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Inaugural Address

Climate Change and Marine Fisheries Management

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ABSTRACT

Fisheries and aquaculture have very important roles for food supply, food security and income generation in India. About one million people work directly in the sector in the country, producing around 3 million tonnes annually. The production from capture fisheries is approaching the potential yield, and scope for further increase in production is limited. Climate change is projected to exacerbate this situation. The potential outcome for fisheries may be decrease in production and value of coastal, and decline in the economic returns from fishing operations. Despite the uncertainties and potential negative impacts of climate change on marine fisheries, there are opportunities to reduce the vulnerability to climate-related impacts. The following measures could contribute to coping with climate change: (i) adapting Code of Conduct for Responsible Fisheries; evaluating the adaptive capacity of important fish groups; (ii) identifying adaptive fishing and post-harvest practices to sustain fish production and quality; (iii) supporting energy efficient fishing craft and gear; (iv) cultivating aquatic algae, which have positive response to climate change for food and pharmaceutical purposes and for production of biodiesel; (v) increasing climate literacy among the fishing communities; (vi) establishing Weather Watch Groups; and (vii) evolving decision support systems for fisheries and aquaculture in the region. It is also important to recognize the synergies between adaptive and mitigation options related to climate change and non-climatic factors such as responsible fisheries.

Introduction

Indian seas have very productive fishing waters among the world oceans. With more than 1,500 species of marine finfish alone, it is one of the regions of richest biodiversity. Marine fisheries is one of the important revenue-earning and employment-opportunity sectors, contributing significantly to the economy of the country. The annual fish production during 2007-2009 was about 3 million tonnes (Table 1). About one million people are employed either fulltime or part-time in marine fisheries. Fish trade has expanded significantly in the country over the last two decades, with annual export exceeding Rs 8000 crores. Production from Arabian Sea (west coast of India) contribute 61.3%, Bay of Bengal (east coast of India) 37.2%, and Andaman & Nicobar and Lakshadweep Islands 1.5%. Production comes from three subsectors, *viz.*, mechanized subsector (60.3% to the region's total production), motorized subsector (35.5%), and non-motorized subsector (4.2%).

Table 1. Profile of marine fisheries in India (Source: CMFRI, 2007)

Component	Profile
Physical Component	
Coastline length (km)	8129
Exclusive Economic Zone (million km^2)	2.02
Contintal shef area (million km^2)	0.50
Area within 50 m depth (million km^2)	0.18
Human Component	
Marine fisher population (million)	3.5
Active fisher population (million)	0.9
Infrastructure Component	
Landing centres	1442
Mechanized vessels	58,911
Motorized vessels	75,591
Non-motorized vessels	1,04,270
Fish Catches	
Annual landings (2008-2009) (million t)	3.18
Potential Yield (million t)	3.92

In recent years, the sector is facing serious challenges. Production from capture fisheries (3.16 million tonnes) is approaching the potential yield (3.92 million tonnes). There are evidences of overexploitation, depletion of coastal fish stocks and competition among stakeholders in sharing the newable, but limited resources. Climate change exacerbates this situation. Indian seas are recognized as being very vulnerable to climate change and sea level rise. Modeling studies show that climate will have the greatest economic impact on the fisheries sector in Asian countries (Brander 2007). A large population of marine fishermen lives in areas vulnerable to sea level rise. The east coast of India is prone to annual events of storms and cyclones. It is being increasingly realized that all the subsectors of fisheries will be impacted by climate change. In spite of the realization that fisheries have very important roles for food supply, food security and income generation in India, research on the impacts, vulnerability and adaptation of this sector to climate change is limited.

Impact of climate change on marine fish

Fish is the largest animal resource exploited from the wild. The most important characteristic of capture fisheries in India is that the resource is a common property, the access to which is free and open. Second, property rights to fisheries are difficult to establish, leading to intrasectoral conflicts. In addition to these, other anthropogenic interventions such as discharge of untreated domestic and industrial effluents into the sea, bioaccumulation and biomagnification of toxic chemicals and trace metals in fish tissues, ballast water discharge, coral mining and habitat destruction cause considerable damage to fish populations. For India, the catches have been either very close to or have exceeded the potential yield in the late 1990s for several fish stocks due to overfishing (Vivekanandan 2001). Climate change is a depensatory factor on fish populations.

