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

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

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

11.1 Introduction

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

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

11.1.1 Fish Production and Food Security

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

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

11.2 Threats and Weaknesses in Food Fish Production

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

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

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

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

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

11.3 Aquaculture Production Systems

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

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

11.4 Systems of Aquaculture

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

11.4.1 Pond Culture

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

Fig. 11.1 Ponds in fish farming

Fig. 11.2 Cage system of aquaculture

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

11.4.2 Cage culture

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

11.4.3 Pen Culture

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

11.4.4 Raceway

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

11.5 The Effects of Aquaculture on Biodiversity

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

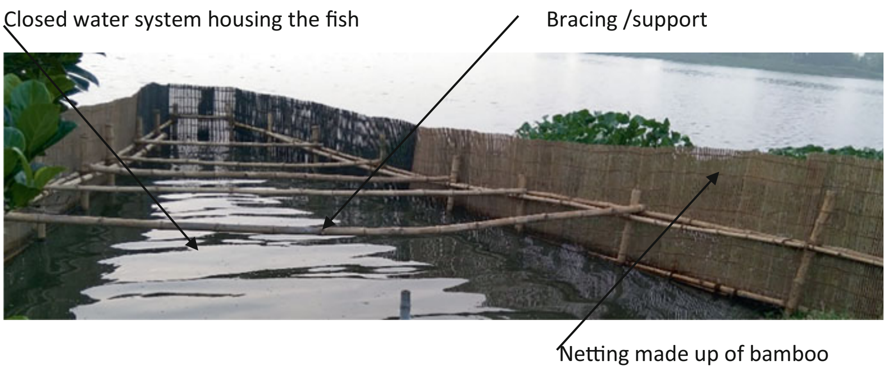

Fig. 11.3 Pen arrangement for fish farming

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

11.6 Mitigation

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

11.7 Negative Implications of Aquaculture on Conservation of Aquatic Biodiversity

11.7.1 Escapement and Genetic Alterations of Wild Stocks

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

11.7.2 The Effects of Effluents on Water Quality

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

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

11.7.3 Sensitive Land Conversion

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

11.7.4 Inefficient Resource Use

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

11.7.5 Disease or Parasite Transfer from Captive to Wild Stocks

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

11.8 Positive Impacts of Aquaculture

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

11.9 Global Freshwater Fish Biodiversity

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

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

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

11.10 FAO's World Major Fishing Areas

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

11.10.1 Africa Freshwater Fishery and Major Fish Species Composition

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

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

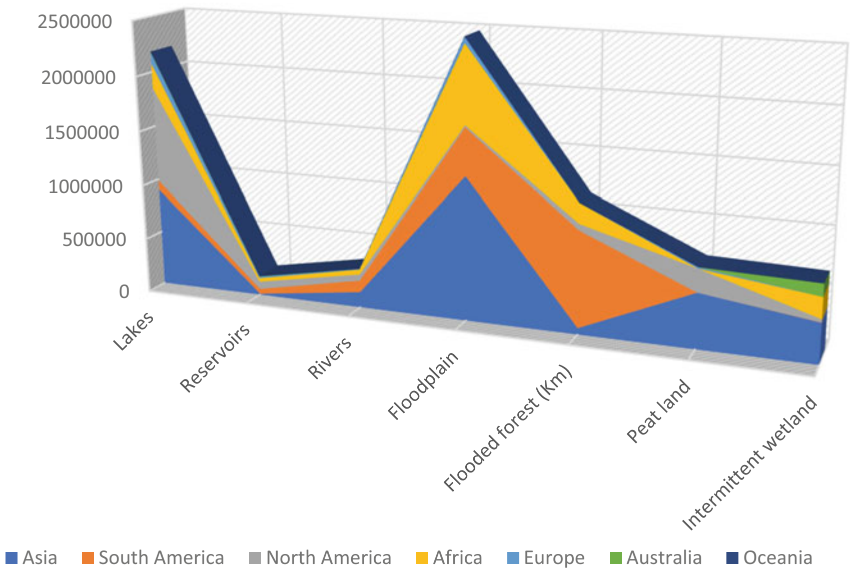

Fig. 11.4 Major surface freshwater resource distribution by continent. (Adapted from Nachtergaele et al. 2011)

Egypt, Algeria, Morocco, Libya Arab, etc.

