Chapter 14
Climate Smart Eco-management of Water and Soil Quality as a Tool for Fish Productivity Enhancement

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Abstract Climate smart eco-management is an approach for reorienting and transforming the aquaculture system under changing climatic conditions to ensure food security for the increasing global population. Widespread alterations in temperature, rainfall pattern, and extreme weather events threaten the aquaculture production system and amplify the risk of economic loss. These potential threats can be minimized by increasing the resilience capacity of the production system through various climate smart strategic approaches. The strategic adaptation approaches include species diversification, integration of agri-aquaculture such as integrated multitrophic aquaculture (IMTA), aquaponics, various advanced techniques like biofloc, recirculatory aquaculture system (RAS), culture of stress-tolerant species, inland saline aquaculture, implementation of BMPs in disease and environment management, etc. Climate smart adaptation strategies are likely to help in achieving 'sustainable fisheries development goal' and create a 'triple win' situation for the practitioners and stakeholders by enhancing fish production, making the production system climate-resilient, and reducing the greenhouse gas emission. Moreover, execution of climate smart aquaculture approach is quite flexible, context-specific, and can be supported by various financial schemes and innovative policies.

Keywords Water quality · Soil quality · Climate smart eco-management · IMTA · RAS

1 Introduction

The menaces of climate change to natural ecosystems and human society have been upraised to a top priority. It is now broadly accepted that climate change is not only a potential threat, but has become a new reality of twenty-first century. The ongoing

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climate change has drawn attention in the global corridor related to various developmental policies and worldwide governance (Ahmed and Solomon 2016). The accumulation of Greenhouse Gases (GHGs) in the atmosphere is associated with global warming and leads to the emergence of distinctive climate patterns in different agro-climatic zones. Change in climatic conditions is believed to modify weather patterns on regional scale, resulting in extreme weather events. Climate change has serious repercussions causing floods, landslides, drought, tropical cyclones, hurricanes, cold waves, heat waves, and alterations in various climatic parameters including rising sea levels, gradual change in water temperature, upsetting seasonal cycles, ocean acidification, and variations in oceanic currents. Weather extremes are certainly more traumatic and acute in nature, triggering injuries and transmission of communicable diseases and deaths (Hashim and Hashim 2016). These changes in the physical parameters can affect the ecological functions of the aquatic ecosystem and would also pose a challenge to the fisheries and aquaculture sector due to their adverse impact on reproductive ability, conception rate, sperm count, feed intake, and untimely mortality of the cultured species (Cochrane et al. 2009; Ahmed and Solomon 2016 ; Bhattacharyya et al. 2020).

Moreover, glacier melting, rising sea level, changes in precipitation rate, ocean acidification, and reduced groundwater level will have a significant effect on coral reefs, estuaries, rivers, lakes, and wetlands. Therefore, mitigative measures to accomplish adaptability and optimum production are required, while minimizing the adverse impacts of climate change on fisheries and aquaculture systems. In this context, it has been observed that fisheries and aquaculture practices also make a modest but still remarkable contribution to greenhouse gas (GHG) emissions during culture operations, transportation, processing, and storage of fish and fishery products. Although greenhouse gas emissions from fisheries and aquaculture sector are minimal when compared with other food production sectors, the situation can be improved further, with various identifiable measures and technical interventions (De Silva and Soto 2009).

To safeguard fish production under changing climatic scenarios, the aquaculture sector has to be governed efficiently. The most appropriate adaptation approach for the sector under changing climatic conditions could be the diversification of the production systems. A diversified production system is more resilient to water scarcity, temperature change, pest attack, and disease outbreak. The adaptation methods are widely classified as resource relocation, use of information and communication technology, diet-based adaptation, and genetic management. Henceforth, the vulnerability of the aquaculture sector can be reduced and the resilience capacity of fisher communities involved in smart aquaculture practices should be strengthened. In the era of global climate change and higher requirements for animal protein, the expansion of climate smart aquaculture can potentially provide sustainable management strategies to the fisheries and aquaculture industry (Bhattacharyya et al. 2020; De Silva and Soto 2009).

