Climate change impact on coastal fisheries and aquaculture in the SAARC region: Country paper – India

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Introduction

Observations in fisheries sciences related to climate change foresee a future with intensified climate change as a consequence of increased greenhouse gases (GHGs) in the atmosphere because of human activities. The increase in GHGs has resulted in warming of climate systems or global warming. In last 100 years, ending in 2005, the average global air temperature near the earth's surface has been estimated to increase at the rate of 0.74 ± 0.18°C (1.33 ± 0.32°F) (IPCC, 2007). In the latest IPCC report (IPCC, 2014), climate model projections indicated that the global surface temperature during the 21st century is likely to rise a further 0.3 to 1.7°C (0.5 to 3.1°F) for their lowest emissions scenario and 2.6 to 4.8°C (4.7 to 8.6°F) for the highest emissions scenario. In the past, 15 of the 16 warmest years have occurred since 2001 and rank among the 15 warmest years in the instrumental record of global surface temperature since 1850. Climate change and associated warming is increasingly being felt in many parts of the globe including India. Climate change is predicted to lead to adverse, irreversible impacts on the earth and the ecosystem as a whole. Although it is difficult to connect specific weather events to climate change, increases in global temperature has been predicted to cause broader changes, including glacial retreat, arctic shrinkage and worldwide sea level rise (Mohanty *et al.*, 2010). With large growing population, low-lying coastline, and an economy that is closely tied to its natural resource base, India is considered vulnerable to the impacts of climate change.

Importance of fisheries and aquaculture

India is one of major fish producing countries in the world contributing over 3% of both marine and freshwater fishes to the world production with third position in capture fisheries. Fisheries and aquaculture play very important role in terms of food supply, food security and employment opportunities in India. India has an Exclusive Economic Zone (EEZ) of 2.02 million sq.km, and a long coastline of 8,118 km and two major groups of Islands with rich and diverse marine living resources. The marine fisheries wealth is estimated at an annual harvestable potential of 4.412 million metric tonnes. An estimated 4.0 million people depend for their livelihoods on the marine fisheries resources. Marine fisheries contribute about Rs. 65,000 crores to the Indian economy and makes up a significant portion of the export earnings (3%) of the country and balance of trade. The share of marine fisheries to India's GDP is 1.11%. The marine fisheries of the country are highly diverse but predominantly comprising small-scale and artisanal fishers. It is estimated that 63% of the marine catch in India originates from the western coast, with the remaining being made up by the eastern coast.

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World food fish aquaculture production expanded at an average annual rate of 6.2 percent during the period 2000-2012 (9.5 percent in 1990–2000) and the production has increased from 32.4 million to 73.8 million tonnes (FAO, 2016). Coastal (brackishwater) aquaculture, a rapidly growing sector in India is more or less synonymous with shrimp farming. Brackishwater aquaculture contributes to the food production, employment and income generation to the tune of 5 billion in export earnings alone.

India's freshwater resources consist of 1, 95,210 km of rivers and canals, along with 2.9 million hectares of minor and major reservoirs, 2.4 million hectares of ponds and lakes and 0.8 million hectares of flood plains and derelict water bodies. Inland fisheries contribute 13% to the total fish production of the country (FAO. 2016).

Food and nutrition security

Fish has been recognized as an excellent food source for human beings for centuries and is preferred as a perfect diet not only due to its excellent taste and high digestibility but also because of having higher proportions of unsaturated fatty acids, essential amino acids and minerals for the formation of functional and structural proteins. Fish provides about 20 % of animal protein intake (Thorpe *et al.*, 2006) and is one of the cheapest sources of animal proteins as far as availability and affordability is concerned.

World population is predicted to reach nine billion by 2050, resulting in increased global food needs in the first half of this century (McMichael, 2001). The capacity to maintain food supplies for an increasing and expectant population will depend on maximizing the efficiency and sustainability of the production methods in the wake of global climatic changes that are expected to adversely impact the former (De Silva and Soto, 2009). On the other hand, fish provide an affordable, often fresh and unique source of animal protein to many rural communities in developing countries. Of all current animal protein food sources for humans, only fish is predominantly harvested from wild origins as opposed to others which are of farmed origin. Overall, there have been significant changes in global fish production and consumption patterns (Delgado *et al.*, 2003) with a major shift in dominance over a 25-year period towards developing countries and China. This changing scenario is accompanied by one in which supplies from capture fisheries are gradually being superseded by farmed and/or cultured supplies, accounting for close to 50 percent of present global fish food consumption (FAO, 2016).

Livelihood and economic development

Fishing is an industry of great cultural and economic significance in India, and historically, one of the fastest growing industrial sectors as well. Production of fish has increased eleven fold since independence, with total production growing from 0.75 million tonnes to 9.6 million tonnes. This represents a year on year growth rate of 4.5%, placing India at the head of global production, just behind China. It is also a source of employment for 14.5 million people, and foreign exchange of US$3.51 billion.

Indian seafood exports reached an all-time high to the tune of 10, 51,243 metric tonnes and 5.52 billion USD in 2014-15. Marine product exports, crossed all previous records in quantity, rupee value and US$ terms. Compared to the previous year, seafood exports recorded a growth of 6.86 % in quantity, 10.69% in rupee and 10.05 % growth in US$ earnings respectively. Frozen shrimp continued to be the major export item in the export basket in terms of quantity and value, accounting for a share of 34.01% in quantity and 67.19% of the total US$ earnings. Farmed shrimps alone account for 51% of the total earnings (www.mpeda.gov.in).

Current trends and status of fisheries and aquaculture

The Indian marine fishing sector is facing serious challenges such as unsustainable harvesting, socio-economic conflicts, low catch per unit effort, low income and related issues and added to that is the issue of climate change and associated sea warming. Climate change is one of the biggest challenges that the fisheries sector is facing and time-bound adaptation and management plans are necessary. The impacts of climate change on marine fisheries are amply visible in the Indian EEZ and surrounding high seas. Such impacts have brought perceptible changes in the fishery of some species, forcing fishers to make changes in fishing operations. Climate change is also one of the reasons for changes in abundance of vulnerable fish stocks. The vulnerability of a species to climate change is generally considered as the extent to which abundance or productivity of species in a region could be impacted by climate change and decadal variability.

Inland fisheries in particular have shown exponential growth, jumping from a share of 46% to 85% in total fish production. Freshwater aquaculture contributes to 95% of the country's aquaculture output, with only a handful of species making up the bulk of the production capacity of the industry. Brackishwater aquaculture and mariculture represent as yet untapped potential in the sector - though traditional practices in the bheries of West Bengal and pokkali fields of Kerala have a long and storied history, the application of these methods is sporadic and ripe for popularization.

Climate change impact on coastal fisheries and aquaculture

Climate change will intensify by 2050 and though climate outcomes cannot be precisely predicted, the probability towards greater impacts of climate challenge is becoming clearer. Climate change is one of the most important global environmental challenges with implications on food production including fisheries and aquaculture sector, natural ecosystems, freshwater supply, health, etc. Climatic scenarios generated by computer models shows that India could experience warmer and wetter conditions as a result of climate change including an increase in the frequency and intensity of heavy rains and extreme weather events (EWEs). The effects of climate change in aquatic ecosystems can be direct, through rise in sea surface temperature (SST), and associated changes in the phenology of the organisms, or indirect *i.e.*, through ocean acidification, through shifts in hydrodynamics and rise in sea level.