(b) **Major fish species:**

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

2. **Sub-Saharan Africa**

(a) **Major countries:**

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

(b) **Major fish species:**

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

11.11 Most Commonly Cultured Freshwater Fish Species in Africa

11.11.1 Nile tilapia and perch

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

11.11.2 Clarias gariepinus

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

11.12 Inland Fisheries Production

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

11.13 Exotic Species Introduction

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

11.13.1 Ways by Which Exotic Species Affect Native Species

1. The effects of non-indigenous fish species on native fish species include extinction of native species due to competition for food, sex, and other resources, as well as predation on them.
2. Contribution to a reduction in local biodiversity.
3. Bring with them novel parasites and pathogens into the invaded area, thus causing havoc to them.
4. Through mating or by hybridising, there is possibility of eroding or diluting local genetic diversity with the indigenous species.
5. Habitat is altered in ways that render it unsuitable for the local species to thrive.
6. There are economic losses as a result of reduction in ecosystem productivity.

11.13.2 Signs of Invasiveness Possibility

The success of an introduced species in becoming invasive and destructive to native species and ecosystems is determined by both the species’ qualities and the invasion site’s attributes. Indicators of possible invasiveness in a species include the following characteristics.

1. strong physiological tolerance
2. distinctive features not seen in the invaded group
3. ecological adaptability
4. high population growth rates, which coincides with high fecundity and short generation time

11.13.3 Characteristics Making a Region Vulnerable to Biological Invasions

Similarity to the source area, presence of unfilled or underused niches, low native species richness, and anthropogenic disruption of the ecosystem are all features that make a habitat or a geographic region more prone to biological invasions. Extreme changes in soil properties, frequent fires, grazing, fertiliser inputs, hydrological shifts, and habitat fragmentation are just a few of the human activities that make a place vulnerable.

Many non-indigenous species that turn out to be invasive in the imported region are often harmless in their native range, which ecologists find perplexing.

11.13.4 Inadvertent (Accidental) Introductions

The most common method of inadvertent introduction for aquatic invaders is ballast water carried by transoceanic cruise ships. Ballast water was said to be a primary avenue for non-indigenous organisms to establish themselves in North America's Laurentian Great Lakes. For a wide range of aquatic creatures, from ciliates to fish, it is the most common means of dissemination. Although non-indigenous zooplankton may not be a substantial source of exotic fish introductions, non-indigenous zooplankton may directly harm native fish by affecting the trophic dynamics of invading water bodies.

11.13.5 Deliberate Introductions

Several reasons are usually offered for introducing a new species into a lake or river; some of the reasons are itemised:

1. Create new fisheries that are more resistant to overfishing or have a higher economic value than existing fisheries. New species are introduced into recreational fisheries to broaden the range of species available to anglers or to introduce a trophy or sporting value species to a specific location.
2. Fill a "empty trophic niche" if present species are not fully using the trophic and geographical resources available.
3. Pest control—pests and disease vectors have been biologically managed using a number of species.
4. When enough phytoplankton-eating organisms are missing, control water quality in eutrophic situations to eliminate excessive algae.
5. Promote aquaculture—one of the key causes of species movement throughout the world is still aquaculture. Many different species have been introduced to be farmed. Escapes from aquaculture operations have resulted in several successful wild introductions.