2 Potential Impact of Climate Change on Fisheries and Aquaculture

Climate change can directly affect the performance of individual aquatic organisms at their various life stages through modifications in morphology, physiology, and behaviour. Combination of climate change along with edaphic stresses will lead to extreme ecological responses which include microevolutionary processes, alteration in species distribution, and reduced productivity and biodiversity (Harley et al. 2006).

Aquaculture practice, like other agricultural activities, will suffer from the consequences of deep-rooted global climate change. Among the inevitable challenges of global temperature rise, substantial water scarcity and ocean acidification will adversely impact the inland and coastal aquaculture operations (Yadav et al. 2021). It is evident that various abiotic stresses of physical, organic, inorganic, and biotoxin origin and biotic stresses of viral, bacterial, fungal, and parasitic origins are the major constraints in achieving optimum aquaculture production (Krishnani et al. 1997; Krishnani and Ayyappan 2006). Besides, climate-driven changes in the spawning activity of the aquatic organisms will influence the successful recruitment, seed production, and growth of the concerned population. Also, global warming or heat increment can strengthen the process of thermal stratification in the aquatic system and cause deepening of the thermocline layer and reduced nutrient supply to the surface water and thus plays a significant role in determining the habitat distribution of various fish species (Barange and Perry 2009). Therefore, it is explicit that various biotic and abiotic stressors coupled with global warming will have synergistic effects and will further worsen the condition.

2.1 Abiotic Stresses

For sustainable aquaculture production, it is very crucial to maintain optimum soil and water quality conditions. Various parameters like dissolved oxygen, temperature, pH, salinity, turbidity, etc. are the determining factors that should be regulated throughout the culture period (Mwegoha et al. 2010). Slight deviation in these parameters will hamper the nutrient uptake, growth, and metabolism of the farmed fish (Africa et al. 2017).

Most of the aquatic animals are poikilothermic (cold-blooded), and therefore, their physiological activities are dependent on external environmental conditions, especially on temperature. Temperature tolerance in fish can be classified as directive, controlling, and lethal temperature. It indicates that fish will start showing alarming responses before it reaches the extreme thermal limits (Fry 1971). Abiotic stresses caused by increased temperature will have negative impact on food conversion, oxygen requirements, and energy expenditure of the fish (Brett 1979). Temperature rise beyond the level of physiological tolerance may also cause reduced feeding, increased hypoxia, and mortality (Ørnholt-Johansson et al. 2017). Ecological adversity arising from climate change includes coastal acidification, reduced benthic oxygen, coastal upwellings, freshwater runoff, phytoplankton blooms, and sea level rises (Kernan 2015; Fitzer et al. 2018). Rise in sea level will result in coastal erosion, alteration of hydrodynamics and coastal geomorphology, and therefore, decrease in the availability of ideal sites for aquaculture activities. Increase in atmospheric CO_2 levels due to climate change has been suggested to cause depletion in the ozone layer and enhanced entry of ultraviolet radiation to the earth's surface with possible effects on the oceanic process (Austin et al. 1992). Ocean acidification or reduction in ocean pH will affect the process of shell formation or calcification in shellfishes. It has been reported that acidification of oceanic water can reduce the sperm motility and fertilization rate in sea urchin (*Heliocidariserythrogamma*), which implies that other marine organisms are also at similar risk (Barange and Perry 2009).

Water scarcity due to the changing climatic conditions is likely to cause conflicts among various water-dependent activities, thus affecting inland fisheries and aquaculture operations. Resuspension of sediments during extreme weather events and deposition of suspended solids from surface runoff can cause retarded growth and acute gill damage in fish while upsetting overall health conditions (Au et al. 2004). Also, extreme climatic conditions like strong waves and storms can potentially damage exposed fish cages in the coastal areas, leading to escapement of the cultured species (Jackson et al. 2015), devastation of aquaculture structures, and increased infrastructure costs (Dankers and Zuidema 1995).

