Chapter 13
Sustainable Resource Utilization in Aquaculture: Issues and Practices

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Abstract Aquaculture is the farming of commercially important aquatic animals and plants with management protocols governed by human intervention so as to supply quality protein and materials of commercial importance towards human welfare. However, in holistic sense, besides farming, it is also inherent with conservation of the aquatic flora and fauna in the process of rearing and sustainability issues of the farming process itself and the environment as well. In comparison to other production sectors those use natural resources; efficacy of animal protein production has been proven higher in aquaculture. Moreover, aquaculture has also proved advantageous over conventional agriculture because of the multi-dimensional characteristics of the water body being the culture environment. Because of the depth dimension, productivity in aquaculture is high per unit area. Sustainable resource use in aquaculture implies judicious rationality in application and use so as to attain break-even point if not positive effect both on renewable and non-renewable resources so as to maintain congenial environment, contribute to the development of the stakeholders, and results in economic profit. However, the principal objective to produce and supply in parallel with the society's demand of aquaculture produce without impacting natural capital has become more challenging especially in the backdrop of global warming and climate change issues which is gaining more and more importance. Integration of environmentally sound farming practices coupled with effective indigenous traditional practices and above all with moral and ethical obligations of all the stakeholders towards nature.

Keywords Aquaculture · Sustainability · Issues · Climate change

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13.1 Introduction

Products of aqua-farming have long been recognized as essential foodstuffs but aquaculture in India inherits a long genesis referred long back in Kautilya's Arthashastra (321–300 B.C.) and King Someswara's Manasoltara (1127 A.D.). Despite Asia's long history of development, aquaculture became an important commercial food production system and a significant source of export earning only in the late 1960s (Chua, 1986, 1994). As stated in FAO (2006), aquaculture is the farming of aquatic organisms with substantial managerial intervention to enhance production. Farming of aquatic organisms of economic importance includes finfish and shell fish viz. molluscs, crustaceans, and, aquatic plants where regular stocking, feeding, protection from predators, disease management are done. In a broader perspective, breeding, seed production and rearing of seeds to their stock able sizes also come under the purview of aqua-farming practices.

In comparison to other production sectors those use natural resources; aquaculture has been established itself in advantageous position over animal protein production systems. Moreover, aquaculture has also been proved to be more effective compared to conventional agriculture because of the 3-dimensional advantage of the aquatic culture medium. Because of the depth dimension, productivity in aquaculture is high per unit area. Boyd and McNevin (2015) reported that because of human consumption of natural resources at a ratio of 1.5:1, regenerative capacity of the Earth is being negated. In spite of higher efficiency, as aquaculture will continue with substantial use of natural resources, it is to be ensured that efficient and judicious use of resources be followed so that the resources are allowed to be renewed at a sustaining rate besides reducing costs and augmenting economic viability of the farming process.

13.2 Indian Aquaculture

Indian aquaculture exhibited a six and half fold growth during the last two decades, where freshwater aquaculture contributed over 95% of the total aquaculture production. Three prized Indian major carps; catla (*Labeo catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus mrigala*) contributed over 1.8 million tonnes (FAO, 2003) which is nearly 87% of the total aquaculture production in India. Following introduction during the 1970s, three exotic carps viz. silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) emerged as the second most important group, altogether contributing 0.169 million tonnes. The average national productivity from inland static water bodies increased from 0.6 tonnes ha^{-1} year^{-1} in 1974 to 2.2 tonnes ha^{-1} year^{-1} by 2001–2002 wherein, many farmers even achieving production levels up to 8–12 tonnes ha^{-1} year^{-1}. Optimum achievable productivity level from different culture systems has been calculated as 3–5 tonnes ha^{-1} year^{-1} in sewage-fed fish culture ponds to 10–15 tonnes

ha^{-1} $year^{-1}$ in feed based intensive pond culture systems with aeration devices. In general, freshwater aquaculture in India at present is practiced with low to moderate levels of intensification utilizing low cost inputs, especially organic manures and agriculture by-products as feedstuffs.