The main variables that contribute to the introduction of exotic fishes into aquaculture may be essential if indigenous species' development is inadequate or they do not reproduce in limited waters. Improve the sport fishing sector—the recreational introduction of alien fish has resulted in the demise of several native fish species throughout the world. Ornamental species have spread widely over the tropical world as a result of escapes from breeding facilities and aquaria, for aesthetic and other reasons. Some species have been introduced for religious or cultural reasons as well.

11.13.6 Challenges to Global Fish Introductions

While general interest in finding target species that have or might reach mass cultivation success, particularly during the 1950s and 1960s, led in fast development of aquaculture, fish introductions throughout the world have produced spectacular triumphs and disasters. According to Wilcove et al. (1998), industrialised countries in temperate zones with stringent environmental and biodiversity legislation are more likely to permit species introductions that cause no or minor damage to natural systems. The opposite is true for countries in the world's emerging regions. In the latter example, there were far more beneficial socioeconomic gains than negative environmental consequences. Invasive species, for example, account for around 17% of global finfish productivity. African Tilapia production is substantially higher (about 20–25 times) than that of other African countries combined. In Chile, introduced salmonids sustain a booming aquaculture business that produces over 20% of the world's farmed salmon and employs roughly 30,000 individuals directly. As a result, the scale used to assess the "success" or "failure" of a certain introduction becomes subjective. The problem is not to outright prohibit fish introductions or to wilfully disregard management of their movements. The challenge is to clearly define the dangers and advantages connected with them, and then establish and implement a plan for their responsible use, if necessary.

11.14 Impacts of Exotic Fish Species

11.14.1 Impacts of Introduced Species

1. Ecological (including biological)
2. Genetical
3. Socioeconomical

Direct encounter with invasive species or increasing fishing pressure may cause ecological or genetic changes. According to the US National Oceanic and Atmospheric Administration, increased fishing pressure or changes in usage patterns caused by the presence of newly established species can have an influence on native species (NOAA). The most often reported explanation, according to the database, was aquaculture development. The bulk of known ecological and genetic consequences in open waters, however, is negative.

11.14.1.1 Ecological Impacts

Competition between exotic and native fishes for living space with similar niche preferences, for food with similar kinds of feeding habits, or omnivorous habitat eating all other species' preferred food, predation on native fishes, and the spread of parasites and pathogens are some of the most common ecological concerns. The African catfish *C. gariepinus* was introduced in India; however, the increased interest in cultivating this exotic catfish poses a major threat to natural stock of other species. The African catfish, according to study in the biology of this peculiar catfish, is a ferocious predator. The African catfish *Clarias gariepinus* (Burchell) was brought into Thailand and Vietnam and is being used to interbreed with the local walking catfish *C. macrocephalus* (Gunther). The hybrid is widely cultivated and valued by Thai farmers because of its much faster growth rate than the indigenous species and good meat quality. Only Thailand produces hybrid catfish, accounting for more than 17% of worldwide catfish output in recent years (FAO 2002). In 2002, the Nile tilapia was Asia's sixth most produced freshwater species, and it must be regarded Asia's most important intercontinentally imported aquaculture species.

For more than four decades, tilapia has been employed in sewage-fish culture systems in India, with no reports of disease transmission among clients or considerable mortality among cultured stocks (Nandeesha 2002). There is no indication that this influx has had an impact on the biodiversity of the region (De Silva et al. 2004).

China is the top producer of farmed tilapias in Asia, and it is the only foreign species that is now relevant for aquaculture in this country. Nonetheless, tilapias make a tiny contribution to overall inland output in China, whereas they make a much larger percentage output in the Philippines and Sri Lanka.

11.14.1.2 Genetic Impacts

The genetic effects of exotic fish introduction on native fish can be divided into two categories: • Decrease in effective population size caused by genetic effects of introduction in addition to ecological and biological factors • Alteration/extinction of gene pools of species/stocks due to crossbreeding, hybridisation, and backcrossing. Crossbreeding is the interbreeding of distinct stocks, whereas hybridisation is the interbreeding of different species or genera.