2.2 Biotic Stresses

Global climate change and ocean acidification can adversely impact the immune response of the fish due to conflict between maintaining homeostasis and increased metabolic rate at higher temperature and fluctuating pH and salinity range. In the case of farmed fish, the affect can be compensated by maintaining optimum feeding regime, but in shellfishes, the immunity will be compromised as the changing climate may influence the availability of natural food sources. Additional stressors like extended photoperiod, temperature rise, depletion in dissolved oxygen content in water, and increased UV radiation can potentially act as immunosuppressive factors and make the fishes more susceptible to diseases (Markkula et al. 2007). Rise in temperature can stimulate the dynamics of pathogens by increasing the virulence factor of the pathogen and supressing immunological activity of the host. It has been observed that ocean acidification and increased sea surface temperature can promote the survival and growth of many opportunistic bacteria, including Vibrio species (Baker-Austin et al. 2017).

The decay rate of viruses and larval *Bonamia* (oyster parasite) tends to increase with rising temperature (Oidtmann et al. 2018). Temperature-induced higher metabolism of the host organism may result in increased viral replication and easy transmission of the diseases (Gubbins et al. 2013). Alteration in the environmental condition can lead to the evolution of the existing pathogenic strain with varying degrees of virulence and replication rate (Murray and Peeler 2005). Also, parasite prevalence in the areas of warm or moderate temperatures is the most common phenomenon. Increased temperature may accelerate the maturation process of fish parasites like sea lice, and therefore, increasing sea surface temperature and salinities may facilitate easy spread of the parasites and thus make them more infectious (Murray et al. 2012; Brooker et al. 2018).

Similarly, fluctuation in salinity can also affect the survival of pathogen. Pathogens have optimum salinity ranges for their growth and replication, but many viral pathogens can grow on a substantial range of salinity (Oidtmann et al. 2018). At higher salinity growth, oyster parasites, sea lice and *Paramoebaperurans,* tend to increase with potential infectivity (Collins et al. 2019; Brooker et al. 2018; Arzul et al. 2009). During the spring and winter months, decrease in salinity may lower the survival of fish parasites (Van West 2006). Climate-mediated stress will give rise to physiological responses in the host organism through which the animal tries to re-establish normal physiological functions. If the stressful condition persists for a longer period of time, it may lower the disease resistance capacity of the fishes. In this situation, the already stressed fishes will easily get infected by opportunistic pathogenic microorganisms (Raman et al. 2013).

3 Climate Smart Aquaculture

The main aim of climate smart aquaculture is to ensure food security by adapting potential mitigation strategies. Climate smart aquaculture deals with minimizing potential adverse impacts of global climate change, increasing productivity, and income generation. The adaptation strategies require efficient use of natural resources for fish production, improving the resilience capacity of the aquatic system, sustainable development, and reducing the vulnerability of fish production which is most likely affected by climate change. The transition of traditional aquaculture practices into climate smart culture technique needs to be done at each stage, including national, regional, community, and individual levels. All public and private stakeholders should get involved in the process of transition to assure that the concerned aquaculture sector is climate resilient (Ahmed and Solomon 2016).

4 Strategic Approaches Towards Climate Smart Aquaculture

Climate smart culture approaches in aquaculture have three main objectives such as achieving sustainable fish production, increasing the resilience of the sector, and reducing greenhouse gas emission. The strategic adaptation approach focuses on building resilience capacity to the consequences of climate change (Bueno and

Soto 2017), whereas mitigation is a long-term solution to global climate change and may take considerable amount of time to visualize the results (Leal Filho 2011). Therefore, adaptation and mitigation approaches should be implemented in a conjoint manner for effective results.

4.1 Mitigation of Greenhouse Gases

Strategic approach towards climate change involves reduction in greenhouse gas emission, especially carbon-di-oxide (CO_2), which can be achieved through a combination of existing and new technologies, including product substitution, bio-based feedstock, electrification, and reducing carbon footprint (Maulu et al. 2021). Aquaculture producers and stakeholders can also play a crucial role in mitigating global climate change by using environment-friendly practices such as renewable energy sources, sustainable waste management, and proper feeding practices (Barange et al. 2018). It has been observed that in aquaculture production improper utilization of feed is the major contributor to greenhouse gas emission. For instance, sinking feeds are more environmentally viable in comparison with floating feeds (Hardy 2010). Hence, application of sinking feeds will have less impact on GHG emission.

