2020). Globally, the highest above-ground carbon sequestration (12.8 t Mg ha^{-1} year^{-1}) was reported when land use changed from degraded land to improved fallow, while in the soil, it (4.38 Mg ha^{-1} year^{-1}) was from grassland system to silvopastoral system (Feliciano et al. 2018). This is because homegardens are a tree-based land management system in an agricultural landscape that can store higher carbon with higher net gains in carbon stock than any other agricultural-based land uses (Jha 2018).

Tropical homegardens were reported with a carbon stock of 0.7–6.3 Gt with a sequestration rate of 1.5–3.5 Mg C ha^{-1} year^{-1}, which can be tripled in 20 years to 70 Mg C ha^{-1} (Watson et al. 2000; Montagnini and Nair 2004). Homegardens both offset deforestation (Nair and Nair 2003) and improve the soil carbon sink (Zomer et al. 2016). Homegardens are more permanent, stable, resilient, and productive agroecosystems due to their higher plant diversity and density with never ever complete removal of their biomass (Shukla et al. 2017). Carbon stored in homegardens is a function of its size, site quality factors, species composition or choice of species, management practices, and socioeconomic condition of the owner along with cultural and traditional practices followed by the owner's society (Wardah et al. 2011). Soil organic carbon (SOC) of homegardens is also influenced by woody species composition, litter quality, and quantity, which vary with locality factors and land management (Scotti et al. 2015; Newaj et al. 2016). Higher organic matter in the homegarden soil due to higher plant and root density promotes soil carbon build-up (Beets et al. 2002; Schmidt et al. 2011), while the presence of trees also helps continuous carbon build-up even in the deeper soil layers of homegardens making it a permanent sink (Mbow et al. 2014).

Overall, within the one-meter soil profile, the amount of ecosystem carbon quantified was higher for older home gardens of Mizoram but younger ones had a higher CO_2 mitigation potential rate (Singh and Sahoo 2015, 2018). Smaller Keralite homegardens were reported to store more carbon than the larger home gardens (Kumar and Nair 2011). Variation in species composition significantly influenced the carbon sequestration of Kashmir Himalayan homegardens (Dar et al. 2019a, b). The order of carbon storage in different land uses of the Philippines was old-growth forest > secondary forest > mossy forest > mangrove forest > pine forest > tree plantation > agroforestry including home garden> brush land > grassland (Lasco and Pulhin 2003). In Sri Lanka, homegardens located in wet zones stored a higher amount of carbon than the homegardens located in dry zones due to higher tree density (Dissanayake et al. 2009). Homegardens in Panama though were estimated to store lesser carbon than the managed forests but stored more than pastures (Kirby and Potvin 2007). Similarly, a higher amount of ecosystem carbon stock was quantified for homegardens than the woodlot agroforestry systems (Mulatu 2019; Semere 2019), while either it was comparable to forests (Siyum and Tassew 2019) or much lesser than forests (Mengistu and Asfaw 2019) and coffee-based agroforestry systems (Betemariyam et al. 2020) in Ethiopia.

According to the land sparing or intensification hypothesis, agroforestry can spare forest lands by avoiding deforestation due to its established noncarbon benefits like improving soil fertility and productivity along with conserving biodiversity (Brandon and Wells 1992; Hoang et al. 2013). Fuelwood, charcoal, and timber are the prime drivers of deforestation (Chakravarty et al. 2012), so improving timber and fuelwood production in the agricultural landscape will spare the forests from avoiding deforestation (Robiglio et al. 2011; Pala et al. 2020). Rotational woodlot systems were reported to release pressure from forest degradation resulting in carbon offset producing 46–102 Mg wood biomass ha^{-1} (23–51 Mg C ha^{-1}) in a 5-year rotation sufficient enough to satisfy household fuelwood demand in the semiarid region of Tanzania (Kimaro et al. 2011). Trees outside forests in Nepal at farmlands were reported to contribute to the national carbon budget and therefore were recommended for consideration for performance-based payments in the forestry sector of REDD+ (Bhandari et al. 2021). In Sub-Saharan Africa, carbon revenue profit in agroforestry farming was 2.5 times more than in monoculture farming, which was remunerative enough to encourage the smallholders to adopt agroforestry with proper management and institutional support to deal with transition and transaction costs (Waldén et al. 2020).