Most fish species have a fairly narrow range of optimum temperatures related to their basic metabolism and availability of food organisms. Being poikilotherms, even a difference of 1° C or 0.1 unit pH in seawater may affect their distribution and life processes. The more mobile species should be able to adjust their ranges over time, but less mobile and sedentary species may not. Depending on the species, the area it occupies may expand, shrink or be relocated. This will induce increases, decreases and shifts in the distribution of marine fish, with some areas benefiting while others lose. From the recent investigations carried out by the Indian Council of Agricultural Research (ICAR) and Central Marine Fisheries Research Institute (CMFRI), the following responses to climate change by different marine fish species are discernible in the Indian seas: (i) Extension of distributional boundary (Vivekanandan et al. 2009a); (ii) Shift in latitudinal distribution; (iii) Shift/extension of depth of occurrence (CMFRI 2008); and (iv) phenological changes (Vivekanandan and Rajagopalan 2009). Some evidences of the responses are given below:

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In recent years, the sector is facing serious challenges. Production from capture fisheries (3.16 million tonnes) is approaching the potential yield (3.92 million tonnes). There are evidences of overexploitation, depletion of coastal fish stocks and competition among stakeholders in sharing the newable, Extension of distributional boundary

The oil sardine *Sardinella longiceps* and the Indian mackerel *Rastrelliger kanagurta* are tropical coastal and small pelagic fish, forming massive fisheries in India (catch during 2007: 0.7 million tonnes valued at about 150 million US$). They are governed by the vagaries of ocean climatic conditions, and have high population doubling time of 15 to 24 months. They are cheap source of protein, and form a staple, sustenance and nutritional food for millions of coastal people. They were known for their restricted distribution between latitude 8°N and 14°N and longitude 75°E and 77°E (Malabar upwelling zone along the southwest coast of India) where the annual average sea surface temperature ranges from 27 to 29°C. Until 1985, almost the entire catch was from the Malabar upwelling zone and the catch was either very low or there was no catch from latitudes north of 14°N. In the last two decades, however, the catches from latitude 14°N to 20°N are increasing, reaching 150,000 t (21% of all-India catch during 2007). A positive correlation was found between the catches and sea surface temperature (SST). The surface waters of the Indian seas are warming by 0.04°C per decade, and the warmer tongue (27-28.5°C) of the surface waters expanded to latitudes north of 14°N, enabling the oil sardine and Indian mackerel to extend their distributional boundary to northern latitudes. It is also found that the catches from the Malabar upwelling zone has not decreased indicating the distributional "extension" and not distributional "shift". Considering the catch as a surrogate of distribution and abundance, it is also found that the two most dominant fish are able to find temperature to their preference especially in the northern latitudes in recent years, thereby establishing fisheries in the extended coastal areas. Assuming further extension of warmer SST tongue in the future, it is expected that the distribution may extend further north of latitude 20°N. However, if the SST in the Malabar upwelling zone increases beyond the physiological optimum of the fish, it is possible that the populations may be driven away from the southern latitudes.

Shift in latitudinal distribution and abundance

Catfish are one of the major resources along the southwest and southeast coasts of India (latitude: 8°N - 14°N). During 1970-2007, the catches from these coasts decreased from 35,000 t to 7,800 t. On the other hand, the catches from the northwest and northeast coasts (latitude: 15°N - 22°N) increased from 16,000 t to 42,500 t during the same period. There was a strong negative correlation between catfish catch and SST along the two southern coasts whereas the correlation between catch and SST was positive along the northern coasts.

As the average seawater temperature in the southern latitudes exceeded 29°C in the last one decade, it appears that the catfish have shifted their distribution to the northern latitudes where the seawater temperature is between 27 and 28.5 °C. This is a response different from that shown by the oil sardine and Indian mackerel to increase in seawater temperature.

Shift/extension of depth of occurrence

The Indian mackerel, *Rastrelliger kanagurta*, in addition to extension of its northern boundary, is found to descend to deeper waters in the last two decades. The fish normally occupies surface and subsurface waters. During 1985-1989, only 2% of mackerel catch was from bottom trawlers, and the rest of the catch was contributed by pelagic gear such as drift gillnet. During 2003-2007, it is estimated that 15% of mackerel catch is contributed by bottom trawlers along the Indian coast. The Indian trawlers operate at a depth ranging from 20 m to 80 m by employing high opening trawlnets. In the last 25 years, the specifications of trawlnet such as mouth opening, headrope length, otterboard and mesh size have not been modified, and hence the increase in the contribution of trawlers to the mackerel catch is not gear-related. As the subsurface waters are also warming up, it appears that the mackerel, being a tropical fish, has extended its veritical boundary to deeper waters.

Phenological changes

Fish have strong temperature preferences to spawning. The process of spawning is known to be triggered by pivotal temperatures. The annually recurring life cycle events such as timing of spawning can provide particularly important indicators of climate change. Though sparsely investigated, phenological changes such as seasonal shift in spawning season are now evident in the Indian seas.