It has been estimated that approximately 93 % of global carbon is trapped in the aquatic ecosystem and approximately 30% of annual carbon emissions are generally sequestered in seaweeds, mangroves, seagrasses, coastal sediments, and floodplain forests (Nellemann and Corcoran 2009). Therefore, it is very crucial to save these habitats from destruction and enhance their sequestration ability through proper management practices. Well-managed seaweed farms and mangroves will serve as a natural breeding ground for various fish species and act as a reservoir of natural foods. Expansion and conservation of these sensitive ecosystems will lead to species richness, healthier ecosystem, and abundance of aquatic species, and thus, it can safeguard livelihoods and provide food security (Palombi and Sessa 2013).

4.2 Livelihood Diversification Through Integrated Agri-aquaculture/Advanced Culture Techniques

Another approach to climate smart aquaculture is the diversification of livelihoods, one of the successful keys to adaptation as it provides additional livelihood options to the producers and build resilience against changing climate. Diversification involves a combination of the aquaculture system with other agricultural sectors such as crops and animal husbandry either as separate or integrated systems. The process of diversification is extremely beneficial in the areas where agricultural production is predicted to increase, whereas fish production is expected to decline (Bell et al. 2013). In order to improve the resilience capacity of the culture system, it is much required to encourage the consumption of diversified fish species, usage of by-products, and reducing wastage throughout the processing chain. These initiatives can potentially stabilize the income of the fisherfolk and secure the availability of nutritious foods.

The expected surge in extreme climatic events resulted in competition for freshwater resources, while making the area prone to droughts. System-based adaptation measures such as water-saving biofloc technology and recirculatory aquaculture practices are considered a viable solution to water scarcity (Boraiah et al. 2021). Biofloc technology is a method of boosting water quality parameters in the aquaculture system through balancing optimum nitrogen and carbon ratio. This technique is scrutinized as a resourceful alternative to traditional culture practices based on the growth of beneficial microbes in the culture medium. The technology has gained recognition as a sustainable culture technique for controlling water quality, minimum or zero water exchange and producing in situ value-added proteinaceous feed (Crab et al. 2012). Likewise, to mitigate the problems of water pollution due to rapid expansion of aquafarming activities, the development of recirculating aquaculture system (RAS) has become essential. In the RAS system, the effluent pass through biological filters and can be reused for fish culture. Through wastewater reclamation, this system can effectively minimize water requirement for fish culture (Sharrer et al. 2007).

Another such promising, economically rewarding, sustainable, and environment-friendly approach is Integrated multitrophic aquaculture (IMTA) where the fish is cultured in combination with other extractive species (van Osch et al. 2019). Similarly, aquaponics is also considered a resilient system which can effectively adapt to diverse climatic conditions. This system is the integration between aquaculture and without soil cultivation of agriculture or horticulture practices. In the aquaponics system, two completely different production systems are combined together into a closed recirculating unit. The nutrient-rich effluent and organic wastes generated from the fish tank are filtered through inert substances containing plant roots. The plant tends to assimilate the nutrients from the effluent for their growth and the filtered water is then pumped back into the fish tank and can be reused for fish culture. Aquaponics system can sustainably produce additional crops along with fish, and therefore, enhance the profitability of the system, reduce the degree of water pollution and effluent discharge, and can significantly overcome the challenges of water scarcity, soil degradation, and climate change. Moreover, aquaponics is a controlled system that maintains a high degree of biosecurity and reduces the risk of disease transmission (Palombi and Sessa 2013).

4.3 Species Diversification

Aquaculture producers can also gain potential benefits from shifting the aquaculture activities in less vulnerable areas and culturing climate-resilient fish species like magur, pangasius, GIFT tilapia, etc. (Maulu et al. 2021). Selection of species for aquaculture purpose based on easy breeding and feed conversion efficiency helps to minimize the negative impacts of climate change and GHG emission (Sae-Lim et al. 2017). Fish species such as *Clariasmagur, Heteropneustesfossilis, Channastriata, Channamarulius, Channapunctata, and Anabastestudineus*can withstand hypoxic conditions, and species like *Pangasionodonhypophthalmus, Oreochromisniloticus, and* Jayantirohu can be reared under varying temperature and salinity (Boraiah et al. 2021). It is evident that stress-tolerant fish species possess improved flesh quality, increased fecundity, and enhanced post-spawning survival. In this context, a robust implementation of a selective breeding program for the development of stress-resistant species is the need of the hour. But genetic intervention for the production of improved variety of fish species greatly depends upon the diversity and availability of genetic resources. The complete information on species diversity in the natural water bodies will be advantageous for exploring the genetic resources for future studies related to the adaptation mechanism of fishes towards multiple stresses (Boraiah et al. 2021).