22.6 Conclusion

The natural resources require more systematic research on various aspects and a framework for sustainable management and conservation. Ensuring fair income to the NTFP collectors can diversify the forest-based industry to NTFP-based cottage industry empowering the rural and fringe communities. The traditional ecological knowledge of the rural and fringe community can be utilized scientifically to achieve sustainable development goals. Presence of global carbon markets has provided an additional opportunity to the small land owners to consider carbon storage potential while managing their land may be through agroforestry practices, which otherwise was less profitable and now is more attractive. Homegardens can be targeted with ecological, social, and economic dimensions for designing socio-ecological sustainable ways of livelihood. The need is to attract farmers to adopt agroforestry practices in their land to satisfy their daily livelihood needs and empower them to enter the carbon market, which requires research on biophysical and socioeconomic issues of carbon sequestration in agroforestry. Empowering the small landholders with capacity building to participate in the carbon trading through their traditional zero energy farming practice of homegardening will go a long way not only in improving livelihoods and ecological sustainability but also taking care of land degradation neutrality including viably offsetting carbon emission. This needs policy, institutional and infrastructural support for capacity building of the non-empowered communities and their local institutions. Holistic institutional intervention is needed to plan biocarbon projects linking climate finance with the asset-poor smallholder forest frontier and rural communities projecting their empowered livelihood through improved productivity, income, market accessibility, sensible institution, assured food security, and resiliency to climate change.

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Indian Forests: Sustainable Uses and its Role in Livelihood Security

23

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Abstract

Forests in India perform an important role in the economic and sociocultural life of the tribal people who live in and around the forests, as they support rural livelihoods and food security. India has a wide variety of forest types, including tropical evergreen, semievergreen, moist deciduous, dry deciduous, subtropical montane, temperate, alpine scrub, and mangrove forests, and the dominant plant species includes both deciduous and evergreen tree species like *Shorea robusta, Tectona grandis, Duabanga grandiflora, Mangifera Indica, Terminalia myriocarpa, Diospyros melanoxylon, Pterocarpus marsupium, Butea monosperma*, and *Madhuca longifolia*. Timber, fodder, fuelwood, and other variety of nontimber forest products (NTFPs) including wild edibles, oilseeds, medicinal plants, different types of resins, spices, fibres, and a variety of construction materials like bamboo, rattans, palms, and grasses are the most commonly extracted forest products of economic significance. Overgrazing and overexploitation of essential plant resources, as well as a lack of awareness and scientific understanding about plants and their harvesting, represent serious dangers to the existing plant populations of economically important plant species. The collection of rare and endangered plant species from natural settings for diverse experimental reasons, along with the natural enemies including pests and diseases, invasive weeds, and unsustainable harvesting for various economic and

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livelihood purposes, poses a threat to the existence of the wild population. Recognizing the ongoing depletion of these precious resources, proper management strategies should be undertaken to satisfy the growing demand and ensure their long-term viability for livelihood security and economic upliftment.

Keywords

Forest goods and services · Forest policies · Livelihood security · Indian forests

23.1 Introduction

India is one of the world's 17 mega-biodiversity nations and the Indian subcontinent hosts four biodiversity hotspots with high endemism and ever-increasing human pressure leading to habitat loss (Saikia and Khan 2018). Forests are the second-largest land use after agriculture, accounting for 21.67% of the country's total geographical area (FSI 2019). The rainforests of the Western Ghats, Andaman and Nicobar Islands, and northeastern states, the coniferous hill forests of the Himalayas, and the desert scrub and thorn forests of Rajasthan and Gujarat are among India's forest types due to its diverse geographical, climatic, and edaphic conditions (MoEFCC and World Bank 2018; Reddy et al. 2015; Singh and Chaturvedi 2017a, b). Tropical dry deciduous forests cover the most land area. They are found in large parts of the Central Highlands and Deccan Plateau in central and southern India. In contrast, tropical moist deciduous forests cover the second most land area and can be found in all regions except the Himalayas and drier parts of northern and western India (Reddy et al. 2015) (Table 23.1).

Forests help to provide sustainable farming by stabilizing soils, regulating climate and river flows, and sustaining water quality, flood control, pollination, disease biological control, and overall forest productivity (Bahuguna and Bisht 2013). Forests not only help in driving sustainable development but also act as a natural stabilizing agent for climate change by regulating the global carbon cycle significantly (Krishnan et al. 2020). Degradation of forests is due to anthropogenic and natural causes like overexploitation of forest resources, lack of scientific information on current population status and exploitation, habitat alteration, and uniqueness, a limited distribution range, overgrazing, attack by pathogens, herbivores, and seed predators lead to biodiversity loss, survival pressure over fragile ecosystems, soil fertility loss, land degradation, erosion, and excess water runoff into the lowlands (Kumar and Saikia 2020a). India has formulated and implemented several policies, and programs with implications on carbon sink, forest management, and biodiversity conservation (Ravindranath et al. 2008) for the preservation and protection of forests in India.

