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Advances in Climate Resilient Aquafarming Practices

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Climate change impacts on various food-producing practices are already being witnessed all over the world, especially in a more vulnerable country like India, having an enormous populace reliant on farming, and extending extreme burden on natural assets with poor coping mechanisms. Among the different food-producing practices, fisheries and aquaculture have prime importance. The risk factors of climate change such as an increase in temperature, sea-level rise, cyclone, storm surges, ocean acidification and all associated ecological changes are causing a wide range of problems in the fisheries sector. The aquaculture sector is sensitive to the changing climate, which needs a different vision for improved production. The socio-economic effects of climate change on the aquaculture industry and communities should be clearly understood to adopt sustainable and environmentally sensitive farming practices. Under changing environmental conditions, the focus should be on the adaptation of climate-resilient culture fisheries for climate-smart aquaculture strategy to improve nutritional security for the growing population. A suitable strategy is to adopt an integrated approach in the farming system. Many traditional integrated farming systems such as agri-aquaculture based system, livestock-based aquaculture system and agri-aqua-livestock integration is already in use. Besides, the scientific interventions in the concept of integrated farming has resulted in many viable advanced technologies such as partitioned aquaculture system, Integrated multi-trophic aquaculture (IMTA), aquaponics, biofloc technology, recirculatory aquaculture systems (RAS) and raceways. All these practices are helpful to improve production as well as in the reduction of climate change impacts and to avoid contribution towards climate change.

(***Key words:*** *Aquaculture, Climate change, Integrated farming, Sustainability)*

Climate change is reflected as one of the serious global concern today. The challenges of climate change such as an increase in temperature, sea-level rise, cyclone, storm surges, ocean acidification and all associated ecological changes are causing a wide range of problems in the fisheries sector. Climate change is considered an additional output of human civilization.

According to IPCC special report (2018), global warming is probably going to reach 1.5°C between 2030 and 2052 from the present rate of 0.8 to 1.2°C, if it keeps on increasing at the current rate. Warming seas too will bring about an ascent in a sea level which can also affect the coastal zone. Thus high temperatures, salinity, pH and oxygenation can also be encountered in coastal regions in particular. An outline of the variety of possible generators of climate change impacts in coastal zones was given by Parry *et al.* (2007) for the IPCC (Table 1).

Fish is known to be the cheapest protein source. The sources of fish can be broadly divided into two sectors, such as capture and culture. The capture fishery solely depends on the nature for the production. Culture is a controlled or semi-controlled production system that is carried out in freshwater, brackish water or marine water. In the current scenario, there is an increase in the demand for fish due to the increase in population. However, the capture fishery production has reached its maximum potential, and there is only a little scope is left to increase the production. Thus the focus is on aquaculture productions as there is vast scope for increasing the production. Nevertheless, increasing climate change brings many challenges to the aquaculture

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Table 1. *Major climate change impacts on coastal ecosystem and aquaculture*

Sl. No.	Climate driver (trend)	Effects on coastal systems and aquaculture
1.	CO_2 concentration (↑)	Increased CO_2 fertilization; decreased seawater pH (or 'ocean acidification') negatively impacting coral reefs and other pH sensitive organisms.
2.	Sea surface temperature (↑)	Increased stratification/changed circulation; reduced incidence of sea ice at higher latitudes; increased coral bleaching and mortality; poleward species migration; increased algal blooms.
3.	Sea level (↑)	Inundation, flood and storm damage; erosion; saltwater intrusion; rising water tables/ impeded drainage; wetland loss (and change).
4.	Storm intensity (↑)	Increased extreme water levels and wave heights; increased episodic erosion, storm damage, risk of flooding and defence failure.
5.	Storm frequency, Storm track	Altered surges and storm waves and hence risk of storm damage and flooding.
6.	Wave climate	Altered wave conditions, including swell; altered patterns of erosion and accretion; re-orientation of beach plan form.
7.	Run-off	Altered flood risk in coastal lowlands; altered water quality/salinity; altered fluvial sediment supply; altered circulation and nutrient supply.

sector. Coastal ecosystems, inland aquaculture and offshore marine aquaculture (Mariculture) are being affected due to long term climate change. Sea-level upsurge can contribute to coastal erosion, impacting coastal geomorphology and hydrodynamics, which can positively and negatively alter the appropriate areas for shellfish cultivation (Filgueira *et al*., 2016).