Climate change on fishery habitat

Marine ecosystems are not in a steady state, but are affected by the environment, which varies on many spatial and temporal scales. Fish populations respond to variation in different ways. Decadal variations may have unforeseen impacts, including cyclic changes in the production level of marine ecosystems that favor one species or group over another.

Sea surface Temperature (SST) increase: Temperature is likely the single most important factor in among the environmental variables affecting the growth and development of aquatic organisms. Earth has been in radiative imbalance since at least the 1970s, where less energy leaves the atmosphere than enters it. Most of this extra energy (~90%) has been absorbed by the oceans (IPCC, 2014). The variation of Sea surface Temperature (SST) along Indian seas during the 40 years from 1976 to 2015 revealed that SST increased by 0.602°C along the northeast India (NEI), by 0.597°C along the northwest India (NWI), by 0.690°C along the southeast India (SEI) and by 0.819°C along the southwest India (SWI). However, the rate of change in SST was highest in northwest India (0.0156/annum) followed by southwest India (0.0132/annum), southeast India (0.005/annum) and northeast India (0.001/annum) respectively. The rate of change in SST over Indian Seas revealed that west coast has more impact than in the east coast of India. Northern Indian Ocean has been identified as one of the 17 climate change hotspots among world oceans. These areas will warm faster than 90% of the world oceans. Long-term climate change is likely to impact the marine environment and its capacity to sustain fish stocks and exacerbate stress on marine fish stocks.

Ocean acidification**:** The ongoing reduction in the pH of the Earth's oceans presents a significant challenge to the survival of marine fish. Seawater, by absorbing carbon dioxide and forming carbonic acid, is slowly dropping in pH from its natural, slightly basic state towards pH neutral conditions. The pH of the oceans has dropped to around 8.069 from a pre-industrial age state of 8.179. A total change of -0.355, to 7.824 by 2100 has been estimated by various studies.

Studies indicated an increasing trend in the annual number of instances when pH of surface waters off Kochi was less than 6. Analysis of the instances of low pH values of surface waters in three depth zones *viz*., 10m, 20m and 30m during the period 2005 to 2012 has indicated that in the year 2012, pH of surface water at 10m depth zone was low for a considerably longer period than in the previous years (CMFRI-NICRA, 2013).

Coral bleaching**:** Warmer water temperatures can result in coral bleaching that resulting in the expulsion of the symbiotic zooxanthellae from the tissues of coral. Between 1979 and 1990, sixty major episodes of coral bleaching were recorded, and in 2016 the longest coral bleaching event on record was observed. Several studies relate bleaching events with global warming and climate change during the last few decades (Lix *et al*., 2016), and 70% of the reports of coral bleaching at that time were associated with reports of warmer than normal conditions (Glynn, 1991).

Observations on bleaching events have shown that individual species respond differently to this change in thermal environment, with higher degrees of mortality typically seen in branching corals such as *Acropora* (Mohanty *et al*., 2013). Successive bleaching events could lead to a reduction in the species richness of corals in certain global warming hotspots.

Coral reef ecosystems support a great diversity of benthic organisms, of which zoanthids, commonly found among degraded reef ecosystems, compose the dominant fauna in the rocky intertidal regions. On the Saurashtra coast, in Gujarat, studies carried out on the distribution and community structure of Zoanthids indicated higher adaptive capacity to changes in environmental and abiotic conditions in comparison to their counterparts. Coral reefs continue to suffer due to high nutrients inputs, bleaching and other anthropogenic activities, leading to shift in reef pattern towards more aggressive and rapidly growing benthic communities such as zoanthids (Kumari *et al*., 2015).

Sea level rise**:** Sea level rise at long time scales is mainly due to thermal expansion and exchange of water between the other reservoirs (glaciers, ice caps, etc.) including through anthropogenic change in land hydrology and the atmosphere. The global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. Additionally the rate of rise accelerated during 1993 to 2003, to 3.1 mm per year. The total 20thcentury rise is estimated to be 0.17 m. The movement of the saltwater/freshwater interface further inland will cause reduction and extinction of estuarine associated habitats that are common nesting and breeding grounds for a wide variety of marine fish.

Sea-level rise estimates for the Indian coast are between 1.06–1.75 mm per year, with a regional average of 1.29 mm per year, when corrected for GIA using model data (Unnikrishnan and Shankar, 2007). These estimates are consistent with the 1–2 mm per year global sea-level rise estimates reported by the IPCC.

Changes in wind speed and direction: As winds are generated by differences in temperature, rising surface temperatures on the earth's surface are causing winds worldwide to slow dramatically. Reductions in wind speed by 1-3% are expected over the next 50 years, and as high as 4.5% over the next 100 years.

Changes in rainfall: Changes in average precipitation, potential increase in seasonal and annual variability and extremes are likely to be the most significant drivers of climate change in aquatic systems. Analysis of historical rainfall data in the Andaman and Nicobar islands revealed that while there has been no change in the amount of rainfall received, the patterns of rainfall have changed with increase in number of extreme rainfall events (Velmurugan *et al.*, 2015)

Variations in annual rainfall intensity, dry season rainfall and the resulting growing season length are likely to create impact on shrimp/ fish farming and could lead to conflict with other agricultural, industrial and domestic users in water scarce areas.

Impact on fish stock

A metabolic increase of 10% corresponds to a 1^{o}C increase in temperature, implying of seawater as low as 1ºC could affect the distribution and life processes of fish. This constraint in physiology will result in changes in distributions, recruitment and abundance. Changes in timing of life history events are expected with climate change. Species with short-life span and rapid turnover of generations such as plankton and small pelagic fishes are most likely to experience such changes. At intermediate time scales of a few years to a decade, the changes in distributions, recruitment and abundance of many species will be acute at the extremes of species' ranges. Changes in abundance will alter the species composition and result in changes in the structure and functions of the ecosystems. At long time scales of multi-decades, changes in the net primary production and its transfer to higher trophic levels are possible.

Changes in timing of life history events are also likely to result from the warming of the Earth's waters. Many tropical fish stocks are already exposed to high extremes of temperature tolerance, and already face regional extinction, and some others may move towards higher latitudes. Shifts in spawning periods of fishes have already been observed in a number of commercially important fish stocks, such as threadfin bream (Zacharia *et al.*, 2016).Changes in distribution patterns of two key species in Indian fisheries have already been established – migration patterns of the Indian oil sardine and Indian mackerel have changed greatly over the past 50 years (Vivekanandan *et al.*, 2009).

Ocean-atmospheric coupled climate models predict changes in the ocean circulation and hypothesize that changes in the ocean circulation will stimulate phytoplankton biomass production in the nutrient depleted areas in the open ocean. The effect on atmospheric CO_2 is uncertain because the relationship between the enhanced primary production and air sea exchange of CO_2 is not understood.

Most models show decreasing primary production with changes of phytoplankton composition to smaller forms, although with high regional variability. Marked effects in plankton distribution have also been noticed concurrent to changes in sea surface temperature. These changes may affect the distribution of fish stocks that predate on plankton. Ocean acidification is believed to have negative consequences for marine denizens, particularly calcifying organisms, subjecting them to the risk of dissolution. A decline in primary productivity has also been forecast.