Forests are essential for ensuring livelihood security to the forest-dependent tribal communities from generation after generation and simultaneously, protecting them from further natural and anthropogenic degradation (Roy 1982). Sustainable management of natural forests helps in reducing poverty and escalating economic growth

Table 23.1 Major Forests groups and type groups of India (Sources: Champion and Seth 1968; Singh and Chaturvedi 2017a, b)

Major forest groups	Forest type groups	Distribution	Dominant species
Moist tropical forests	Group 1: Tropical wet Evergreen forests	Maharashtra, Karnataka, Tamil Nadu (TN), Kerala, Andaman, West Bengal (WB), Assam, Odisha, and throughout northeast (NE) India	*Dipterocarpus grandiflorum, D. costatus, Hopeaodorata, Shorea assamica, Artocarpus chaplasa, Mesuaferrea*
	Group 2: Tropical Semievergreen forests	Maharashtra, Goa, Karnataka, Kerala, Andaman, Assam, WB, Odisha	*Xylia xylocarpus, Terminalia paniculata, T. tomentosa, Schleichera oleosa, Syzygium* spp., *Cinnamomum* spp.
	Group 3: Tropical moist deciduous forests	Madhya Pradesh (MP), Chhattisgarh, Maharashtra, Karnataka, TN, Kerala, Andaman and Nicobar, Uttar Pradesh (UP), Bihar, Odisha, WB, Assam	*Tectona grandis, Terminalia* spp., *Pterocarpus marsupium, Schleichera oleosa, Shorea robusta, lagerstroemia* spp.
	Group 4: Littoral and swamp forests	In coastal regions of WB, Odisha, Andhra Pradesh (AP), TN, and Gujarat	*Manilkara littoralis, Casuarina equisetifolia, Rhizophora mucronata, R. candelaria, Avicennia alba, Ceriops roxburghiana*
Dry tropical forests	Group 5: Tropical dry deciduous forests	MP, Gujarat, Maharashtra, AP, Karnataka, TN, Punjab, UP, Bihar, Chhattisgarh, Jharkhand, Odisha	*S. robusta, T. grandis, Anogeissus latifolia, T. tomentosa, Buchanania lanzan*
	Group 6: Tropical thorn forests	Maharashtra, AP, Karnataka, TN, MP, UP, Rajasthan, Gujarat, Punjab	*Acacia catechu, A. leucophloea, A. arabica, Capparis deciduas, Prosopis spicigera, Ziziphus mauritiana, Z. nummularia*
	Group 7: Tropical dry evergreen forests	Karnataka, AP, TN	*Manilkara hexandra, Mimusops elengi, Diospyros ebenum, Memecylone dule, Drypetes sepiaria*
Montane subtropical forests	Group 8: Subtropical broad-leaved hill forests	Maharashtra, Karnataka, TN, Kerala, Rajasthan, MP, Odisha, WB, NE India	*Eugenia wightiana, Memecylon sp., Quercus vercus, Q. serrata, Castanopsis tribuloides C. indica, Alnus nepalensis*
	Group 9: Subtropical pine forest	Western and central Himalaya, Punjab, Uttarakhand (UK), Sikkim, Meghalaya, Manipur	*Pinus roxburghii, P. insularis, Quercus griffithii, Rhododendron arboreum, Syzygium cumini*

(continued)

Table 23.1 (continued)