13.3 Resources for Aquaculture in India

Naturally endowed with vast freshwater and brackish water spread area (Tables 13.1 and 13.2), India is inherent with tremendous potentiality in the aquaculture sector. Three Indian major carps along with three exotic carps in the composite fish culture practice in the freshwater aquaculture sector continued as the backbone of inland aquaculture in India since 1970s. On the other hand, shrimp culture has been developed extensively in the coastal areas during the mid1980's because of abundant natural fry and brackish water resources especially in the estuaries of Bay of Bengal (Karim & Khandaker, 1997). Moreover, India is endowed with 8118 km long coastline and 2.02 million sq. km of Exclusive Economic Zone (EEZ) stretching along the vast geographically varied terrain and climate that support wide diversity of inland and coastal wetland habitats.

Table 13.1 Inland freshwater resources

Resources	Extent/area	Fishery practices
a. Rivers (km)	29,000	Capture
b. Canals and streams (km)	1,42,000	Capture
c. Lakes (million ha)	0.72	Capture
d. Reservoirs (million ha)	3.152	
Large	1.14	Capture
Medium	0.53	Capture
Small	1.52	Culture-based
e. Ponds and tanks (million ha)	2.85	Culture
f. Flood plain wetlands (million ha)	0.2	Culture-based
g. Swamps and derelict water bodies (million ha)	0.054	Un-classified
h. Upland lakes (million ha)	0.72	Not known

Table 13.2 Inland brackish water resources

Resources	Extent/area	Fishery practices
Brackish water (million ha)	**2.70**	
Estuaries	0.30	Capture
Back waters	0.048	Capture
Lagoons	0.14	Capture
Wetlands (Bheries)	0.043	Culture
Mangroves	0.36	Subsistence
Coastal aquaculture lands	1.42	Culture

13.4 Culturable Species

So far the genetic diversity of fishes, out of 24,600 fin-fishes in the world 2163 species (coldwater: 157; warm water: 454; brackishwater: 182 and marine: 1370) are available in India. Besides, a number of shell fishes like prawns, shrimps, crabs, scallops, oysters etc. abound in Indian waters. Even, some commercially important marine weeds are also considered highly valuable so far their cultural prospects under open sea farming are concerned.

Therefore, resources for aquaculture in India are plenty both in terms of cultivable area and culturable species. Besides comparatively cheap labour in India has made the sector more labour intensive than capital intensive, thereby incorporated the human resource more effectively with this sector even with less gender bias. Above all, the tropical climate is highly conducive for production of the cold-blooded aquatic animals including fish, and cycling of nutrients particularly the recycling of wastes generated from the farming and husbandry practices in fish farming ponds.

13.5 Legal Definition of Sustainable Agriculture

The Brundtland Commission Report stated that “Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (UNDP, 1987). Therefore, the concept of sustainable development indicated limitations imposed by the current technological status, social organizations on environmental resources use simultaneously by the ability of the biosphere to absorb the impacts of human activities. However, ‘need’ is highly variable and non-elastic which changes with economic progress, societal, racial and geographical variations.

The word sustainable is a Latin derivative, *sustinere* which is literally close to *keep in existence*, implies permanence. With reference to agriculture and allied sectors, sustainability in farming systems denotes which are ‘capable of maintaining their productivity and usefulness to society indefinitely. As a result, sustainable production system based on environment should be resource conserving, socially supportive, commercially competitive and environmentally sound (Ikerd, 1990). Therefore, *sustainable agriculture* practice implies horizontally integrated plant and animal production practices having a site-specific application which in the long-term:

(a) Satisfy human food, fiber, fuel and manure needs,
(b) Improve environmental quality and natural resource base,
(c) Assure most efficient use of non-renewable resources, on-farm resources,
(d) Integrate natural biological cycles and controls wherever possible,
(e) Ensures economic viability of farm operations.
(f) Improvise the quality of life of the practitioners and society as well.

13.6 Sustainable Development and Aquaculture

There has been much debate about the concepts of sustainability and sustainable development during the last two decades. Although most of the authors avoided coining a precise definition of sustainable aquaculture, a general consensus implication is that sustainable agro-ecosystem recycles materials with maximum energy efficiency and minimum foot prints over the natural resources. Jana and Jana (2013) suggested a modular depiction in which long-term sustainability has been designed through amalgamation of improved farm management practices, integrated farming, use of selective aqua chemicals and probiotics, conservation of natural resources, regulatory mechanism, and policy instruments.