Impact on fish stock availability

Evidence exists for increasing damage by extreme weather events, particularly cyclones, over time. There are various explanations for this, ranging from greater population densities to the wider effects of climate change (IPCC, 2013).

Until the mid-1980s, the restricted distribution of oil sardine ensured that the entire catch of oil sardine was obtained from the southwestern coast of India. North of 14^{o}N, little to no oil sardine was caught previously. In the last two decades, however, the oil sardine catch from 14^{o}N to 20^{o}N has gradually and consistently increased, contributing 15% to the all-India oil sardine catch by 2006 (Vivekanandan *et al.*, 2009). Since the catch in the Southwestern regions has not decreased in overall terms, this represents an extension of the distributional boundaries of the oil sardine.

Studies on the seasonal distribution of skipjack tuna reveal that during winter months, when sea surface temperature is lower, migration occurs towards offshore areas, and during warmer months, migration occurs towards inshore areas during warmer months. Changes in sea surface temperature due to global warming could result in changes in the seasonal distribution of certain species, and ultimately disruption in their harvest, which is usually based on indigenous knowledge (Zacharia *et al.*, 2016). Changes in distributional boundaries also bear the potential to bring up delicate questions of fishing rights, especially within the context of geopolitics and exploitation of the resources found within neighbouring exclusive economic zones.

Impact on the harvesting sector

Climatic changes that affect distribution also affect the fishing methods used to harvest affected fish stocks. In the Bay of Bengal, rising sea surface temperatures have caused fisher folk to increase the depth at which nets are cast. Studies have shown increase in recruitment and catch of oil sardine and Indian mackerel during the post southwest monsoon season as a result of increased temperatures (Zacharia *et al.*, 2016).

Change in wind direction and speed adversely affect yellowfin tuna fishery of the southeastern coast of India. The north to south winds during October-January is favorable for tuna fishery with tuna moving along with wind and current from offshore deeper waters to near shore shallower waters. In Mumbai, studies of sea surface temperature against catch per unit effort in hour revealed a mild positive correlation between the two parameters, indicating that with rising temperatures, greater amounts of energy must be spent to harvest a particular quantity of fish (CMFRI-NICRA, 2016).

Studies confirm that the impact of fishing pressure is very high and wider spread as compared to that of sea surface temperature on the fish abundance. However, as 14% of species are also vulnerable to changes in SST, measures to control fishing need to be increased in parallel with conservative management measures, which can increase resilience of vulnerable species to climate variability (CMFRI-NICRA, 2016).

Vulnerability assessments carried out through surveys of 8000 households from coastal villages in India have revealed that the level of knowledge on the effects of climate change is inadequate, and requires further input, both from government institutions as well as stakeholders (CMFRI-NICRA, 2013).

A potential impact from climate change is the increase in frequency of extreme weather events and the associated damage to the fishing sector. Cyclones of sufficient strength may damage equipment and fishing facilities, as well as cause disruptions in fishing operations.

Life cycle assessments (LCA) performed on the fishing industry has shown the majority of emissions originating from the fishing sector are generated during the actual harvesting phase, followed by the processing phase (CMFRI-NICRA, 2014).

Impact on aquaculture

Nearly 65% of aquaculture production is inland and concentrated mostly in the tropical and subtropical regions of Asia, with major contributors including China, Indonesia India and Vietnam (De Silva and Soto, 2009). Rapidly depleting fish stocks necessitate aquaculture as an invaluable component of the world's agricultural output, especially if sustainable consumption is to be attained. From 1970 to 2006, the contribution to food fish supply from aquaculture grew from less than 20% to just below 50%.

Unlike other farmed animals, all animal species reared under aquaculture are poikilothermic. As a result, any increase or decrease of the temperature of the associated habitats of these stock animals would significantly influence metabolism and growth, and hence, output and income. Rising sea temperatures, would, up to a point, increase the production of mariculture. However, these benefits will likely be superseded by adverse effects of growth at higher temperatures. Studies carried out on the growth of silver pompano revealed that fingerlings raised at higher temperatures underwent a higher rate of growth up to ambient temperatures of 31°C. At 32°C, however, significant defects in growth were observed, particularly in the musculoskeletal system. Internal abnormalities including bile duct hyperplasia and acute tubular necrosis in the kidneys was also noticed at higher temperatures.

Increased temperature also brings about changes in hydrology and hydrography of water bodies, increasing the likelihood of occurrence of algal blooms and red tides, affecting the production of mariculture facilities. Rising temperatures will ultimately limit the spectrum of species that can be successfully cultured. Additionally, increased water temperatures and other associated physical changes, such as shifts in dissolved oxygen levels, have been linked to increases in the intensity and frequency of disease outbreaks (Goggin and Lester, 1995; Harvell *et al.*, 2002; Vilchis *et al.*, 2005).

Future climatically induced modifications to the upwelling system and circulation characteristics of the Northern Indian Ocean and other regions experiencing strong wind-driven upwelling may have profound effects on future biogas emissions from the oceans. Algal blooms, depletion of dissolved oxygen (oxygen minimum zones) and consequent production losses were observed in inland coastal and mariculture farms.

The lack of rains during summer months will lead to an increase in the salinity of the creek beyond the tolerable limits of the cultured shrimps. High rainfall resulted in a rapid drop in salinity to levels that were lethal for *Penaeus japonicus*, causing mass mortality of the farm crop (Preston *et al*., 2001). Droughts will also cause higher salinity within culture ponds, leading to intolerable conditions for cultured species.

Ocean acidification could likely cause difficulty in the farming of calcareous organisms such as molluscs. Increase in pH has already been shown to have deleterious effects, particularly on size, of the larvae of shrimp and mussels (Effects of ocean acidification on early life stages of shrimp and mussel (Bechmann *et al*., 2011). Low pH values can lead to dissolution of the thin exoskeleton of several zooplankton including larval forms of shrimps, molluscs and fishes. This can lead to low food availability (secondary productivity) of the early life stages and also low survival rates of commercially important species, which in turn can affect the fish catch (CMFRI-NICRA, 2013).

Floods, droughts, and cyclones are the main extreme climatic events in tropical Asia and any increase in the intensity and/or frequency of these can damage brackishwater aquaculture. Cyclones viz., *Nisha* in coastal Tamil Nadu (2008), *Aila* in West Bengal (2009), *Laila* in Prakasam District, AP (2010), *Thane* in Cuddalore Dist, TN (2012), *Phailin* in Odisha (2013); Krishna River Flood in AP (2009) and *Tsunami* (not an ECE) in 2004 caused damage to infrastructure and escape of shrimp stock (Ponniah and Muralidhar, 2009; Muralidhar and Vijayan, 2016). The farms were inundated almost one meter above bund level and the damage included erosion of bunds, heavy siltation and damage to electrical installations, sluices, shutters and screens associated negative impacts such as changes in salinity, heavy siltation and introduction of disease and predators into aquaculture facilities along with the flooded water resulted in yield reduction and crop losses.

Risk assessment based on consequence and livelihood scores in coastal states of India revealed that seasonal variations cause 20-40% loss in production and extreme weather events, though not very common in every year results in 50 to 100% loss in production (Muralidhar et al., 2013a; Muralidhar and Jayanthi, 2014; Muralidhar and Vijayan, 2015).