Major forest groups	Forest type groups	Distribution	Dominant species
	Group 10: Subtropical dry evergreen forests	Shivalik hills, Western Himalaya, Jammu, and Punjab	*Olea cuspidata, Acacia modesta, Punica granatum, Dodonaea viscosa*
Montane temperate forests	Group 11: Montane wet temperate forests	TN, Kerala, eastern Himalaya, WB, Assam, NE India	*Ternstroemia gymnanthera, Eugenia calophyllifolia, Meliosma wightii, Rhododendron nilagiricum, Quercus lamellosa, Q. pachyphylla, Machilus edulis*
	Group 12: Himalayan moist temperate forests	Jammu and Kashmir (J&K), Punjab, Himachal Pradesh (HP), UK, WB, Assam, eastern Himalaya	*Abies densa, Cedrus* spp., *Picea spinulosa, Pinus wallichiana, Tsuga dumosa, Quercus dilata, Q. lamellose*
	Group 13: Himalayan dry temperate forests	J&K, Punjab, HP, UK, Sikkim, NE India	*Cedrus deodara, Pinus gerardiana, Juniperus wallichiana, Abies spectabilis, Quercus ilex, Acer pentapomicum*
Subalpine forests	Group 14: Subalpine forests	J&K, Punjab, HP, UK, WB, NE India	*Abies spectabilis, Pinus wallichiana, Betula utilis, Rhododendron campanulatum, Quercus semecarpifolia*
Alpine forests	Group 15: Moist-alpine scrub	Kashmir, UK, Sikkim, Manipur, Western and eastern Himalayas	*Rhododendron campanulatum, R. wightii, R. molle, R. thomsoni, Betula utilis, Sorbus foliolosa*
	Group 16: Dry-alpine scrub	HP, Kashmir, UK	*Eurotia ceratoides, Juniperus wallichiana, J. communis, Artemisia maritima, A. sacrorum, Lonicera* spp., *Potentilla* spp.

(Islam et al. 2015). Forests provide the subsistence needs of ~300 million tribal and forest-dwelling rural poor in India, including trade commodities that produce monetary revenue (Angelsen et al. 2014). More than 50% of the rural tribal population residing in our country (GoI, TRIFED 2019) is dependent on forest and forest resources for their sustainable livelihood (Haque 2020). The living standard of rural people in India mainly depends on the resilience of forests and with the agricultural intensification, the forest productivity is decreasing, which affects their sustenance (Quli et al. 2017). In India's forest-dwelling rural households, forest-related subsistence and monetary income frequently account for a larger overall income (Angelsen et al. 2014; Belcher et al. 2015). Approximately 40–60% of the total annual earnings of tribal people are basically based on the collection and selling of forest goods and forest-based products (GoI TRIFED 2019). Realizing the importance of forest and forest resources, this chapter attempted to provide an overview of the Indian forest and its sustainable uses for the livelihood security of the forest-dwelling rural Indian populations.

23.2 Indian Forests and Forest Cover Change

Despite possessing only 2.5% of the world's total geographical area and 1.8% of the world's total forest area, India is home to 16% of the world's people (Maan and Chaudhry 2019). India's overall forest cover is 7,12,249 sq. km (of which mangrove contributes 4975 sq. km), accounting for 21.67% of the country's entire geographical area (FSI 2019), but unfortunately, the overdependence and unsustainable harvesting of the forest resources by large forest-dependent populations have degraded 1.6 M ha of forest cover (INAB 2019). A comparative assessment of forest cover change from 1991 to 2019 in the states and UT of India as per SFR (FSI 1991, 2019) showed a drastic change in forest cover (Fig. 23.1) with an increase of 73,067 sq. km, that is, 2.23% of the total forest cover. The dense forest cover of India has increased by 0.68%, while the open forest cover has been enhanced by 1.63%, and scrubland has decreased by 0.41% during the last three decades (1991–2019) (Fig. 23.2).

Dense and open forests are increasing at a steady rate in all three decades (1991–2001, 2001–2011, and 2011–2019). Simultaneously, the nonforest cover is constantly declining from 2001 (79.45%) to 2011 (77.67%) and 2019 (76.92%). Forest cover change is reaching near 1800 sq. km, which is more than 20% in some states and UTs like Delhi, Goa & Daman Diu, Chandigarh, West Bengal, and Kerala have marked increased forest areas by more than 5%, whereas forest-rich UTs and states like Andaman &Nicobar island (10.68%), Nagaland (10.81%), Mizoram (4.06%), and Manipur (4.64%) have decreased forest areas as compared to 1991. Forest-rich north Indian states have seen tremendous deforestation in the past 30 years with ~14,000 sq. km of forests destroyed to accommodate various economic and industrial projects (Roy 2020). On the other hand, various forest-poor states and union territories such as Delhi, Haryana, Kerala, and West Bengal showed an increase in forest cover (FSI 2019), of which Delhi showed the highest percent change in forest cover during the period 1991 to 2019 due to successful implementation of several afforestation and reforestation programs such as urban forestry, social forestry, farm forestry, extension forestry, etc., and other forests and sustainable development programs (FSI 2019). Better conservation measures, protection, afforestation efforts, tree plantation drives, and agroforestry may be responsible for the increase in forest cover or improvement in forest canopy density (Roy 2020). The 2019 joint progress report on forest restoration by the International Union for Conservation of Nature (IUCN) and the Ministry of Environment, Forest and