13.7 Sustainability Transition in Indian Aquaculture

Following blue revolution, aquaculture has been evolved as a highly priced farming practice transited from the level of traditional artisanal activities as practiced during almost the last four decades. In other words, environmentally sound low input sustainable aquaculture (LISA) has been gradually shifted towards a more intensive production system leading to a number of environmental fall-outs viz. soil salination, reduction in agricultural crop and livestock production, changes in demographic profile, migration of artisanal fishers, destruction of mangrove forests etc. Coastal shrimp farming has also resulted in negative impacts on coastal aquatic biodiversity primarily because of wild shrimp seed collection with non-selective gears and by-catch loss (Das & Sarkar, 2010). In addition to the environmental effects, conflicts in resources uses, health and socio-politacal issues have also been emerged as major concerns in many areas. The Coastal Aquaculture Authority Act, 2005 framed the regulatory measures for practicing coastal aquaculture in a more sustainable and eco- friendly way. Moreover, National Centre for Sustainable Aquaculture (NaCSA) was established by the Marine Products Export Development Authority (MPEDA) under the Ministry of Commerce, Govt. of India in the year 2007 for uplifting the livelihood of small-scale shrimp farmers. The definition of 'coastal aquaculture' therein means 'culturing shrimp, prawn, fish or any other aquatic life in saline or brackish water ponds, pens, enclosures or otherwise (Puthucherril, 2016).

13.8 Essence of Sustainable Aquaculture

Sustainable aquaculture is the farming of commercial aquatic organisms which must ensure positive economic returns as commercial venture without compromising ecological ways and means, and, ensures societal benefits in the long run. Conceptually, it has evolved through debates and discussions with somewhat consensus in factual notes that wild fisheries either have already been or being overexploited and alarming numbers of native finfish and shellfish species are becoming endangered to be extinct. Such negative environmental impacts of traditional aquaculture practices have acted as impetus to frame a comprehensive definition for the issues on, open water fisheries in the oceans and food production, and to format practitioner's guidelines for sustainable aquaculture. In spite of all these, any universally accepted definition has yet not been agreed upon, nor does an international certification mechanism on sustainability been adopted. As sustainability in environmentally supported production system like aquaculture is dynamic with respect to a number of factors viz. species of culture, intensity of operation and input usage, duration of rearing, culture environment, societal need and demand etc.; updating database from research output, learning and adoption of knowledge, refining and reassessment of methods under practices are necessary to retain and maintain ecological equilibrium in aquatic ecosystems. Aquatic species are cultured with reasonable stocking densities in the controlled euphotic zones where natural feed and compounds abound. Also, water quality is naturally conserved by eco-technological methods like ecological homeostasis up to a certain extent thereby interference in natural ecosystems is minimized in utilization of organics and vital limiting compounds.

In general, as the principal objective of sustainable aquaculture is to produce aquatic organisms keeping pace with society's nutritional requirements without degrading natural capital, integration of eco-technologically sound methods coupled with area specific indigenous traditional knowledge and techniques is highly rational in practical terms. The likely positive attribute of such strategy is that, it might be less expensive with minimum collateral environmental damage caused by massive and highly variable inputs in the production process, post-harvest processing and transport, energy, and, minimize waste generation associated with them.

13.9 Issues of Sustainability in Aquaculture

The strategies towards sustainability in aquaculture have been focused much on horizontally integrated farming fish with livestock and or agri-horticulture stems like rice-cum-fish culture; carp polyculture and composite culture, rural aquaculture, intensification of small farms, wastewater-fed aquaculture, environmental regulations and fisheries acts, trans boundary aquatic ecosystems and impact of alien and introduced species (Jana & Jana, 2013). In recent years, community participation, safeguarding stakeholders' interests, ethical issues of intensification, responsible fisheries, better management practices in aquaculture, quality control and certification, and, environmental impact assessment in the sector have come into force. The two main factors preventing the attainment of sustainable aquaculture are: (i) the fact that the development process takes place under the context of a market driven economic system and (ii) the existence of a partial set of regulations. With respect to the market driven economic system there is clear evidence that even though markets are essential components of economic activities and development, markets, by themselves they are far from perfect resource allocators (i.e., market failures due to externalities and imperfect property and use rights). Thus, market imperfections prevent the efficient allocation of natural and human made capital over time (i.e., use and conservation of the environment and the natural resource base, through the use of physical-man-made capital and technologies). On the other hand, most economies relying on market drive economic systems, expect markets to good resource allocators and have over time implemented a patched and partial set of regulations usually aimed to prevent impacts with respect to the *Natural Enabling Environment* (NEE) refers to the environment and the natural resources base required to develop aquaculture as a human activity (APEC, 2009). Very few economies have set regulations or initiatives to prevent and correct the effects of impacts on the Social and Cultural Environment and on Human livelihood. Towards orienting aquaculture sector in a sustainable production practice encompassing all the facets of stakeholders, it should:

(a) Conserve natural resources and biodiversity
(b) Achieve the least degradation of the environment
(c) Utilize techniques and technologies appropriate to situation and site
(d) Generate profit or economic benefits in excess of costs
(e) Foster minimal social disruptions and conflicts and
(f) Provide for community needs.

13.10 Measures in Indian Aquaculture

With the above issues and objectives inherent within, Indian aquaculture sector should incorporate the following measurers so as to achieve sustainability:

(a) To take steps for conserving and propagating the indigenous fish species particularly the minor fishes and the environment of culture-the water bodies herein
(b) To effectively monitor/restrict unauthorized introduction of exotic species considering their ecological impacts upon the native species
(c) To functionally integrate aquaculture with other farming sectors like agriculture, animal husbandry and others so as to minimize risk and maximize resource utilization efficiency.
(d) To recycle and reuse wastes and farming sector by products for production of valuable animal protein so as to minimize environmental pollution and establish the facts in practice that waste is nothing but a misplaced wealth
(e) To adopt multi-trophic aquaculture which involves farming of species like shellfish, seaweed and carp alongside the targeted farmed species viz. salmon, trout, or shrimp in a vertically integrated design. Such farming design reduces waste generation and accumulation thereby, helps improve water quality
(f) Not to run for achieving maximum productivity but to ensure production practice with a moderate level of intensification
(g) To ensure people's participation effectively with this sector and above all
(h) To ensure strong political will which is the key factor in discussing the subject of sustainability either in aquaculture or in any spheres of resource utilization.

13.11 Climate Change and Sustainability

In recent years, global warming and climate change has been an important point of discussion throughout the globe in addressing sustainability issues in agriculture among others. The primary manifestation of such ecological changes is sea level rise, irregularity in precipitation and rain fall patterns, increased occurrence of drought and flood, increased occurrence and severity of tropical cyclones. Such phenomena very often resulted in increasing water stress which in turn adversely affected aquatic ecosystems, wild fisheries and fishers' livelihood patterns (Cruz et al., 2007; Handisyde et al., 2006; Das et al., 2013). As most of the Asian artitional fishers live in anthropogenically perturbed areas and are depend upon aquatic resources for their sustenance, they are mostly vulnerable to climate variations (FAO, 2011). As a result, the multidimensional impacts of fisheries and aquaculture in contributing poverty alleviation of the coastal populations in this geographical region are threatened by climate change. Moreover, as the productive agricultural lands in this zone are located in the vicinity of floodplain lakes, ox-bow lakes and reservoirs, marshes and swamps, adaptation strategies towards sustainability in aquaculture is imperative to establish linkages between fisheries, aquaculture and agriculture considering area specific variable agro- climatic zones. Besides, wild capture fisheries in these regions very often act as capital generators for agriculture and livestock and if the fishing system is challenged with stress, the potential of the other components is bound to be reduced (WFC, 2007).

13.12 Impact of Climate Change on Aquatic Resources

The consequence of climate change on aquatic resources are potentially huge and there is imminent fallout from increase in thermal stress and from changes in mean annual values and variability of precipitation (Anderson et al., 1991; Sarma et al., 2009). Heat waves are expected to amplify in magnitude and frequency under anthropogenic climatic variation (IPCC, 2014a, b, 2018). Projections indicated that an increase in temperature by 2–3.5 °C would reduce net agricultural income by 25% and without additional mitigation, global temperature is to increase by 3.7–4.8 °C. Because of the increasing atmospheric temperature, the sea level will rise by approx. 50 cm by 2100 (IPCC, 2014a; IMD, 2017). The increased occurrence of late summer and pre-monsoon thunderstorms, monsoon breaks and frequent short duration intense drought, non-seasonal rains, delayed monsoon and changes in seasonality, and winter rains in Asia have also been predicted by Sarkar et al. (2017) which might further stress the aquaculture sector if the trend continues.