The aquaculture sector is sensitive to the changing climate, which needs a different vision for improved production. The social and economic impacts of climate change on the aquaculture industry and communities should be clearly understood to adopt sustainable and environmentally sensitive farming practices. Temperature is a regulatory variable for finfish and shellfish growth (Elliott and Elliott, 2010) which can affect the metabolism and energy expenditure needs. The temperature rises inside the species physiological resilience may increase growth, nevertheless growth and feeding decrease and mortality increase if resilience is surpassed; high temperatures can also undesirably affect the quality of the flesh (Ørnholt Johnsen *et al*., 2017). Under changing environmental conditions, the focus should be on the adaptation of climate-resilient culture fisheries for climate-smart aquaculture strategy to improve nutritional security for the growing population. It is the need of the hour to concentrate on the reduction of climate change impacts and to avoid contribution towards climate change. A suitable strategy is to adopt an integrated approach to farming (Ahmed *et al*., 2018). The basic principle of integration is that the waste of one component acts as a valuable input for the other. Based on this concept, there are many traditional integrated farming systems such as Agri-aquaculture based system, Livestock based aquaculture system, Agri-aqua-livestock integration (Fig. 1.) (Ayyappan *et al*, 2006).

Advanced climate resilient aqua-farming practices

Scientific interventions in the concept of integrated farming have resulted in many viable advanced technologies. Some of such advanced technologies are as follows:

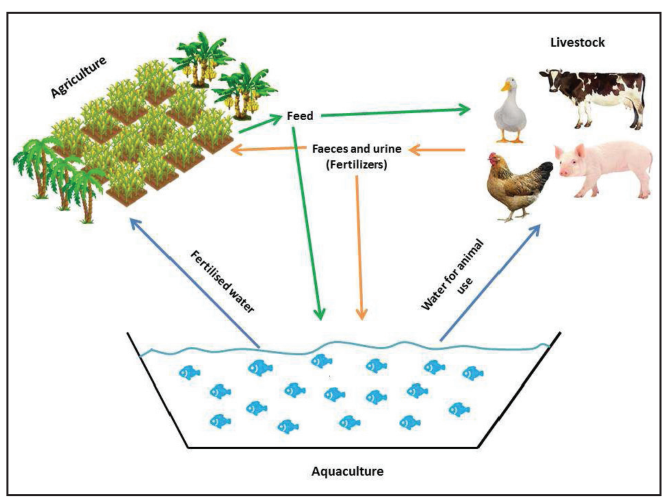

Fig. 1. *Schematic diagram of agri-aqua-livestock integration*

Algae based integrated culture systems

Algae being the primary producer play an important role in keeping the integrity and sustainability of the ecosystems. Monoculture of algae is carried out to use as feed, food and for manufacturing cosmetics, medicines, etc. and also used as by-products. However, the studies have shown that the integration of algae into the aquaculture helps to maintain the water quality and yields better production. Some of the algae-based culture practices include:

The partitioned aquaculture system (PAS)

The PAS system was developed at Clemson University in 1989. Basically, this system is microalgae-based re-circulating aquaculture. The design includes conventional culture ponds integrated with shallow algal tanks. The pond water which is enriched with the fish and feed wastes is circulated to the algal tanks where the same is utilized for photosynthesis and algae production (Drapcho and Brune, 2000; Turker, 2003). The water circulation in the system is maintained with the help of a paddle wheel. It is found that the unconventional photosynthesis yield 2 to 3 g C fixation m^{-2} day^{-1} whereas this low energy paddlewheel mixing of the bulk pond water can sustain algal yields of 10 to 12 g C m^{-2} day^{-1} (Brune *et al*., 2004). Algal photosynthesis helps detoxification (ammonia removal) of pond water and solar-driven natural oxygen production. In short, this system can be called a solar-powered biological waste treatment systems. However, the growths of cyanobacteria in such microalgal tanks were considered a threat owing to its negative impacts. Many studies were conducted to find suitable filter-feeding organisms for controlling algal populations. Turker *et al*. (2003) found that the use of Nile tilapia controls microalgae production, which reduced the occurrence of cyanobacteria compared to the non-tilapia system. Hence, the PAS is a viable option that is sustainable, low impact, high-yield, and more controllable fish production system which provides algae as additional output.