11.14.1.3 Socioeconomic Impacts

The socioeconomic consequence is visible on two different levels: (1) capture fisheries and (2) aquaculture. Because alien fishes never command a greater price than native types, and because the presence of exotic species in natural waterways reduces native fish output, the total economic return for stakeholders in capture fisheries decreases. Conversely, in most situations, it gives instant benefit without regard for long-term ecological effects in aquaculture.

11.15 Efforts to Regulate Introductions at the International and National Levels

11.15.1 Institutions Responsible for Monitoring of Exotic Aquatic Species

It should be acknowledged that aquaculture is the ultimate measure in the production of edible fish. Species introductions will continue to be a viable option for increasing aquaculture and fisheries productivity and profits. To address the issue of species introductions, a proportion of global, regional, and national institutions have been formed. They are as follows:

1. World Trade Organization (WTO).
2. The World Organization for Animal Health is a non-governmental organisation that promotes animal health (OIE).
3. The International Council for the Exploration of the Sea is a non-profit organisation dedicated to the study of the sea (ICES).
4. United Nations Food and Agriculture Organization (FAO) (Code of Conduct for Responsible Fisheries).
5. NACA/SEAFDEC/ASEAN Regional Initiatives.

11.15.2 Suggested Strategies to Be Followed While Introducing Exotic Fish Species

- Fish introduction should be avoided as much as feasible, and efforts should be made to boost native species production using biomanipulation or biotechnological approaches. More native species that can be grown profitably should be found and assessed as a top priority.
- If indeed the introduction is necessary, the greatest steps should be taken prior to its introduction, and it should not be permitted in natural water until a thorough investigation of the long-term influence on the ecosystem has been completed. Prior to allowing such introductions, ecological connections, genetic problems, socioeconomic implications, and probable disease infestation should all be properly investigated.
- A central body or panel should be established to investigate the planned introduction's effects, risks, and benefits.
- Importing and cultivating broods or seeds of certain species that have been shown to be damaging to the native fauna and ecology should be prohibited entirely.
- For imported live specimen shipments in the ornamental fish sector, stringent quarantine precautions should be implemented. It must be guaranteed that they do not mistakenly escape into natural waterways, either from hobbyist aquariums or during shipping.

- Creating awareness of native types via training and education may motivate ornamental fish sellers and buyers to utilise them.
- Fish introduction or commerce that is prohibited or unofficially/illegally done should be punished by law. It is necessary to introduce comprehensive legislation.

The worldwide history and current state of alien species introduction in many nations, as well as analyses of their ecological, biological, and genetic impacts, clearly reveal that certain species have a detrimental influence. In addition to direct effects on eco-biological consequences, certain fish have gone extinct as a result of genetic variability and heterozygosity loss, hybridisation between alien and native species, and other factors.

11.16 Conservation of Inland Fish Biodiversity

With world's rapid development, population explosion, and ever-increasing demand for fish as a protein-rich food, the many country's aquatic ecosystems are constantly under threat from anthropogenic stresses, such as habitat destruction, overexploitation, wanton killing of juveniles and adults, excessive water abstraction leaving insufficient water for fish, aquatic pollution, diseases, and uncontrolled exotic introduction. Fish populations have shrunk due to overexploitation of fish resources combined with habitat loss. Consequently, of these circumstances several species of fish in certain traditional fishing sites are fast diminishing, and some have become endangered.

11.17 Factors Affecting Fish Diversity

Because of the country's rapid general growth and constant increasing demand for fish as a food source, water resources are always under stress from man-made pressures to the disadvantage of aquatic flora and fauna. Although this decreasing trend of individual fish species is frequently linked to multiple proximate factors, the possible causes of fish extinction in coastal habitats have been recognised as shown in Fig. 11.5.