Impact on fishing communities

Erosion due sea level rise and abnormal weather events presents a significant risk for vulnerable coastal communities. In some coastal areas of Asia, a 30 cm rise in sea level can result in 45 m of landward erosion. The east coast of India is considered more vulnerable due to its flat terrain and the numerous deltas. Estimates show that the inundation area will be about 4.2 km^2 for a 1.0 m rise in sea level in the region surrounding Nagapattinam (Shetye *et al*., 1990).

Areas with large number of creeks and backwaters are likely to be at a higher risk of inundation, due to easier influx of water into vulnerable areas. Recent studies indicated that a net decrease in coastal area was suffered due to erosion. While the total area lost is a small fraction of the total Indian coastal area, it represents a significant loss of income and livelihood for the affected communities.

Cyclonic weather events such as the recent cyclone *Vardha* in Chennai also wreak havoc on fishing communities, in multiple ways – by preventing fisher folk from carrying out fishing operations as well as causing infrastructural damage to key equipment utilized in the practice of the craft.

The group most likely to be affected by the effects of climate change on fisheries is the small scale fisheries sector, comprising artisanal and subsistence fishers. Low and irregular income derived from fishing activities will result in low flexibility and poor adaptability to the economic effects of climate change. Damage to the sector's ability to contribute to the output of the fisheries sector will also be a likely result. Aid and assistance programs to mitigate these effects will likely be necessary but at the same time, will place a strain on the ability of governmental institutes to provide an economic buffer for this sector.

Impact on market and trade

An increase in market costs of commonly consumed fish stocks is to be expected as a result of climate change. Shifts to more sustainable fuels, while necessary, will also contribute to these increases.

Due to shifts in distribution of fish stocks, commercial fisheries will also be severely impacted. Climate change is expected to change future fisheries production patterns, either by shifting production as species move to new habitats, or as a result of changes in net marine primary production (Brander, 2007). The effects of climate change on the output and reliability of aquaculture practices, however, present a significant hurdle to the food security of states dependent on aquaculture. Ensuring that fisheries are efficiently governed and that aquaculture continues to grow in a sustainable manner will be the main constraints to the sustainability of global fish production (Merino *et al.*, 2012).

Potential positive impacts

A small number of potentially positive effects of climate change exist. Warmer temperatures may lead to quicker growth and earlier maturity, which, in certain situations, may be beneficial. Silver pompano fingerlings were found to grow at a greater pace at slightly higher temperatures, though once the temperature exceeded the optimal maximum, abnormalities in growth were noticed (CMFRI-NICRA, 2016).Elevated temperatures of coastal waters also could lead to beneficial impacts with respect to growth rate and feed conversion efficiency (Lehtonen, 1996), and increased production.

A survey by ICAR-Central Institute of Brackishwater Aquaculture (CIBA) revealed that around 829 ha of seawater inundated areas in the Andaman & Nicobar Islands after 2004 tsunami are now suitable for brackishwater aquaculture (Pillai and Muralidhar, 2006) after the lands became completely saline. These lands cannot be used for agricultural crops and brackishwater aquaculture is the only option for the livelihood of farmers and provides employment opportunities and nutritional security.

Certain species, such as oil sardine and mackerel, have undergone range extensions over the past few decades in response to the warming waters of the Indian Ocean (Vivekanandan *et al.*, 2009). This is distinct from a distributional shift, which could cause disruptions in traditional fishing practices and knowledge. Range extensions on the other hand allow the usage of a particular stock in a greater number of areas. For stocks capable of being utilized at sustainable levels, this is unlikely to be detrimental.

Adaptation to climate change impacts on coastal fisheries and aquaculture

The implications of climate change are far reaching and there is a need to develop and implement management plans to boost the resilience of fresh, cold-water, brackish, inland and marine systems, as well as the resilience of infrastructure that allow stakeholders to utilize these systems. A multifaceted action plan would compose several key elements – targeted scientific, a robust coastal ecosystem, community and industry cooperation and climate sensitive technologies with reduced carbon footprints.

A number of initiatives, such as the Global Coral Reed Monitoring Network, Global Coral Reef Alliance and the International Coral Reef Initiative, are now in place to serve to monitor reef zones and bleaching events, while also spreading awareness among the public. The Ministry of Environment and Forests, India, has bracketed studies on the reefs of India under Coastal Zone Studies, employing satellite oceanography as a cost effective strategy to address mapping and monitoring aspects of reefs. In this capacity, baseline maps on coral eco-morphology for most of the Indian coastal system have been prepared.

Adaptation on fisheries habitat

Habitat mapping and modeling: In the context of climate change, research on fish habitat is of high significance. Regional or zone wise (SW, NW, NE, SE) mapping and spatial representation of Indian aquatic habitat and its linkage with eco-system services is identified as a prospective adaptation option. Habitat mapping could be extended specifically for commercial as well as vulnerable species for better conservation, management and sustainable utilization of aquatic resources. Development of regional as well as species level models with representation of oceanic and climatic parameter variation could predict quantitative changes of climatic stressors. Habitat mapping coupled with regional models and continuous monitoring of habitat change provides better adaptation and management of fisheries habitat. Continuous monitoring of habitat change shall lead to enhanced adaptation.

Spatio-temporal distribution of shellfish population and their habitats were carried out using Satellite Remote Sensing and GIS at Vembanad lake; the largest humid tropical wetland ecosystem of the southwest coast of India, famous for its live clam resources and sub-fossil deposits (Paul *et al.*, 2016).

The Indian satellites IRS – 1C, 1D, P4 and P6 with their improved spatial resolution (PAN – 5.8 m, LISS III – 23.6 m, LISS IV – 5.8 m, WiFS – 188 m and AWiFS – 56 m), extended spectral range (inclusion of middle infrared band in LISS – III) and increased repeatability (5 days for WiFS data) have opened up new applications in coastal zone. The information available from merged PAN and LISS III, IV data about coral reef zonation, especially for atolls, patch reef and coral pinnacles, is valuable for coral reef conservation plans. Presently the reef validation experiments are happening in South Andaman reefs so as to develop a database on spectral signatures produced by different reef groups, dead reefs and sand at different optical conditions to develop sensors for hyper spectral satellites which can support reef mapping at an accurate scale (Paul *et al.*, 2016).

Biological processes such as fish larval transport can be modelled based on a clear understanding of the physics of a water body. There are few larval transport studies in the coastal waters in particular regions. A study combining observational data with a two-dimensional numerical model product has been carried out to determine the fate of fish eggs released in Gulf of Kachchh. Fish eggs were treated as passive particles in the model, and were released from probable spawning sites identified during exploratory surveys (George *et al.*, 2011).

Mangrove mapping, conservation and restoration: India accounts for nearly 3 % of world's mangrove vegetation and carbon sequestration potential of mangroves and their sediments makes more significant in the context of climate change. Mangrove ecosystem provides a significant habitat for several aquatic species and act as breeding ground and nursery of valuable biota. Mangroves ecosystem mapping, conservation and restoration is identified as an adaptation option to enhance coastal resilience. Ecosystem productivity could be increased by improving the habitat resulting in beneficial implications on coastal fisheries. This could to a certain extent supplement the fishermen income, thereby enabling them to adapt to vulnerability and loss of fishing days. Mangrove planting in shallow extensive and semi-intensive aquaculture ponds could be done to abate stress due to high temperatures. Besides, it supports artisanal aquaculture activities as breeding, nursery and feeding grounds for many commercially important prawns, fish, crabs and molluscs, enhance the fishery potential of adjacent coastal waters by providing them with large quantities of organic and inorganic nutrients.