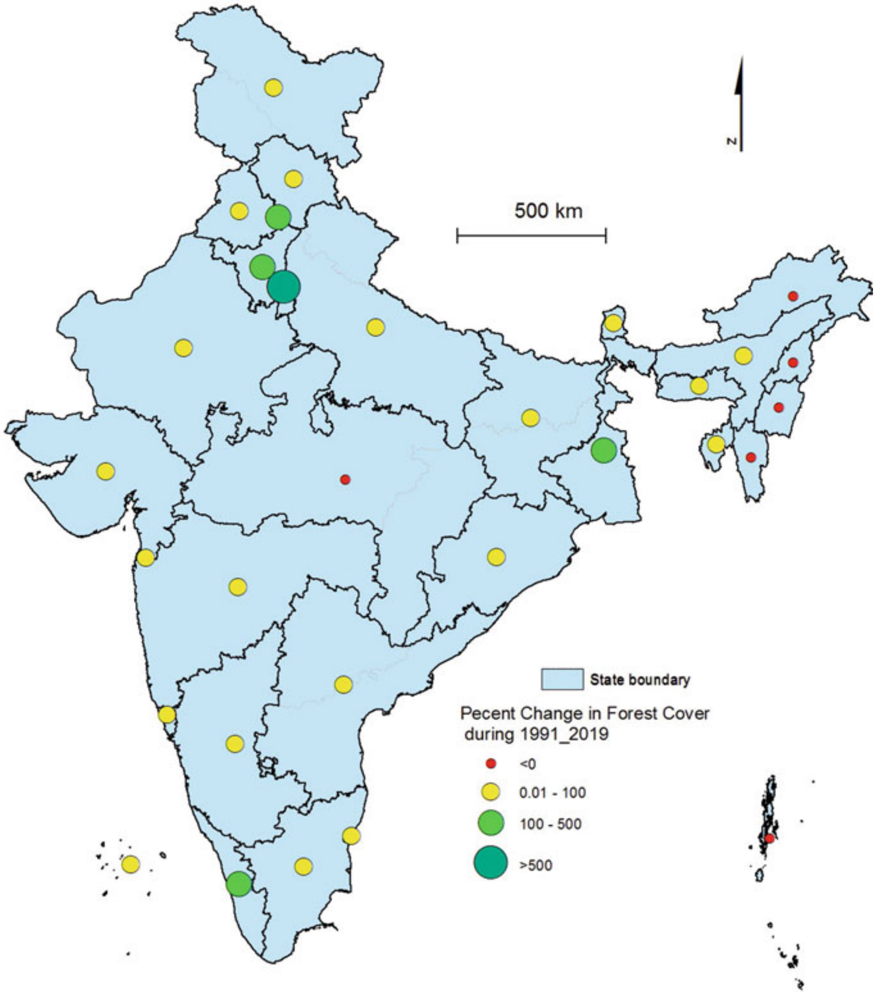

Fig. 23.1 Forest covers change during 1991–2019 (FSI 1991, 2019)

Climate Change (MoEFCC) shows that, despite some percent of land loss over the last few decades, some 9.8 M ha hectares of deforested and degraded land have been restored since 2011 (IUCN 2021).