11.17.1 Habitat Destruction

Siltation from catchment regions has ruined the feeding and spawning habitats of many fishes, in addition to affecting the environment owing to dam building. Fish habitats and local fish communities have been drastically altered as a result of power dams and reservoirs. Reservoirs, which are adverse for rheophilic species, have

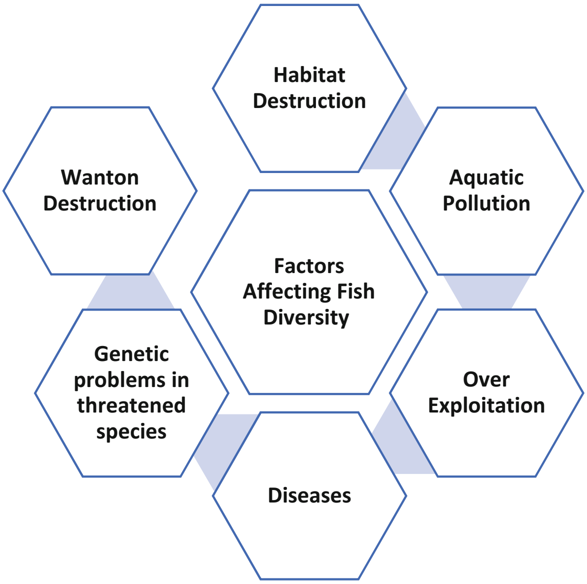

Fig. 11.5 Factors affecting fish diversity

resulted in the loss of highland rapid flowing habitat. Excessive water loss from river courses for agriculture, household, and industrial applications, leaving insufficient water for pleasant fish life, is another primary cause of fish germplasm depletion.

11.17.2 Over-Exploitation

Over-exploitation of fishing resources, owning to their exceptional financially viable, has been a contributing factor in worsening the population's susceptibility. Tor spp. are disappearing at a quicker rate in highland waters, *Notopterus chitala* in warm waters, and *Lates calcarifer* in brackish water habitats.

11.17.3 Wanton Destruction

A number of food and game fishes in highland waterways have been impacted by indiscriminate dynamiting, electrofishing, and use of poison for brood fishes during spawning season.

11.17.4 Aquatic Pollution

Pollution is most likely the single most important cause driving large population declines in many fish species. These are wreaking havoc on genetic thresholds, which, in addition to their direct harmful effects, might result in lasting damage to genetic resources. Chemical contamination from factories and plants in the many industrial cities has wiped out several endemic fishes that formerly thrived in the area's aquatic environments.

11.17.5 Diseases

Among the range of various diseases caused by bacteria, fungi, and viruses, the most virulent and menacing one threatening many species is the Epizootic Ulcerative Syndrome (EUS).

11.17.6 Genetic Problems in Threatened Species

Natural fisheries decline and recovery are thought to be genetically caused by inbreeding, negative selection, and a lack of adoption; however, hatchery stock restocking programmes are unlikely to fully solve the problem because these stocks were selected for adaptation to hatchery conditions rather than natural habitats. Because genetic variety is a key feature in population dynamics that allows animals to adapt to changing environmental conditions, any loss of genetic diversity reduces evolutionary flexibility. As a result, organisms are less able to adapt to their surroundings, increasing the likelihood of extinction. Genetic bottlenecks, genetic drift, and homozygosity build-up are among the serious genetic issues that plague the tiny genetically effective population.

11.18 Strategies for Fish Biodiversity Conservation

The arguments for food security and biodiversity protection are both compelling. Is it possible to find a solution that does not put them at odds? There are undoubtedly technical changes that can be made to fishing and aquaculture techniques to lessen their ecological footprints and, as a result, their negative ecosystem consequences.

Concerns over the loss of aquatic biodiversity, as well as the possible social and economic ramifications, have prompted a variety of regional and national efforts to conserve and manage aquatic resources sustainably (Fig. 11.6).