4.4 Inland Saline Aquaculture

Soil salinization is a global concern for both developed and developing nations. Inland saline water is unfit for traditional aquaculture activities, and therefore, culture of diversified or potential alternative fish species will ensure considerable economic growth (Pathak et al. 2019). Inland saline groundwater generally contains high concentration of calcium and lesser concentration of magnesium and potassium ion. This variation in ionic concentration adversely affects the growth and survival of fish and shrimp species as potassium concentration of inland saline water plays a significant role in osmoregulation in fishes (Evans et al. 2005). After the necessary amendment, inland saline water can be effectively used to culture a range of finfishes, crustaceans, and algal species. Euryhaline finfish species like sea bream, tilapia, eels, pangasius, milk fish, pearl spot, silver perch, red drum, barramundi, and pampanoo, and crustacean species such as *Litopenaeusvannamei and Penaeusmonodon* can be commercially cultured in inland saline water with moderate to high salinity (Singh et al. 2014).

4.5 Culture-Based Fisheries

In smaller seasonal water bodies and flooded fields, culture-based fishes can be carried out as stock enhancement process. In the case of culture-based fisheries, the only input is stocking of the seeds and it does not require any external feed resources as the selected fish species can efficiently utilize the vacant food niches. Although the fish production from culture fisheries is relatively less compared to intensive farming, it is eco-friendly, cost-effective, and involves no GHG emission related to external feeding(Palombi and Sessa 2013).

4.6 Climate Smart Eco-management as a Tool for Fish Productivity Enhancement

In aquatic system management, climate smart practices are intended to prevent negative environmental impacts including water pollution. Minimization and subsequent reduction in pollution from point sources of fish production system are in demand by various public and regulatory authorities (Boyd 2003). From the aquaculture point of view, Better Management Practices (BMPs) are considered as one of the climate smart eco-management tools for responsible and sustainable farming of aquatic organisms, while allowing the production to be carried out in a cost-effective and profitable manner. Although BMPs are not certification standards, implementation of BMP can enhance the product quality based on animal health, food safety concerns, and environmental sustainability. BMPs are voluntary, location-based, and commodity-specific management norms that have been developed to fulfill the criteria of responsible fish farming, reducing the risk associated with culture operations, and profit maximization. However, BMPs are subjected to constant improvement, evolution, and timely revision, depending on changing climatic conditions (Market 2010).

4.6.1 Environment Management of Aquaculture

Environmental management through the implementation of BMP can lead to the overall improvement of the aquaculture production system, including optimum utilization of resources, enhanced growth performance, reducing disease occurrence, and improved marketability of the produce while achieving the food quality standards. Adoption of BMP guidelines is easy without any additional input costs. Availability of quality soil and water is the basic requirement for fish culture. Different soil properties can deeply impact pond construction and influence aquaculture production. Prior to fish culture, the soil characteristics such as texture, pH, water holding capacity, organic carbon content, etc. should be studied carefully and the necessary adjustments should be done to make the soil suitable for fish culture. Similarly, water quality parameters like pH, salinity, dissolved oxygen content, hardness, alkalinity, total suspended solids, free ammonia content, etc. should be taken into consideration before selecting the aquaculture site and the species to be cultured. Adoption of BMPs provides strong evidence to the fact that environment-friendly culture activities make better business sense (Woynarovich et al. 2011). However, the areas having extreme soil and water quality parameters, where amendment is impractical, can be used to culture various stress resilience fish variety to boost the aquaculture production (Boraiah et al. 2021).