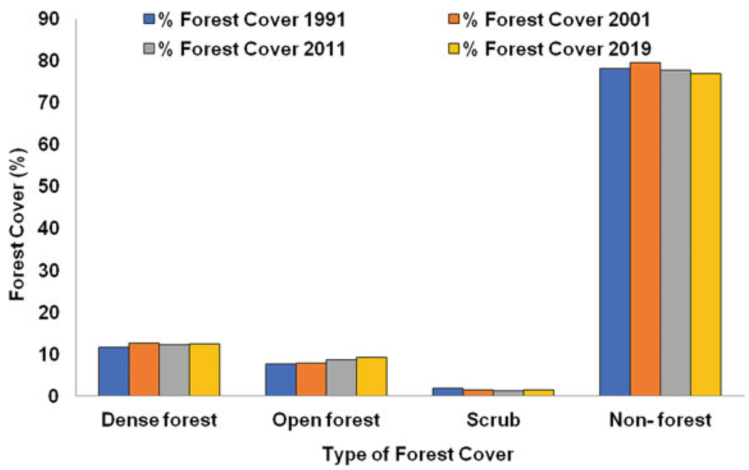

Fig. 23.2 Change in forest cover in different forest types during 1991–2019

23.3 Climate Change Impacts on Forests and Its Role in Climate Change Mitigation

Climate change is widely acknowledged as a major man-made global environmental threat with significant contemporary impacts on biodiversity patterns (Sahney et al. 2010) and will continue to be a primary driver of biodiversity change in coming years as well (Sala et al. 2000). Climate change has a direct effect on decreasing biodiversity (Loarie et al. 2008) by reducing the species variability and a higher rate of species extinction (Franco et al. 2006), affecting biological systems' ability to serve human requirements (Dar et al. 2020). Industrialization, urbanization (Dar et al. 2020), and intensified agricultural activities are considered as the main factors for shifting the land use and land cover pattern (Ahmad et al. 2018) by increasing constraints on habitat, landscapes, and biodiversity (Stanners and Bordeaux 1995). Forest fire is also a phenomenon that is enhanced by the changing climate and ultimately ends in desertification (Abrams et al. 2018). Plants respond to climate change in four ways: phenotypic plasticity, which allows species to survive in changing climates, evolutionary adaptation to new climates, emigration to better habitats, and extinction (Bawa and Dayanandan 1998; Saxena and Purohit 1993). Climate change influences life cycle events of plants along with their distribution pattern in altitudinal, latitudinal, and longitudinal gradients (Lynch and Lande 1993; Parmesan and Yohe 2003). Phenology is being used to determine the sensitivity of a species to changing climate (Bharali and Khan 2012). Climate change is also responsible for reducing genetic diversity by changing genetic drift, migration of species, and directional selection of species (Rinawati et al. 2013). Different species of plants are moving their habitat ranges in elevation and latitude in response to changing scenarios of climatic circumstances (Saikia et al. 2016). Poleward shifting of species with respect to climate change again enhances the diversity of invasive plant species and simultaneously reduces the native plant diversity (Katz and Ibáñez 2016).

Forests are the world's most prominent terrestrial ecosystems, serving as a shelter for a variety of terrestrial biodiversity (Hui et al. 2017; Pan et al. 2013). Highly biodiverse forests can reduce the rate of global climate change and boost resilience, because they are rich in species (Bruno et al. 2003). Forests are appealing in terms of mitigating global climate change as they are considered the most productive among the terrestrial ecosystems and have a woody composition that lasts a long time (Nabuurs et al. 2007). Forests also provide a variety of important ecosystem services that help to mitigate the consequences of climate change by limiting water and wind erosion, shading lower-story vegetation, and conserving soil moisture through litter accumulation (Espeland and Kettenring 2018). Tropical forests and savannas account for ~60% of worldwide terrestrial photosynthesis each year (Field et al. 1998). Carbon is divided fairly evenly between plant and soil in tropical forests, 84% of carbon is present in soil organic matter, and only 16% in active living biomass in high latitude forests, particularly in the boreal zone (Malhi et al. 1999). Forests help in balancing both ecological and economical aspects with reference to changing climate (Dar et al. 2020). Besides, forests have altered the gaseous makeup of the atmosphere, which has influenced global temperatures and weather patterns (Sigman and Boyle 2000; Zachos et al. 2001). By trapping particulate matter on the leaf surface, forests can help to reduce pollution levels (Chiabai et al. 2018). Terrestrial ecosystems, mainly forests, also manage to reduce CO_2 up to 1/third level released due to anthropogenic activities to the environment (Grassi et al. 2017). Plants have also been shown to lower the speed and severity of cyclones and storms, both of which can result in flash floods (Hu et al. 2015).

23.4 Impact of Forest Products on Livelihood and Their Sustainable Uses

Approximately 33% of forest cover of the earth's surface area (FAO 2015) serve a critical role in preserving the species diversity along with key ecological products and services in order to keep human life viable (Daily 1997). It performs a variety of regulatory functions, including maintaining air, water, and soil quality, controlling climate, floods, pollination, and biological control of diseases and pests (Bahuguna and Bisht 2013). A major portion of India's tribal population relies on forests for survival, as marketable goods provide financial income when markets are available at a favorable distance and also forest goods act as raw materials for a range of processed industrial products (Angelsen et al. 2014). Forest products can meet a variety of human needs, including material needs like wood, paper, ecological needs like soil erosion check, mitigating climate change, and socioeconomic needs like providing employment to the community, business opportunities, wealth creation, recreational needs, and sources for both individual and family (Richardson 2006). In wood-based and small-scale forest-based enterprises, the use of local skills and village-level technology provides secondary employment and livelihood prospects for people (Islam and Quli 2016). Forest products are valuable cultural and spiritual resources in addition to being providers of food, medicine, and finance (Rist et al. 2012). Besides, people living in and around forests rely on NTFPs for their survival with limited nonagricultural earning options (Quang and Tran 2006) as it contributes significantly to the rural livelihoods of India's forest-dependent inhabitants (Chandrasekharan 1994; FAO 1991).