The threadfin breams *Nemipterus japonicus* and *N. mesoprion* are distributed along the entire Indian coast at depths ranging from 10 to 100 m. They are short-lived (longevity: about 3 years), fast growing, highly fecund (annual egg production around 0.2 million per adult female) and medium-sized fishes (maximum length: 35 cm). Data on the number of female spawners collected every month off Chennai (southeast coast of India) from 1981 to 2004 indicated wide monthly fluctuations. However, a trend in the shifting of spawning season from warmer (April-September) to cooler months (October-March) was discernible. Whereas 35.3% of the spawners of *N. japonicus* occurred during warm months during 1981-1985, the number of spawners gradually reduced and only 5.0% of the spawners occurred during the same season during 2000 - 2004. During 1981-1985, it was observed that 64.7% of the spawners occurred during October-March, whereas as high as 95.0% of the spawners occurred during the same season in 2000 - 2004. A similar trend was observed in *N. mesoprion* too. The percent occurrence of spawners of the two species linearly decreased with increasing temperature during April-September, but increased with increasing temperature during October-March over the time scale. It appears that SST between 28 and 29°C may the optimum and when the SST exceeds 29°C, the fish are adapted to shift the spawning activity to seasons when the temperature is around the preferred optima.

Currently, it is difficult to find out how much of catch fluctuation is due to changes in fish distribution and phenology. However, these changes may have impact on nature and value of fisheries (Perry et al. 2005). If small-sized, low value fish species with rapid turnover of generations are able to cope up with changing climate, they may replace large-sized high value species, which are already showing declining trend due to fishing and other non-climatic factors (Vivekanandan et al. 2005). Phytoplankton are the basis for the productivity of the oceans and are critically important to the flow of resources. Plankton are particularly sensitive to environmental fluctuations, and therefore those fish, which are directly dependent on plankton for food, will be strongly influenced by climate change (Briones et al. 2006). The larvae of several marine fish have wider dispersal ranges (aided by currents) than terrestrial organisms. Major changes to ocean circulation will cause changes in dispersal pattern of larval fish, particularly the pelagics. This will change the food webs as well fish catch. Such distributional changes would lead to novel mixes of organisms in a region, leaving species to adjust to new prey, predators, parasites, diseases and competitors (Kennedy et al. 2002), and result in considerable changes in ecosystem structure and function.

Vulnerability of corals

Coral reefs are the most diverse marine habitat, which support an estimated one million species globally. They are highly sensitive to climatic influences and are among the most sensitive of all ecosystems to temperature changes, exhibiting the phenomenon known as coral bleaching when stressed by higher than normal sea temperatures. Reef-building corals are highly dependent on a symbiotic relationship with microscopic algae (type of dinoflagellate known as zooxanthellae), which live within the coral tissues. The corals are dependent on the algae for nutrition and colouration. Bleaching results from the ejection of zooxanthellae by the coral polyps and/or by the loss of chlorophyll by the zooxanthellae themselves. Corals usually recover from bleaching, but die in extreme cases.

In the Indian seas, coral reefs are found in Gulf of Mannar, Gulf of Kachchh, Palk Bay, Andaman Seas and Lakshadweep Seas. Indian coral reefs have experienced 29 widespread bleaching events since 1989 and intense bleaching occurred in 1998 when the SST was higher than the usual summer maxima. By using the relationship between past temperatures and bleaching events, and the predicted SST for another 100 years, Vivekanandan et al (2009b) projected the vulnerability of corals in the Indian Seas. The outcome of this analysis suggests that if the projected increase in seawater temperature follows the trajectory suggested by the HadCM3 for an SRES A2 scenario, reefs should soon start to decline in terms of coral cover and appearance. The number of decadal low bleaching events will remain between 0 and 3 during 2000-2099, but the number of catastrophic events will increase from 0 during 2000-2009 to 10 during 2000-2099.

Given the implication that reefs will not be able to sustain catastrophic events more than three times a decade, reef building corals are likely to disappear as dominant organisms on coral reefs between 2020 and 2040 and the reefs are likely to become remnant between 2030 and 2040 in the Lakshadweep region and between 2050 and 2060 in other regions in the Indian seas. These projections on coral reef vulnerability have taken into consideration only the warming of seawater. Other factors such as increasing acidity of seawater would slow down formation of exoskeleton of the reefs, and if acidification continues as it is now, all the coral reefs would be dead within 50 years. Given their central importance in the marine ecosystem, the loss of coral reefs is likely to have several ramifications.