Mangrove reforestation, carbon stock assessment in mangrove sediments, assessment and mapping of mangrove ecosystems, are the important mangrove research being carried out in India. The status and trends of mangrove area in India including the causes of loss and its restoration and traditional conservation has been assessed. The implications of loss of mangroves with respect to exposure to cyclones, hurricanes and sea water intrusion, tsunami and climate change were also scientifically reported (Sahu *et al.*, 2015). Mangrove wetlands mitigate the adverse impact of storms, cyclones and *Tsunami* in coastal areas, reduce coastal erosion and on the other hand, gains land by accreting sea and adjacent coastal water bodies. Mangroves in Nagapattinam District, Tamil Nadu protected the shrimp farms and livelihood during *Tsunami* 2004 and created a widespread interest as adaptation strategy in the restoration of degraded mangrove forests, promotion of joint mangrove management systems involving local communities and in the raising bio-shields and shelterbelts along the coastal zone (Rao, 2009).

Adaptation on fishery stocks

Stock modeling: To enhance the resiliency of stocks and their ability to recover from population collapses stock modeling could be done. Several research institutions of the nation are capable of carrying this out.

Vulnerability assessment along Indian coastal zones and conservation: Scientific criteria developed by CMFRI for long term vulnerability assessment of Indian marine fishes could be used to assess the species level adaptability to climate change. Species identified as highly vulnerable could be prioritized for conservation and management strategies. Conservation and fishing protocols based on species stock vulnerability could also be developed so as to enhance the sustainability.

Monitoring, Control and Surveillance (MCS): India has effective Monitoring, Control and Surveillance (MCS) mechanism in the EEZ for sustainable usage of oceanic resources. Highly vulnerable stocks identified after scientific analysis could also be brought under MCS for better conservation and adaptation for an optimum period.

Adaptation on fish stock availability

Potential fishing zone could be identified for reducing scouting time and increasing fishing profitability. Activities at fishing zones could be monitored for sustainable exploitation of fisheries resources. Fish catch forecast models could be developed for Indian coast, so as to enable the fishermen folks and stakeholders to cope up with the stock shift. New technologies and fishing methods developed could be implemented in the context of climate change and stock availability. Fishermen folks, self-help groups and other stakeholders could be trained and empowered to augment marine fish production. Regulation of fishing (fleet size, mesh size, spatiotemporal closure) could be ensured for sustainable fisheries stock utilization.

Adaptation on the harvesting sector

Implementation of Minimum Legal Size (MLS): Catch is of serious concern in the harvesting sector which could be directly attributed to climate change and stock distribution. However, this increases the fishing pressure on vulnerable populations. Hence to bring about sustainability, minimum legal size could be implemented. The MLS sets the smallest size at which a particular species can be legally retained if caught. Indian coastal states have its own Marine Fishing Regulation Act. Better exploitation and utilisation opportunities exist for small pelagics in all the maritime zones. Research institutes carryout scientific analysis and make significant recommendations. Central Marine Fisheries Research Institute (CMFRI) based on scientific studies recommends to department of fisheries and state governments to implement the suggested MLS for 58 commercial species and to carryout inspections and studies to determine the violations (Mohamed *et al.*, 2014).

Green fishing protocols for carbon foot print reduction: Alternative energy usage in fishing operations could be considered. However owing to the direct contribution of fisheries sector directly to food and nutritional security to millions of populations, implementation of shift in operational techniques to reduce the C footprint need to be done only after caution. Carbon foot print in life cycle of marine fisheries was carried out in major fishing harbours of Andhra Pradesh and in Vishakhapatnam of India by Central Marine Fisheries Research Institute (CMFRI). In both studies, highest emissions were found in harvest phase. Suitable modifications to the diesel engines, speed of operation and to craft and propeller design need to be carried out to reduce the energy consumption and subsequent emissions (Ghosh *et al.*, 2014; 2015). Central Institute of Fisheries Technology (CIFT) also made a comparative study between three different types of ring seine fishery (mechanized, motorized, motorized and traditional ring seines) operated in the same geographical area and time to determine the environmental burden associated for the production of oil sardine. Fuel used for fishing contributed more than half of the total impacts in eight of the ten environmental impact categories analyzed. Motorized ring seine fleet was having higher impact when compared to mechanized ring seine fleet with a 24% higher value for global warming potential (ICAR-CIFT, 2016).

Adaptation on coastal aquaculture

To cope with climate change that is likely to be both rapid and unpredictable, aquaculture systems must be resilient and able to adapt to change. Resilient aquaculture systems are those that are more likely to maintain economic, ecological and social benefits in the face of dramatic exogenous changes such as climate change and price swings. Resilience requires genetic and species diversity, low stress from other factors, 'healthy' and productive populations. Aquaculture is the best adaptation of fisheries to climate change by its ability to respond to demand, improving efficiency of resource use and overcoming disease shocks. Improving efficiency of resource use is mainly through improved feeding technology, diet formulation, conversion and integration on a global scale, and zero exchange systems, recirculation systems, integration with irrigation and intensification (Muralidhar et al. 2010). ***Identification of climate resilient species suitable for mariculture:*** After experiments on impacts of climatic parameters, stress tolerant species (silver pompano, cobia, *etc*.) were identified along with development of technologies for its culture. As climate change had affected wild species distribution and catch, focus on mariculture is an adaptive option and accordingly identification of stress tolerant species is significant. Zone-wise commercially valuable stress tolerant species could be identified and cultured for better adaptation. Studies on the genes which mediate and contribute to the physiological plasticity of bivalves in stressful situations, induced by natural and anthropogenic agents are gaining importance. The molecular expression and detection of heat shock protein genes (Hsp70) from the Indian edible oyster *Crassostrea madrasensis* and the Indian brown mussel *Perna indica* with unique distribution in Indian waters were reported. Phylogenetic analysis of the Hsp gene sequence data revealed the unique position of the Indian edible oyster and Indian brown mussel among the other counterparts inhabiting rest of the world. This stands out as the first report on the expression and PCR amplification of stress related genes from Indian bivalves (Paulton *et al*., 2012). Similarly, another study, (Purohit *et al*., 2014) pointed out that Hsp70, Hsp78, and Hsp60 are involved in thermal acclimation and long term survival of aquatic animals at high temperature.

Taking advantage of the short generation time and high fecundity, it would be possible to selectively breed fishes to tolerate higher temperature, salinity and increased diseases that are likely to impact aquaculture due to climate change. Despite significant advances in wide range of physiological information available on the link between environmental stress and some indicators of host response, the influence of different abiotic stressors on gene expression has been understudied. The research should focus on the evolution of physiological and genetic adaptations to osmotic and thermal stress in aquatic animals. With simultaneous changes in temperature, precipitation, and pathogen dynamics, the breeding challenge will be enormous. The molecular and mechanistic basis of the osmotic stress response and how it relates to other environmental stress responses have to be understood. Drought, thermo and salinity tolerance, resistance to diseases are traits that need to be engineered into aquatic species for climate change adaptations.