Around 80% of the population in developing countries relies on NTFPs for their nutritional and medicinal requirements (Brack 2018). Almost 70% of NTFPs are collected in the tribal belt in India (Pandey et al. 2016). NTFPs-based small-scale enterprises contribute up to 50% of revenue, 55% of employment in the forestry sector, and 20–30% of rural inhabitants are dependent on NTFPs collection, harvesting, processing, and marketing (Joshi 2003). The collection of tendu leaves employs over 7.5 million people in India for roughly 90 days each year (Mistry 1992). The promotion of NTFPs for community development, poverty reduction, livelihood security, and socioeconomic development of forest-dependent communities is driven by sustainable collection, usage, and commercialization (Shit and Pati 2012).

NTFPs are typically the key motivators for local forest management participation (Ahenkan and Boon 2010). Systematic collection of NTFPs may boost the economic prospects of forest dwellers, while also reducing their overreliance on timbers, which may be an effective way to address the problem of forest degradation (Ghoshal 2011). The quantity of NTFPs obtained by the forest dwellers varies greatly according to season, access, and alternatives (Warner 2000). Forest products provide 20–25% of personal wages to forest dwellers in developing nations (Vedeld et al. 2007) and simultaneously provide safeguards during times of crisis and food shortages (Shackleton and Shackleton 2006). NTFPs are a major source of livelihood based on forest restoration in sustainable forest management as NTPFs serve as a means to alleviate the need for environmental conservation and the financial, social, and livelihood needs of communities (Delgado et al. 2016).

One facet of sustainable forest management is the involvement of the forestry sector in national economies (FAO 2021). More than 25% of the livelihood security of the global population depends on valuable and renewable natural resources (Kaur and Mittal 2020). Increased timber commerce has aided economic growth and poverty reduction in various developing countries (Anonymous 2016). Harvesting timber and fuelwood boosts the rural economy by contributing significantly to increased self-sufficiency, family income, and job opportunities (Hall et al. 2015). Timber collection and sale are the primary sources of revenue for the forest-dwelling population in the majority of developing nations (Belcher et al. 2015; Htun et al. 2017).

Wild edible plants are a rich source of medications that can be used to cure a variety of ailments (Bako et al. 2005) and also to supplement the nutritional requirements of rural tribal populations (Kumar and Saikia 2020). In rural areas, herbal medicines play an important role, and numerous locally made drugs are still utilized as household cures for a variety of disorders (Qureshi and Ghufran 2005). Local healers or indigenous groups have vast expertise and information about each species, as well as a deeper understanding of medicinal flora, formulations, and therapeutic powers that can be utilized to cure a variety of disorders (Saikia and Khan 2011). For poor rural people, the utilization of medicinal herbs and aromatic plants as additional food and ethnomedicine, as well as the potential financial gain, is an enormously essential source of livelihoods and resilience (Shrestha et al. 2020). Medicinal plants are found in India's Himalayas, sea, desert, and rainforest ecosystems, and plant compositions are used in ~95% of traditional systems such as Unani, Ayurveda, Homeopathy, and Siddha (Satyavati et al. 1987). People in developing nations such as Bangladesh (90%), Myanmar (85%), India (80%), Nepal (75%), Sri Lanka (65%), and Indonesia (60%) have a strong belief in traditional herbal therapies as it has few side effects and is very cheap (Salam et al. 2016).

23.5 Policy Interventions for Sustainable Forest Management

Policies play a critical role in preserving forests and meeting people's needs (Pratap 2010; Saxena 1999), while forest policies basically deal with wood production and conceptually on the subject of sustainable yield (Shah 2020). Systematic forest management and forestry policies have been undertaken since 1855 by the British colonialists with the Charter of Indian Forests (Roy 2020). The National Forest Policy of 1952 formally acknowledged the protective effect of forests and established a national aim of 33% forest cover that plays a major role in maintaining the ecological balance and simultaneously meeting the demand of stakeholders by the initiation of the first policy in India through production forestry (GoI, National Forest Policy 1952). The National Forest Policy of 1988 resulted in a shift in perspective from revenue-driven forest management to conservation-driven forest management (Joshi et al. 2011). The National Forest Policy (1988) (GoI, National Forest Policy 1988) established the collaborative management strategy among village communities, nongovernmental organizations, and state forest departments bolstering ecological security, sustainable forest management, and participatory forest management, with the purpose of maintaining ecological balance and environmental stability, particularly atmospheric equilibrium, for the survival of all life forms (Rawat et al. 2008).