Options for fisheries and aquaculture sector for adaptation

Tackling overfishing

Options for adaptation are limited, but they do exist. The impact of climate change depends on the magnitude of change, and on the sensitivity of particular species or ecosystems (Brander 2008). Fish populations are facing the familiar problems of overfishing, pollution and habitat degradation. Food and Agriculture Organization has estimated that about 25% of all fish stocks are overexploited and 50% are fully exploited (FAO 2007b). About 1.2% of global oil consumption is used in fisheries, and it is found that fish catching is the main contributor to global warming in the fish production chain (Thrane 2006). Reduction of fishing effort will benefit in relation to adaptation of fish stocks and marine ecosystems to climate impacts; and mitigation by reducing greenhouse gas emissions. Hence, some of the most effective actions which we can be taken to tackle climate impacts are to deal with the old familiar problems such as overfishing (Brander 2008) and adapt Code of Conduct for Responsible Fisheries (FAO 2007b).

Cultivation of sea plants

Sea plants are excellent carbon sequestration agents and many of them sequester at a rate better than their terrestrial counterparts (Zon 2005). The emission of CO_2 through their respiratory activity of sea plants is very low as they are capable of reutilizing the respiratory release of CO_2 within their cellular interspace for subsequent photosynthesis (Kanwisher 1966). CO_2 sequestration by the common sea plants such as the red algae *Gracilaria corticata* and *G. edulis*, brown alga *Sargassum polycystum* and the green alga *Ulva lactuca* has been quantified in laboratory studies in India by Kaladharan et al (2008). The carbon sequestering efficiency was found unaltered even in higher levels of dissolved CO_2. Green algae were found to have better CO_2 sequestering ability than the red and brown algae. It is estimated that the standing crop of sea plants in the Indian waters is 260,876 tonnes, comprising 14% agar and carrageenan yielding red algae (Rhodophyceae), 16% algin yielding brown algae (Phaeophycea) and 70% green algae (Chlorophyceae). Estimates indicate that the standing crop in the Indian Seas is capable of utilizing 9052 tonnes of CO_2 per day. Mass cultivation of these plants will help reducing the CO_2 concentration from the seawater. Coastal communities along the Palk Bay (southeast coast of India) have taken up commercial cultivation of *Kappaphycus alvarezii* for the last three years.

There are two methods for cultivation of sea plants, one by vegetative propagation and the other by reproductive method. In the vegetative propagation method, the fragments of the plant are inserted in the twist of coir ropes and the fragments tied to nylon twine are allowed to grow in the coir mat, which are fixed off bottom in the coastal waters or in floating raft/cages (Kaliaperumal 2005). In 60 days, *G edulis* shows upto 30-times increase in yield. Similar technique is being followed for commercial cultivation of another carrageenan and high yielding plant, *Kappaphycus alvarezii* (Eswaran et al. 2005). The bays, creeks and lagoons in the open shore in the South Asian region are suitable for cultivation of sea plants.

There is increasing international demand for products from sea plants. These plants can be used as human food, cattle food, fertilizer, and are rich source of agar and algin, which form the basis of confectionary and pharmaceutical industries. Mass cultivation will effectively sequester carbon, augment supply of raw materials to the food and pharmaceutical industries and provide employment to the coastal population.

Cultivation of halophytes

In coastal areas and mudflats near the sea, where the salinity does not allow farming of the usual food crops, plants that grow and flourish those conditions are advocated. One such plant is the sea asparagus, *Salicornia*. It is a succulent, bushy plant found in the salty terrains along the east coast of India, Bangladesh and Sri Lanka. The variety, SOS-10, grows well in desert sands irrigated with seawater. The tender stems and tips of the plant are edible by humans. The seeds yield edible oil (rich in polyunsaturates), which is similar to safflower oil in fatty acid composition and is usable as biodiesel. The plant grows well with maximum yields in hot climates if the seeds are sown in cool season so as to reach maturity during the hot months (www.hindu.com/seta/2003/09/05.htm).

Salicornia is a better photosynthesizer than several food grains. It uses C-4 pathway, converting the captured CO_2 first into compound containing four carbons (oxaloacetate) using the enzyme PEPCase. Thus *Salicornia* sequesters CO_2 better, grows in saline water, and gives edible oil and biodiesel. With the rising seas inundating the low-lying coastal areas, growing *Salicornia* that is available in South Asia may be an opportunity. A 2000 hectare farm would yield biomass of 30,000 tonnes and 2,500 t of seeds. It suits small, labour-intensive farms as well as highly mechanized farms. The Seawater Foundation, Arizona is advocating diversion of flow of inundating seawater inland through ocean canals in the northern Mexican State of Sonora and nourish commercial fish and shrimp aquaculture operations, mangrove forests and crops such as *Salicornia* that produce food and fuel (www. seawater foundation.org).