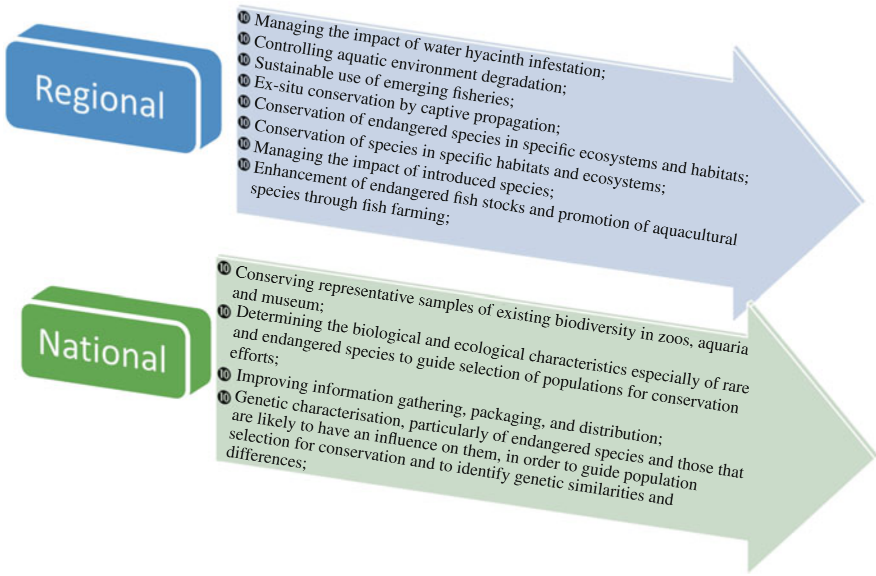

Fig. 11.6 Efforts towards conserving and management of aquatic resources

It is critical devising all available conservation and rehabilitation strategies in order to prevent future deterioration of our fish germplasm resources. The conservation policy should encourage management techniques that preserve aquatic ecosystem integrity, avert endangerment, and aid threatened species recovery. Some of these approaches include the following methods.

11.18.1 In Situ Conservation

In situ conservation is the technique of preserving and restoring viable populations of species in their native habitats, or, in the case of domesticated or produced species, in the environments where they have formed their unique characteristics (Article from the Convention on Biological Diversity 2) (Jena and Gopalakrishnan 2011). This method of conservation takes into account data on fish and habitat diversity, habitat use, life cycle characteristics, as well as human involvement and other socioeconomic factors (Jena et al. 2011). In situ protection of marine ecosystems is achieved by designating specific areas as Marine Protected Areas (MPAs), National Parks, Wildlife Sanctuaries, or Biosphere Reserves. MPAs protect not just depleted, vulnerable, uncommon, or endangered species and populations but also their ecosystems.

11.18.2 Ex Situ Conservation

This strategy is used to conserve species outside of their natural habitats, either by keeping the population alive in a genetic resource centre or by employing gene pools, gamete storage, and germplasm banks. In the case of fishes, as well as a number of other species, rapid freezing of gametes to ultralow temperatures has been shown to be efficient. For conservation and aquaculture sustainability, the ability to preserve fish milt, eggs, and embryos without losing viability is crucial. (1) The construction of a gene bank for the conservation of endangered fish genetic resources and the development of a gene bank for the conservation of endangered fish genetic resources are two advantages of cryopreservation. (2) Seasonal brooders have year-round access to gametes; (3) Germplasm may readily be moved over a geographical region. (4) Assists in the process of selection and hybridisation. Induced breeding in several cultivable species is complicated by insufficient milt production or asymmetry in the maturing of the two sexes. Milt-related difficulties can be solved with cryopreserved sperm. Teleosts and crustaceans' eggs and embryos have yet to be cryopreserved due to their large size, large volume of yolk, and stiff chorion with a low permeability coefficient. Fish cell lines, embryonic stem cells, and germ cells from Indian fishes, as well as cloning procedures, must be developed for long-term storage of fish eggs and embryos (Jena and Gopalakrishnan 2011).