Indian Forest Act, 1927, covers all the laws related to forests, regulates forest production, and imposes taxes on timbers and other forest products (Asia Pacific Law and Policy Review 2019; Pratap 2010). The Forest Conservation Act of 1980 and the Wildlife (Protection) Act of 1972 were enacted to prevent further deforestation of India's forest areas by requiring the central government's approval for the diversion of forest land for nonforest purposes Meanwhile, the Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act of 2006 recognizes communities' traditional rights to forest land and tackles difficulties surrounding the transfer of tribally managed forest properties to the state government. Through afforestation, the National Action Plan on Climate Change (NAPCC) of 2008 aims to cover one-third of India's land area with forest cover. Later, the current National Forest Policy (2018) intends to protect people's ecological and livelihood security, both now and in the future, through sustainable forest management (GoI, National Forest Policy 2018).

Sustainable Management of Forests, Management of Trees outside Forests, New Thrust Areas in Forest & Tree Cover Management, Strengthen Wildlife Management, Facilitate Forest Industry Interface, Research and Education, Extension and Awareness, Management of North-Eastern Forests are some of the strategies undertaken for sustainable forest management as per National Forest Policy (2018). Legal and institutional frameworks, training and skill development, financial assistance, alignment with other policies and regulations, assimilation of international commitments, promotion of regional cooperation, good governance, a framework for implementing a plan for the future, and periodic review. Besides, India is a signatory to the World Heritage Convention, the Convention on Migratory Species or Bonn Convention, the Ramsar Convention, and five major international conventions on wildlife conservation, including the Convention on International Trade in Endangered Species of Wild Fauna and Flora, the International Union for Conservation of Nature and Natural Resources, the International Whaling Commission, and the Convention on Biological Diversity (TERI 2015). Some of the strategies for sustainable management of forests (UNFF 2007) are adoption of various community participation measures to reduce the threats to forests, improving the quality and productivity of natural forests by implementing strong conservation measures and planting indigenous species to aid natural regeneration, plantation in degraded and underutilized land with scientific interventions and intensive management, sustainable management of the various NTFPs to provide enhanced employment and economic opportunity for indigenous communities, extensively examined and catalogued country's forest biodiversity, promotion of modern ex situ conservation strategies for the preservation of Rare, Endangered, and Threatened (RET) species.

23.6 Future Research Prospects and Recommendations

A community-based monitoring system needs to be urgently introduced in India for assessing the current status of NTFPs and ongoing changes to safeguard the integrity of natural forests and the sustainable livelihood of the poor forest dwellers. Government investment and/or public-private partnership in the NTFPs production, cultivation, value addition, and manufacturing is necessary to ensure assured return to the producers. With necessary initial technical and financial support, the local people can effectively cope with open market competition. To address the ever-increasing subsistence demands of the human population living on the outskirts of the forest and their rising standard of living, intensive land-use practices including the growing of high-value medicinal plants, agroforestry, and other types of mixed cropping combined with value addition is the need of time to supplement natural forest economy. Finally, the role of forests needs to be seen in a larger perspective of sustainable development of local communities encompassing education, healthcare, infrastructure, minimum needs, including the entire spectrum of human development. The different government departments need to converge in their efforts under a single delivery system to alleviate poverty in the forest fringe areas.

23.7 Conclusions

The need for forests and their services as well as benefits increases with rising human and livestock populations. The socioeconomic conditions of India will be able to improve by making better use of the natural resources, local awareness, and knowledge as well as skills in different sectors. NTFPs play an important part in stabilizing the rural economy and sustainable livelihoods of India's indigenous peoples; hence, employment in NTFP-based value-added enterprises, as well as their well-organized system of marketing, should be encouraged. Plant-derived medications play a major role in traditional and modernized medical systems, because India is quite enriched in plant diversity. For long-term sustainability, more broad and rigorous research is required to recommend a strategy based on the conservation and preservation of all the medicinal plants and other forest and forest-based products. Forests are a source of income for society by providing direct and indirect uses of numerous ecosystem goods and services that enable people to thrive and live better lives through employment and other opportunities. Forest resources can be sold to create additional sources of income for those living on the outskirts of forests. Agroforestry, urban greenery, plantation programs, and other forest-related management policies and plans put forward multiple strategies for the improvement of forests as well as livelihood.

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