Seaweed farming

Seaweed is a macro algae with great commercial applications. There are about 9200 species of seaweeds globally; only 221 species are economically important. Indian coastline hosts around 896 species of marine algae comprising Chlorophyta - 228 species, Phaeophyta - 210 species, Rhodophyta - 455 species and Xanthophyta - 3 species (Umamaheswra Rao, 2011). Application of seaweeds is diverse, starting from direct consumption to pharmaceutical applications. Seaweed farming has numerous advantages such as feedstock for bio-ethanol creation, as the mode of carbon sequestration and ocean acidification mitigation, as a helpful alternative for coastal living. Seaweed sap is used as a foliar spray as a bio-stimulant to increase the productivity of crops (Layek *et al*., 2015; Singh *et al*., 2015). Like micro algae seaweeds also possess bio-mitigation properties in the live form as well as in the form of biochar. Biochar, a permeable carbonaceous solid, created by the thermochemical transformation of organic materials in an oxygen-depleted atmosphere possessed physic-chemical properties appropriate for long-lasting storage of carbon in the environment and are potentially beneficial for the enhancement of soil quality. Biochars additionally have bioremediation applications in re-establishing the lands as well as marine ecosystems contaminated with heavy metal. Like plants, seaweeds utilize carbon dioxide and release oxygen, thus help to reduce the amount of greenhouse gas (Zacharia *et al*., 2015). Seaweed cultivation is commonly carried out in coastal waters. There are different types of methods of cultivation such as; broadcasting, line culture, net culture, raft culture, pen, cage, net bag and tube systems. The selection of culture methods is made based on the conditions of the culture sites.

Integrated multi-trophic aquaculture (IMTA)

IMTA is a sustainable integrated farming system. IMTA was designed and developed to reduce the environmental impact on marine cage farming (Troell, 2009). The system integrates different trophic level species to utilize the effluents from the cages and to avoid their negative impact on the ecosystems (Chopin, 2006). The major components of this system include

- Commercially important culture species or fed aquaculture species (e.g. finfish/shrimp)
- Organic extractive aquaculture species (e.g. shellfish/herbivorous fish)
- Inorganic extractive aquaculture species (e.g. seaweed)

Integration of these organic and inorganic extractive feeders utilizes the organic and inorganic contents of the wastes released from the marine cages, respectively (Neori *et al*., 2004).

Aquaponics

Aquaponics has become increasingly popular in recent years. It is a recirculating aquaculture system that offers the combined production of plants and fish (Rakocy, 2012). It is an integrated multi-trophic framework that consolidates the segments of recirculating aquaculture and hydroponics (Rakocy *et al*., 2006), in which the nutrient-rich water from the fish tank is utilized for plant growth. Nutrients recycling will be performed efficiently through the transfer of minerals from aquaculture to hydroponics, while water recycling decreases water usage (Turcios and Papenbrock, 2014). The necessity of a substantial quantity of macro and micronutrients from industrial and mining source in hydroponic systems prompts high energy consumption (*i.e*., for production and transport) and limited resources use (e.g., phosphorus and oil) (Sonneveld and Voogt, 2009; Ragnarsdóttir *et al*., 2011; Sverdrup *et al*., 2011). Also, irregular removal of the significant volumes of nutrient-rich water in the non-recirculating system results in high water utilization along with surface and groundwater contamination (Gagnon *et al*., 2010). These systems are intended to rear more number of fishes in comparatively less water by treating it to eliminate toxic waste products and afterwards reusing it (Rakocy, 2012). Recirculating aquaculture systems also exhibit a high degree of water reuse (95 to 99%) (Dalsgaard *et al*., 2013) with water utilization drop down 100 litres per kg of fish produced (Martins *et al*., 2010). The process of reusing the water several times leads to the accumulation of non-toxic nutrients and organic matter. In aquaponics, the excess nitrate is utilized for important plant production and the removal of nitrate in the vapour state will be prevented in denitrification components (Van Rijn, 2013). Aquaponics combines the activities of vegetable growing and fish farming in a climate-controlled greenhouse setting. The process results in increasing food production efficiency and prevents loss due to pests and irregular weather patterns.