11.18.3 Live Gene Banks

Live gene banks help delist vulnerable species by reproducing them in captivity and replenishing them in species-specific recovery programmes. The goals of live gene banks are to gather endangered, uncommon, and vulnerable fish species and maintain their populations on a farm as well as to study their growth, maturity, survival, and adaptability in controlled conditions, and to investigate their life cycle characteristics as a tool for both in situ and ex situ conservation (Jena and Gopalakrishnan 2011).

11.18.4 Tissue Preservation

This is a quick way to store biological material for longer periods of time without having to follow any species-specific methods, and it can be used to regain genetic information for hereditary adaptation experiments afterwards (Jena et al. 2011).

11.18.5 Breeding in Captivity

These programmes have become the primary method for replenishing diminishing populations, particularly vulnerable species, in their native habitat while also supplementing and increasing wild species yields. These procedures for captive breeding and larval rearing of various ichthyofauna have had a lot of success (Jena et al. 2011).

11.18.6 Aqua Ranching

This strategy is used to improve resources by seeding open waterways with desired aquatic species and providing them with proper built habitats so that the animals may defend themselves from natural hazards and grow to a level when predation and juvenile mortality are considerably reduced. This technique can be used to restock degraded resources, including lakes, streams, estuaries, and even seas (Rout et al. 2007).

11.18.7 Biomass Conservation

This includes the population's long-term viability. This may be achieved by creating safe zones in certain settings. This type of conservation will be crucial in reducing the pace of species extinction (Rout et al. 2007).

11.18.8 Translocation

Stripping wild fish, fertilising their eggs in the field, returning the broodfish back into the donor water body, and transferring the species as fertilised eggs, yolk-sac larvae, or juveniles into other water bodies to produce self-sustaining populations in case the original populations go extinct (Rout et al. 2007).

11.18.9 Control of Exotic Fishes

Exotic fish introduced indiscriminately may obliterate the indigenous ichthyofauna. When bringing a new species, it is crucial to evaluate the prospective species' biology, its genetics, and potential influence on native species in the natural habitat in order to minimise the potentially disastrous environmental and socioeconomic repercussions of the alien species' introduction (Rout et al. 2007).

11.18.10 Sustainability in Fish Harvest

Regulation of aquatic resources especially fisheries, exploitation in traditional fishing grounds, is required. To maintain a sustainable resource, brood fishes and juveniles must be preserved. To protect brood, there must be strictly enforcement in size limits for net and mesh. The use of dynamite and chemicals to kill fish at random must be absolutely prohibited (Rout et al. 2007).

11.18.11 Implementation of Closed Seasons

The term "closed season", sometimes known as a "biological rest period", refers to the prohibition of fishing during a fish's reproductive period. It is a method of lowering fishing pressure on stocks when they are at their most productive, allowing fish to lay eggs to restore the population lost due to fishing and other natural reasons. If a sufficient number of fishes remain to breed, the "closed season" can expand the supply available for fishing in just a few years by "preserving the pregnant fish". Other sorts of fishing pressure, such as the use of unlawful small mesh size nets, light fishing, poisons and harmful chemicals, and dynamite, will be most successful when a "closed season" is implemented.

11.18.12 Habitat Restoration

Based on the type of habitat degradation, situation-specific habitat restoration programmes must be implemented. In the case of sedimentation/siltation, for example, deforestation efforts must be halted promptly, along with a substantial afforestation programme in erosion-prone areas. Polluted water bodies require instantaneous attention, which can be achieved by maintaining strict adherence to pollution control regulations (Rout et al. 2007).

11.18.13 Mass Awareness

It is commonly established that the effectiveness of biodiversity conservation depends on raising public awareness about the diverse ecological, socioeconomical, nutritional, cultural, artistic, recreational, pharmaceutical, and other services available to mankind. As a result, every citizen bears responsibility for preserving declining diversity.