Shrimp (*Penaeus monodon*) breeding and reproductive performance in hatchery was better at 27-28^{o}C and moderate elevated (29-30^{o}C) than at high elevated temperature (33- 34^{o}C). Higher maturity and spawning (37 and 26%) were observed at 29-30^{o}C than at 27-28^{o}C (27 and 20%) and 33-34^{o}C (13 and 10%). Cellular parameters like total hemocyte count and phenoloxidase activity reduced significantly at high elevated temperature. Vitellogenin gene showed maximum up-regulation in shrimps maintained at 29-30^{o}C and marginally expressed (0.4 fold decrease) in shrimps maintained at high elevated temperature. Similar profiles were observed for Hsp70 and Hsp21 (NICRA Research Highlights 2014-15).

Adaptations to integrated farming technologies:
The integration of aquaculture, fisheries, agriculture and other productive or ecosystem management activities has an integral role to play in the future of the aquaculture industry. The techniques include ranching, agriculture/aquaculture (IAA), *integrated multi-trophic aquaculture* (IMTA) and links with renewable energy projects. Integration is a key element of the 'ecosystem approach to aquaculture (EAA)' which 'is a strategy for the integration of the activity within the wider ecosystem in such a way that it promotes sustainable development, equity, and resilience of interlinked social and ecological systems' (Soto et al. 2008). Expansion of the farming of low trophic level fish, more efficient shrimp (*Litopenaeus vannamei* vs *Penaeus monodon), m*ore efficient feed conversion, lower protein and fishmeal content in diet, zero water exchange systems, closed breeding cycle, domesticated SPF and SPR strains, more efficient use of fish meal and fish oil inputs.

IMTA - farming fish with seaweed and mussel has been demonstrated as a successful adaptation measure. Integrated cultivation doubled the weight of seaweed yield and also enhances the fishermen income through co-farming yields as well. Carbon sequestration ability of cultivated seaweeds (*Kappaphycus alvarezii*) along Tamil Nadu coast of India were assessed for the year 2013 and 2015 and the total amount of CO_2 sequestrated was estimated as 1.38 million and 0.32 million kg respectively. This implies a loss of 1.06 million kg carbon credit to the nation due to the reduction in *Kappaphycus* production for the year 2015 alone. The specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 by the seaweed was estimated as 0.0187gday^{-1} which highlights the potential of utilization of seaweeds as climate resilient option.

Paddy-fish integrated farming was successfully implemented as an adaptive measure across several states of the nation. Successful demonstration of integrated farming of paddy (pokkali) with finfishes (mullet and pearl spot) in Kerala resulted in profitability (Rs.83, 000 per hectare per annum) in otherwise kept fallow paddy fields. Owing to the success, several government agencies initiated schemes for supporting the integrated paddy-fish farming practices.

Ecosystem approach to aquaculture:
Effective Ecosystem Approach to Aquaculture (EAA) should lead to resilient social-ecological systems. EAA addresses the adaptation through creating resilient communities (ecosystem, human, governance), decreasing vulnerability (impacts, adaptive capacity, sensitivity), enhancing inter-sectoral collaboration (e.g. integrating fisheries into national adaptation), promoting context specific and community-based adaptation strategies, allowing for quick adaptation to change, promoting natural barriers and defenses. It addresses mitigation (increased sequestration and decreased emissions) through understanding the role of aquatic systems as natural carbon sinks, supporting a move to environmentally friendly and fuel- efficient fishing practices (harvest and post-harvest) and Governance/responsible practices, eliminating subsidies that promote overfishing and excess capacity. Mitigation and adaptation together are addressed through safeguarding the aquatic environment and its resources against adverse impacts of mitigation strategies and measures from other sectors, avoiding mal-adaptation, benefiting from win-win synergies. In the face of uncertainty, aquaculture food production systems should be

established which are diverse and relatively flexible, with integration and coordination of livestock and crop production.

***Regional wetland restoration and implementing scientific fish farming*:** Wetland restoration along with incorporation of scientific fish farming at village level was identified as a prospective climate resilient strategy. India had developed a spatial database of wetlands through the National Wetland Inventory and Assessment (NWAI) project, which reports extend of wetlands estimate as 15.26 mha and inland wetlands of the nation as 69.22% of the total wetland area, whereas the coastal wetland accounts to 27.13% and remaining 3.64% includes small wetlands that are less than 2.25ha (National Wetland Atlas, 2011). In India 5, 55,557 small wetlands were detected and mapped as point features (Panigrahy *et al.*, 2012) Developing wetlands of size below 2 ha for fish farming could enhance the regional resilience along with village level food and nutritional security and the surplus production could be channelized to global supply chain. Beyond assessing and developing for reduced GHG emissions, emphatic and comprehensive focus need to be given on enhancing the wetland ecosystem functions such as productivity, habitat, biodiversity, recreation, etc., (Rojith and Zacharia, 2016). Geospatial techniques could provide a qualitative assessment, while implementing fish farming shall results in quantitative assessment of wetland health status and hence is a sustainable approach.

Preparedness and forecasts

Evaluation of weather trends and forecasting models in Nagapattinam District, Tamil Nadu indicated that availability and quality source waters for shrimp farming may get affected as there is increase in the maximum temperatures coupled with no trend in the precipitation over the years and helps in planning proper crop calendar (Ashok Kumar et al. 2013). In terms of responding to EWEs, shrimp aquaculture should be integrated into coastal zone management (ICZM) that can be seen as an essential institutional mechanism to deal with all competing pressures on the coast, including short, medium and long-term issues.

Sea level rise

Area of Inundation of different land resources including aquaculture was predicted using geospatial techniques at 0.5 m and 1 m SLR for the vulnerable coastal districts of the country. Aquaculture area of 13,211 ha and 21,763 ha will be inundated at 0.5 m and 1 m SLR, respectively in Sunderbans area of West Bengal (NICRA Research Highlights 2013-14). The predicted submerged area for agriculture and aquaculture in Alappuzha District, Kerala and Navsari & Surat districts of Gujarat at 1 m SLR was 14521 and 70 ha and 296 and 153 ha, (NICRA Research Highlights 2014-15). Agriculture and aquaculture area of 67 and 39 ha and 273 and 110 ha will be inundated with 0.5 and 1 m SLR in Kancheepuram District (NICRA Research Highlights 2015-16). While a little area under aquaculture will be inundated a large area will become available for brackishwater aquaculture from the inundation of other land use categories.

GHGs and carbon foot print in aquaculture

Aquaculture, like agriculture is an important man made source of GHGs concentration, the contribution of which has not been estimated and not included in any of the GHGs inventory. The stocking density of aquatic species, large amount of feed required for their growth, types of chemical inputs for their survival, water logged condition, plankton density and animal biomass clearly indicate that aquaculture is a major anthropogenic activity. A comprehensive methodology was developed for sampling through a fabricated floating chamber and simultaneous analysis of greenhouse gases (GHGs), carbon-di-oxide

(CO_2), methane (CH_4) and nitrous oxide (N_2O) from the aquaculture ponds. GHGs emissions were quantified from shrimp and finfish species farming systems varying in stocking densities in different geographical locations of Andhra Pradesh and Tamil Nadu (Muralidhar *et al.*, 2013b; Vasanth *et al.*, 2016). GHGs emission in terms of kg CO_2 eq./kg shrimp yield was comparatively less than agriculture and livestock production systems indicating that aquaculture production systems are climate friendly. Continuous measurement of GHGs directly from the culture ponds provides meaningful information on gases emission trends and help to combat climate change.