Biofloc technology

Bioflocs are the association of microorganisms, micro and macro invertebrates, filamentous organisms, extracellular polymers, faeces and uneaten feed which are suspended in the water column (Kuhn and Lawrence, 2012). Biofloc based culture systems can be broadly classified into two categories, such as *in-situ* and *ex-situ*, based on the origin and existence of biofloc. In the *in-situ* system, the biofloc is developed within the culture tanks which facilitate the feed availability (biofloc) throughout the day for the fishes. In the *ex-situ* system, the biofloc is developed and produced in the required quantity outside the culture tanks and are provided along with the feed for the fishes. Biofloc culture system can solve two problems at once, firstly, the elimination of water exchanges to maintain water quality and second the reduction of protein inputs. It reduces the nitrogen and ammonia from the culture system and improves the environmental control over production. It also acts as nutrient trappers which can be useful in feed management, thereby reducing the feed cost. Biofloc technology is also helpful in improving biosecurity and health. Biofloc can be advantageous for sustainable aquaculture in terms of minimizing water exchange and maintains acceptable water quality inside the culture ponds (Hari *et al*., 2006; Samocha *et al*., 2007; Arnold *et al*., 2009; Ballester *et al*., 2010).

The quality of water in biofloc system is maintained by bacteria which immobilize the inorganic nitrogen (Lancelot *et al*., 1991; Avnimelech, 1999) and diminishes the harmful ammonia nitrogen in a couple of hours when contrasted to slow conventional nitrification process (Hopkins *et al*., 1995; Hargreaves, 2006). Along with all the advantages of biofloc system it also helps to prevent the release of nitrous oxide (N_2O), a major greenhouse gas (GHG). N_2O is produced during the process of nitrification and denitrification, typical in aquaculture systems with a global warming potential 310 times greater than that of carbon dioxide (CO_2) over a period of hundred years. (Hu *et al*., 2012).

In addition, the incorporation of biomimicry in biofloc system has resulted in the use of another technology called copefloc technology in shrimp farming. The copefloc system produces natural food biomass and provides recyclable waste nutrients from aquatic animals by imitating the natural habitat of the shrimp (Santhanam *et al*., 2019). The copefloc technology is gaining its importance as an effective intensified yet, sustainable culture practice to increase shrimp production.

Recirculatory aquaculture system (RAS)

Recirculating aquaculture systems (RAS) are intensive tank-based culture system which facilitates water reuse using different treatment steps. A typical RAS unit consists of a culture tank, along with a solid removal unit followed by a nitrogen removal and disinfection unit. These units recycle the outlet water from the culture tanks and are circulated back to the culture tank, which reduces the dependence on water and gives almost complete control over the culture system. As a result, the RAS can be used in any part of the world irrespective of the climatic condition (Badiola *et al*., 2018). This attribute helps in the reduction of CO_2 emission associated with food transport by facilitating the culture of seafood near the market areas (Martins *et al*., 2010). The research has also proved that integration of aquaponics in the RAS system can help in the effective utilization of unwanted nitrogen from the RAS system and can produce vegetables as an extra output (Calone *et al*., 2019). However, it is quite cost-effective technology and needs further research in India to conclude which species best suits RAS.

In-pond raceway system (IPRS)

The flow through raceway production systems is evolved from earthen ponds. Earthen ponds were then replaced with a wooden or concrete structure to avoid the soil erosion that happens in earthen raceways (Fronshell *et al*., 2012). Then also the major disadvantages of raceway were the demand for a huge volume of water and the release of organically rich water to nature (Masser, 2012). Hence, an advanced raceway system named In-pond raceway system (IPRS) has been developed by the U.S. Soybean Export Council (USSEC) as a technique for increasing fish production with reduced environmental effects. It is an effective intensive aquaculture practice for regions with high water consumption and limited land resources (Li *et al*., 2019). In general, the IPRS system integrates the benefits of four aquaculture technologies: re-circulation systems, raceway models, cage farming and pond aquaculture systems. The principle of IPRS is to aggregate fed fish into cells or "raceways" inside a pond and provide them with a continuous circulation of water to maintain optimum water quality and improve feed management. It also can minimise the loading of solid waste in the pond by concentrating and eliminating it from the downstream end of the raceway units. As in the case of other intensive culture practices, IPRS also has the threat of disease and in addition, the system needs electricity backups for continuous and smooth running.

Climate change is certainly not a forthcoming event, but it is a current issue what the entire world is witnessing. The major action points include the adoption of methodologies to reduce the already happened unprecedented changes and the other one is to avoid further addition to the already existing negative impacts. Aquaculture being one among the topmost contributor and fastest-growing food sector; it is necessary to adopt the best method of culture, taking into account the need as well as the sustainability.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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