11.18.14 Geographic Information System

The use of GIS and remote sensing techniques has grown in importance in the analysis of natural resources, particularly water environments, and is now being utilised as a tool for fishery resources and conservation efforts.

11.19 The Interplay: Is There a Way Forward?

According to the research, there are opportunities for raising fish and aquatic invertebrates sufficiently to contribute considerably to global food security in a world with a growing human population. These alternatives do not come without a price tag. Almost all of the possibilities, if pursued aggressively, would work against growing global biodiversity protection agreements. Rice and Garcia (2011) highlighted some activities required to balance the food fish security and biodiversity conservation (Fig. 11.7).

11.20 Conclusion

If imbalance in the fish production and biodiversity could have ecological (disease, climate change, or overharvest), genetical and socioeconomic impact on both human and fish population, widespread starvation or malnutrition as well as ecologically unsecured environment could be the consequence. To preserve the long-term sustainability of our food fish supply, we must safeguard our natural biodiversity (from overfishing) and create new and improved aquacultural practices that pose little or no danger to natural stocks and the environment.

This can be accomplished by involving stakeholders in order to create collaborative and integrated partnerships that provide a future in which healthy and productive natural systems provide long-term services to people and the environment.

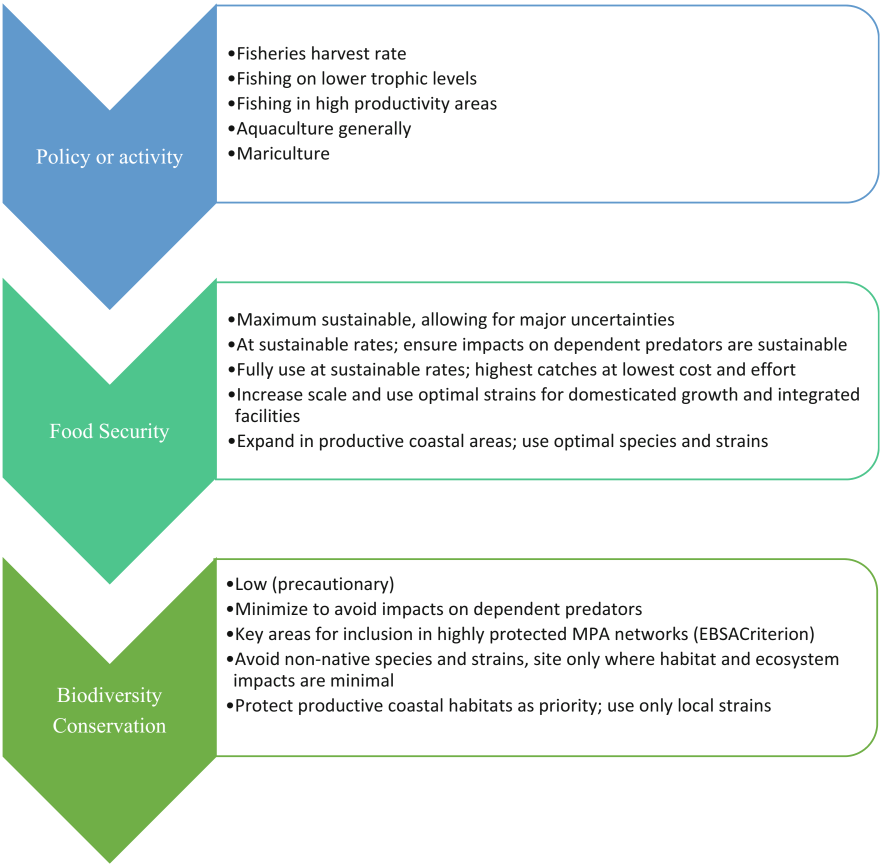

Fig. 11.7 Required activities in balancing food fish security and biodiversity conservation. (Adapted from Rice and Garcia 2011)

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