Life cycle analysis (LCA) of shrimp production systems indicated that category-wise impact for every ton of shrimp production was mainly due to feed preparation in feed mill and energy use by water pumps and aerators during farming except for eutrophication due to feed use (Muralidhar *et al.*, 2013c).

Mangement, energy and microbial interventions such as minimising energy use through actual aeration requirements estimation in shrimp culture ponds, Anammox bacteria, *Kuenenia stuttgartiensis* that produces no or less of nitrous oxide presence in aquaculture pond sediments, enhancing the carbon sequestration potential of shrimp culture pond sediment, biochar Synthesis from the organic carbon rich harvested pond sediment can mitigate the emission of GHGs from aquaculture ponds.

Water foot prints for aquaculture:
Brackishwater aquaculture do not have water foot prints unlike freshwater and there is no competition with other sectors. In the scenario of decreased freshwater availability due to climate change, brackishwater aquaculture is the best option for increasing fish production through aquaculture.

Seaweed farming along Indian coasts: Seaweed farming is identified as a prospective climate resilient strategy. Large scale seaweed cultivation along Indian coastal waters aimed at carbon sequestration, reducing ocean acidification, coastal pollution abatement, co-farming of mussels, oysters and fishes, marine product development, coastal livelihood supplementation and fish feed formulation could enhance the adaptability level of coastal aquaculture. Regional level potential seaweed cultivation zones could be identified and large scale farming could open new horizons in bioproducts and biorefineries industries across the nation.

***Development of climate resilient products*:** Development of climate resilient products from mariculture residues is another adaptive measure. Biochar is a climate resilient product with carbon sequestration ability and could be produced by the pyrolysis of mariculture residues (seaweeds, aquatic plants, etc.) and could be further utilized for aquaculture treatment applications as well. Biofuel production from micro and macro algae is also a significant climate resilient strategy upon which India is focusing.

Adaptation on fishing communities
Climate change preparedness of vulnerable coastal populations: Several climate preparedness activities (CPAs) could be implemented effectively to enhance the preparedness levels of coastal populations. Improved climate change awareness, adaptation and preparations of the fishermen folks could be done through suitable scientific interactions and trainings. Nation has competent research institutions and scientific personals to deliver this goal. To negate the uncertainties in fish catch and loss of fishing days due to climatic events, vulnerable fishermen communities could be

strengthened with supplementary avocations and trainings could be done across the coastal fishing villages. In order to successfully implement the disaster management plans, fishermen communities could be trained well towards disaster preparedness, evacuation and related procedures.

Strengthen basic amenities in coastal villages: As extreme climate events negatively impacts on basic needs of coastal population, alternative facilities need to be developed for easy access to food, potable water, sanitation, shelters, etc. Local infrastructure (roads, health supports, etc.) could be developed for reducing climate change vulnerability. Since fishermen are forced to move out to deeper areas, protection aids must be made available even for traditional /artisanal fishers. Strengthening of seawalls and bio-shields (coastal forestry) could be beneficial. Regulation of unplanned coastal activities which would affect tidal amplitudes in village canals/ riparian areas has to be done. Sea erosion is another impact of climate change and its magnitude and nature varies widely. Hence to minimize the damages, identification and development of new settlement areas with location based elevation levels and planning could be done.

Increase disaster preparedness: India had established early warning system and also has a very good natural disaster management system to deal with extreme climatic events. In 2013 a very severe cyclonic storm 'Phailin' equivalent to category 1 hurricane affected around 12 million people of the nation. The cyclone prompted India's biggest successful evacuation in 23 years with shifting of more than 5, 50,000 people from coastline of Odisha and Andhra Pradesh to safer places. Successful disaster management plans of the nation could be implemented at each coastal village to cope with even moderate climate change events. Installations of automatic weather stations and similar facilities along with awareness at village level shall enable better weather forecasting and climate change adaptations.

Development and familiarization of E-commerce technologies for fishermen communities: Though E-commerce solutions for fish products are available, gap still exists to develop multivendor platform for directly engaging various self-help groups of fishermen communities as multiple vendors. We are ambitiously working out on the concept to develop such a system for fishermen community livelihood improvement and empowerment. Such systems could be in line with the national goal of farmer income increment. The system could fetch better income as well as better marketing for the engaged fishermen communities.

National policy and planning

Climate change risks assessment and preparedness planning could be done through cooperation between governmental and non-governmental sectors. Social media such as radio, television, etc. could be used to inform fishers about weather forecasts and warning and also effective engineering could be put along the coast so as to reduce damage to properties and life. The climate change policies have to be integrated with sustainable development strategies in general, and poverty alleviation measures, in particular. This will make the problem of adaptation more continual in nature. A greater attention is required from policy makers on the part of policy formulation. Adapting aquaculture to climate change could be made through selective breeding, regulating the environment and through resilient species. Schemes could be undertaken to set up mariculture farms/ parks, setting up of hatcheries, capacity building of fishers & entrepreneurs to take up mariculture, development of markets so as to increase fish production from coastal areas.

Aquaculture vulnerability has to be prepared similar to agriculture. Assessment of the aquaculture resources available in the country and derive the plans based on the available resources from the satellite data and identify the suitable sites with buffer zone incorporating soil and water resources. Aquaculture need be treated as an agriculture activity and should be supported with relief and compensation as given to agriculture. The fisheries research institutes need to prepare guidelines for providing relief, institutional credit and insurance to aquaculture during the times of extreme weather events.

The Department of Animal Husbandry, Dairying and Fisheries (DADF, Govt of India) has called for a revolution in the fishing industry, identifying the following objectives for the period 2015/16-2019/20:

- To tap the total fish potential of the country in both the inland and marine sector, tripling production by 2020
- To transform the fisheries sector into a fully modernized one, focusing especially on new technologies and processes
- Doubling the income of fishers and farmers, and establishing better marketing and postharvest infrastructure
- Ensuring inclusive participation of fishers and fish farmers
- To triple export earnings by 2020, with a focus on benefits flow to sector stakeholders through deployment of institutional mechanisms such as cooperatives, producer companies and other structures
- To enhance nutritional security of the country

Establishment of weather watch groups and decision support systems could be done on regional basis. Scientific models such as Mass-Balance models, SEAPODYM etc. that help study the relation between climate change and fish population need to be put into practice. The mitigation measure for carbon release as a part of fishing activities lies in the fuel use and efficiency of boats and vessels.

Over the last 25 years there has been an overall increase of 64 percent of carbon dioxide per tonne of fish caught. Measures to reduce carbon footprint include setting emission norms and improving the fuel efficiency of engines. Life cycle assessments from pre-harvest to post consumer wastes will provide a more detailed picture of the specific emission sectors that require focus to shift to more sustainable production modes. Switching from fuel intensive techniques to alternatives would use less fuel thereby reducing the carbon footprint of fishing practices. For example the fuel use can be reduced from 9l to 2.2l to land 1kg of Norway lobster (*Nephrops norvegicus)*, if trap fisheries are used rather than the typical trawling method (Ziegler and Valentinsson, 2008).