4.6.2 Fish Health management

Disease is one of the prime limitations in aquaculture production causing worldwide economic loss (Sahoo et al. 2013). Mostly, frequent disease outbreak is the result of intensified culture activities and complex interaction between pathogen, host, and environment (Bondad-Reantaso et al. 2005). Disease management in the aquatic system is a tough proposition due to the unique affairs where the opportunistic pathogens are constantly looking for the immune-compromised host (Mishra et al. 2017). In many instances, the occurrence of disease is closely associated with environmental deterioration, poor water quality, nutritional deficiency, higher stocking density, and high microbial load (Mishra et al. 2015). Therefore, the most appropriate approach to reduce the risk of disease outbreak is the implementation of Better management practices (BMPs). This can be best achieved by maintaining optimum water quality, providing adequate nutrition, preventing the entry of pathogens in the culture system, and reducing the stress by following realistic stocking densities. A better understanding of disease predominance, suitable detection and control measures, biosecurity program, usage of disease-resistant strains, and farm-level execution of BMPs can ascertain sustainable fish production (Mishra et al. 2017).

4.7 Implementation of Policies

It has been reported that extreme climatic events mostly affect the small-scale farmers due to their poor adaptive capability and lack of financial assistance. Though the concept of insurance in the field of aquaculture is relatively new, it is gaining remarkable attention throughout the world (Pongthanapanich et al. 2019). Therefore, introduction and proper implementation of insurance schemes could significantly assist the fish farmers to build resilience against changing climate (Barange et al. 2018). In this regard, the ecosystem approach to aquaculture (EAA) and fisheries will provide the tools and strategies for successful

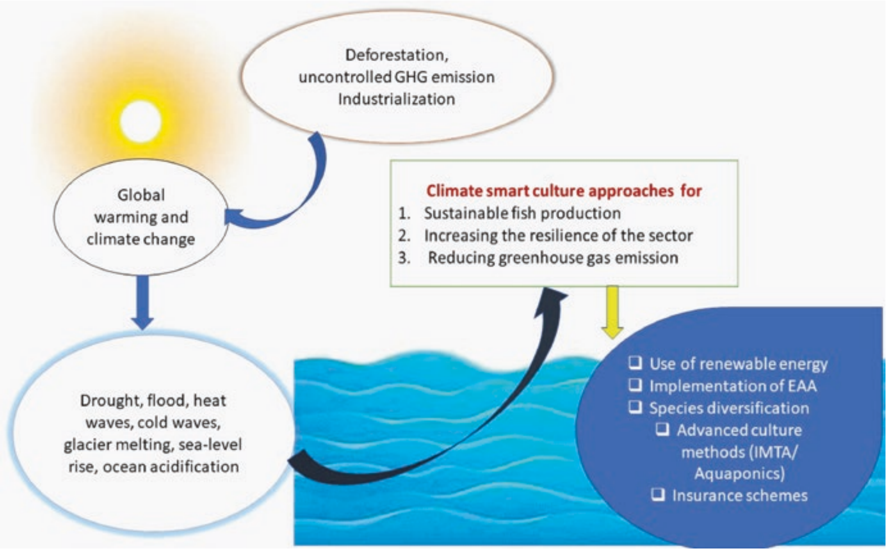

Fig. 14.1 Impact of climate change on aquaculture and their mitigation strategies

implementation of environmental guidelines, code of conduct, and policies for sustainable fish production under climate variability. Proper execution of EAA can ensure efficient use of natural resources, promoting scientific information system/ integrated monitoring services, increased adaptability of the sector, and livelihood security (Palombi and Sessa 2013) (Fig. 14.1).

5 Conclusion

The potential impact of climate change on fisheries and aquaculture activities has been highlighted in this article. Aquaculture production is continuously being exposed to the adverse effects of climate change and affects global food security. To improve the resilience capacity of the culture system, it is mandatory to make necessary amendments in the production practices. Optimization of all variables may not be always possible and hence, adaptation strategies on a priority basis should be implemented in a given production system. Developing effective and rapid responses to changing climatic conditions depends upon wider developmental goals and significant strategic planning. However, real-time adaptation methods for vulnerable regions with poorer economics will require further developmental research and execution strategies.

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