With the existing predictions and climate warming backdrops, scarcity of water in the Ganga river basin will bound to be magnified and even may be critical with regards to ecosystem goods and services derived from the inland water bodies including riverine fisheries and aquaculture. Therefore, sustainability of riverine fisheries and aquaculture activities in the concerned basins will be poised to serious threat out of the climate changing scenario. Das (2009) expressed concerns that with the increasing demand, balancing the needs of the aquatic environment and related stakeholders might be difficult in near future. The sustainability issues of coastal aquaculture and fisheries in India will be maximally impacted as the Indian coastline of 7517 km is vulnerable with water intrusion and increase in coastal salinity as a consequence of climate change. Therefore, it is extremely pertinent to the aquaculture operators and associated stakeholders to adopt climate resilient practices towards sustainability.

Increasing surface water temperature in the sea and river is likely to alter habitat and feeding niches, affects metabolisms, breeding and migration pattern and ultimately catch and harvesting patterns which are crucial to sustainability of both capture fisheries and aquaculture. IPCC (2014b) predicted that a rise in temperature as low as 1 °C could have a profound impact on survival and the geographical distribution of different fresh water and marine fish species. Dey et al. (2007) observed advancement on the onset of breeding of Indian major carps by 1 month during the last decade which was primarily attributed primarily by the effect of increased water temperature and shifting of the rainfall pattern facilitating early maturation and spawning. Potential climate change-induced stresses on wetland fisheries were identified as water stress (95%), wetland accretion/ sedimentation (85%), proliferation of aquatic macrophyte (70%) and loss of wetland connectivity (65%) (Sarkar et al., 2019).

13.13 Carbon Sequestration and Aquaculture Sustainability

As carbon di-oxide and methane were identified as the major green house gases towards climate change via increasing environmental temperature, it has become a serious point of debate whether aquaculture can act as a source of carbon or helps in sinking the same. As the low intensive low input aquaculture strategies are generally practiced in most of the tropical and sub-tropical aquaculture practicing countries, in terms of carbon sequestration and carbon budgeting, they appear to be more sustainable compared to the intensive aquaculture technologies being practiced in other parts of the globe. The Central Inland Fisheries Research Institute has developed C budgeting strategy to quantify the rate of total carbon sequestration per annum taking into account the operating biotic and abiotic components of the system. This would help in explaining the differences in C sequestration potential of different type of wetlands and in quantifying the ‘commercial blue C’ in the form of fish crop harvested from the system as a spinoff of the C-cycle (Sarkar et al., 2019).

13.14 Technology Scouting and Prioritization Towards Climate Resilient Aquaculture

To attain and retain sustainability in the aquaculture sectors with the perspective of environmental warming and climate change, it is imperative to select appropriate technologies which are suitable and climate smart. The National Mission on Sustainable Knowledge for Climate Change (NMSKCC) under Department of Science & Technology (DST), Government of India has scouted about 778 technologies that are subdivided into 11 sub-categories following different foresight techniques with respect to agriculture and allied disciplines. The top ten technologies under each sub-category were shortlisted following a logically drawn quantitative Multi Criteria Decision Analysis (MCDA) technique. Primarily, in the MCDA method, technologies are prioritized using five broad parameters viz. Social, Technological, Environmental, Economy and Policy (STEEP). Three steps were followed to prioritize technologies (Das, 2019). These technologies need immediate attention for validation in various agro-ecological regions in cognizance with all the concerned stakeholders' participation.

The key issues of climate change related to agriculture are (i) effect on crops (ii) implications on water availability (iii) impacts on livestock and milk production iv) effect on freshwater and marine fisheries. Considering the above potential impacts an urgent need has been felt for developing climate smart sustainable agriculture (CSSA) in India. This will be an integrated approach to achieve sustainable agricultural development for food security under climate change (Das, 2019).

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