New development schemes for enhancing the skills and capabilities of the traditional fishermen to undertake deep sea fishing shall be introduced. Scope of the Marine Fishing Regulation Acts (MFRAs) of maritime States/UTs to include registration of boat building yards, standard design specifications for boats, construction material and procedures for continuous monitoring and control of boat construction could be enlarged, so that this will produce fuel efficient engines and boats could be considered.

Suggested methods to reduce Green House Gas emission include eliminating inefficient fleet structure, improving fisheries management, reducing post-harvest losses, increasing waste recycling, shifting to more efficient vessels and gears, safeguarding stocks and increase their resilience to climate change. Programmes to maintain cleanliness and hygiene in fish landing centres, harbours and fish markets, building up of infrastructure such as harbour based fish dressing centres & processing estates on a public- private partnership so as to reduce post-harvest losses, measures to reduce post-harvest losses through better onboard fish handling could be put into action.

Promotion of mass cultivation of sea plants that can sequester large quantities of carbon could be considered. Of these green algae *Ulva lactuca*, brown algae *Sargassum polycystum* and red algae *Gracilaria corticata* are more efficient. *Kappaphycus alvarezii* in particular shows promise as a sequestering vehicle for carbon with specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 as 0.0187 g day^{-1}.

Artificial reefs that are made of sand filled geotextiles would help protection of coast from the effects of climate change. Fishermen are aware of the variables of climate and their relation to fish catch. Indigenous knowledge can be made useful for reducing the impacts of climate change on fisheries sector.

Effective and timely warning of population decline of fish species would reduce the pressure on the declining population of small and large pelagics. This would help a smoother transition to other fisheries or industries. Pressures on small pelagics could be reduced by control and regulation of the number of fish meal plants and by implementing National Marine Fisheries Data Acquisition Plan for the timely, reliable & comprehensive data sets of marine fisheries sector.

Gaps in knowledge

Further efforts to be taken always exist, and this is no less true in the case of institutional response to the damaging effects of climate change. We are yet to use Representative Concentration Pathway (RCP) scenarios (in 2030, 2050 and 2080) developed by the IPCC in concert with predictive modelling techniques to gauge the intensity of future changes likely to occur in the marine fisheries sector. Several key areas exist in which to improve the response to the pervasive effects of global warming.

Common knowledge databases: Common, shared knowledge databases must be made available to researchers across the country. This will streamline research and study in the field of climate change, as significant time is lost on bureaucratic efforts between research organizations during collaborative effects. Tools and indicators have to be developed for the purpose of assessing and monitoring not only the impacts of aquaculture on the environment, but also the impacts of the environment on aquaculture and site selection.

Continuous evaluation and fish stock monitoring and dynamic regulation: Constant monitoring of potential vulnerable species, accompanied by dynamic regulation of the utilization of fish stocks could shift the fishery status of certain fish stocks into sustainable territory.

Historical data records for important fish stocks: Data records for important species could be compiled and made publically available to increase transparency and allow for greater insight into population and exploitation trends being displayed by commonly harvested species.

Inclusion of scientific committees in policy determination: Greater involvement of scientific committees comprised of expert panels during the process of policy determination would allow for quicker policy responses to changes resulting from climate change. Increased awareness amongst policy-makers and consumers about the importance of aquaculture in national economy and the extent of damage to the sector due to EWEs is required.

Institutional Capability

The Central Marine Fisheries Research Institute (CMFRI) and Central Institute of Brackishwater Aquaculture under the umbrella of the Indian Council of Agricultural Research (ICAR) with their Head Quarters at Kochi and Chennai, respectively focused on mitigating the adverse effects of climate change and developing new climate resilient strategies for the marine fisheries and coastal aquaculture sectors. CMFRI Founded in 1947, originally under the Ministry of Agriculture and Farmers Welfare, comprises seven research centres and three regional centres spread across the coastal areas of the country and is headquartered in Kochi, Kerala. Ten divisions including Mariculture, Marine Biodiversity, Fishery Resource Assessment, Pelagic Fisheries, Demersal Fisheries, Crustacean Fisheries, Molluscan Fisheries, Fishery Environment Management, Marine Biotechnology and Socio Economic Evaluation & Technology Transfer, one field centre and Krishi Vigyan Kendra (KVK) work on an integrated approach for improved and timely application of strategies to offset the impacts of climate change on various focal areas of marine fisheries. The Institutes also regularly conducts programmes to disseminate technologies and strategies developed in-house to key stakeholders.

Some climate resilient strategies to offset the effects of climate change include Integrated Multi-Trophic Aquaculture (IMTA), integrated finfish-paddy farming, low cost cage farming, wetland restoration and scientific fish farming, seaweed farming and marine product development, conversion of mariculture residues and pond sediment residues into biochar, multivendor E-commerce solution for fishermen community, establishment of early warning and weather forecasting system. Coastal aquaculture of Asian seabass, pearl-spot, genetically Improved farmed tilapia (GIFT), silver pompano and mullets are identified as good candidate fishes for low saline and brackishwater bodies.

Conclusion

The impacts of climate change on Indian fisheries were evident through scientific studies carried out by leading national institutes. Habitat change was induced due to variability in climatic as well as oceanographic parameters. Rise in sea surface temperature was observed around 0.5 – 1.3^{o}C along Indian coasts along with precipitation changes and changes in wind pattern. These climatic parameters impacted the fisheries sector of the nation creating challenges to food and nutritional security. Changes in phenology and trophodynamics of fish species were also revealed by research. The spawning season shift, changes in maturity, mean length reduction and distributional shift of fish species were identified which have implications on stock availability, catch, livelihoods and national economy. Technologies to adapt with climate change are to be developed and demonstrated directly to fishermen communities. Integrated farming methods developed need to be popularized across the nation with support from government. Large number of fishermen communities and other stakeholders are to be empowered to cope-up with climate change through trainings, workshops, awareness programs, etc.

Greater climate variability and uncertainty complicate the task of identifying impact pathways and areas of vulnerability in aquaculture environment, requiring research to devise and promote coping strategies and improve the adaptability of aquaculture. The existing pressures of demand on aquaculture production, and anticipated challenges, will require better multi-scale understanding of the impacts of climate change, both positive and negative along with possible strategies to counter them. Brackishwater aquaculture is a climate friendly production system for enhancing fish production, providing employment opportunities and nutritional security. There is a need to forecast the likely effects of climate change on the finfish and shellfish aquaculture sector and to develop strategies to assist farmers and rural communities to adapt to the upcoming changes. A very strong focus on building general adaptive capacity can help the aqua farming communities to cope with new challenges and become climate resilient. More research is needed to look at the adaptation strategies that could help the small scale farmers to improve the production and income in the context of changing climate and extreme events. Research to develop the adaptation strategies and the means to implement them are needed. Links will need to be improved among fisheries, aquaculture and other sectors that share or compete for resources, production processes or market position, in order to manage conflicts and ensure that food security aims are maintained. Cooperation among research institutes, industry and communities needs to be fostered in order to form a framework through which the effects of climate change can be mitigated. Existing management plans for the fisheries and aquaculture sectors, coastal zones and watersheds need to be reviewed and, if needed, further developed to ensure they cover potential climate change impacts, mitigations and adaptation responses. Fisheries and aquaculture need to be adequately addressed in climate change policies and programmes dealing with global commons, food security and trade and also in the decisions related to climate change in the other major sectors.

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