Biofuel from algae

Biodiesel is a clean burning alternative fuel for diesel engines. It is produced from renewable resources, biodegradable, non-toxic, and as a blended product, can be used in most diesel engines without modifications. Biofuels come from agricultural crops such as soy, jatropha and jajoba. Considering the current debate about agricultural land being used to produce biofuels, algae may be a potential alternative fuel source. Algae can be grown easily in ponds or tanks constructed in poor quality land. The first stage should be identification and development of suitable algal strains to achieve stable, continuous and high yield production. The process will also produce byproduct for animal feed stock. Products from *Spirulina* can be used for human consumption.

Algae require large volumes of CO_2 to grow, which means less CO_2 is released into the atmosphere. It may be a good option to locate the farms near major industries and power stations. Companies that produce CO_2 will eventually be able to claim carbon credits as the CO_2 can be stored or captured and released into algae farms (www.greencarcongress.com). The production of biodiesel complements ethanol as an alternative renewable fuel.

Strategies for evolving adaptive mechanisms

In the context of climate change, the primary challenge to the fisheries and aquaculture sector will be to ensure food supply, enhance nutritional security, improve livelihood and economic output, and ensure ecosystem safety. These objectives call for identifying and addressing the concerns arising out of climate change; evolve adaptive mechanisms and implement action across all stakeholders at national, regional and international levels (Table 2). In response to shifting fish population and species, the fishing sector may have to respond with the right types of craft and gear combinations, on-board processing equipments etc. Governments should consider establishing Weather Watch Groups and decision support systems on a regional basis. Allocating research funds to analyze the impacts and establishing institutional mechanisms to enable the sector are also important. The relevance of active regional and international participation and collaboration to exchange information and ideas is being felt now as never before.

Table 2. Options for coping with climate change in fisheries and aquaculture (modified after Allison et al. 2004; Handisyde et al. 2005; FAO, 2008)

Concerns & Adaptive mechanisms

Uncertainties in fish availability and supply

i) Adapt Code of Conduct for Responsible Fisheries

ii) Develop knowledge-base for climate change impact on fisheries and aquaculture;

iii) Predict medium and long term probabilistic production;

iv) Assess the adaptation capacity, resilience and vulnerability of marine production systems;

v) Adjust fishing fleet and infrastructure capacity;

vi) Consider the synergistic interactions between climate change and other factors such as fishing

New challenges for risk assessment

i) Consider increasing frequency of extreme weather events;

ii) Consider past management practices to evolve robust adaptation systems;

iii) Identify and address the vulnerability of specific communities; consider gender and equity issues

Complexities of climate change interactions into governance of frameworks to meet food security objectives

i) Recognition of climate-related processes, and their interaction with others;

ii) Action plans at national level based on (a) Code of Conduct for Responsible Fisheries; (b) Integrated ecosystem-based fisheries and aquaculture management plans, (c) framework for expansion of aquaculture; (d) linkage among cross-sectoral policy frameworks such as insurance, agriculture, rural development and trade;

iii) Action plans at regional level by (a) strengthening regional organizations and place climate change agenda as a priority; (b) addressing transboundary recourse use; (c) evolving common platforms and sharing the best practices;

iv) Action plan at international level by (a) linking with mitigation activities; (b) enhancing co-operation and partnerships; (c) applying international fishery agreements

Fisheries and aquaculture may be more vulnerable in conflicts with other sectors

i) Action plans should involve not only fisheries institutions/ departments, but also those for national development planning and finance;

ii) Sharing and exchange of information with other sectors;

iii) Existing management plans for fisheries need to be reviewed by considering climate change.

Financing climate change adaptation and mitigation measures

i) Fishermen, fish farmers, processors, traders and exporters should increase self protection through financial mechanisms;

ii) Improving equity and economic access such as microcredit should be linked to adaptation responses;

iii) Investment on infrastructure, such as construction of fishing harbour, should consider climate change;

iv) Financial allocation in national budget for risk reduction and prevention practices such as early warning systems and disaster recovery programmes and for relocation of villages from low lying areas;

v) Fiscal insensitive for reducing the sector's carbon footprint and other mitigation and adaptation options;

vi) Full potential of existing financial mechanisms has to adapt and mitigate the issue of climate change.

For the marine fisheries sector, climate change notwithstanding, there are several issues to be addressed. Strategies to promote sustainability and improve the supplies should be in place before the threat of climate change assumes greater proportion. While the fisheries sector cannot do much to mitigate climate change, it could contribute to reduce the impact by following effective adaptation measures.

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