ISSN 0972 - 2351

CMFRI Special Publication No.105

Marine Fisheries Policy Brief-3

Climate Change and Indian Marine Fisheries

Central Marine Fisheries Research Institute
(Indian Council of Agricultural Research)
P. B. No. 1603, Kochi-682 018, India
www.cmfri.org.in

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E. Vivekanandan

भाकृ अनुप
ICAR

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Climate Change and
Indian Marine Fisheries

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ISSN 0972 - 2351

Printed at
Niseema Printers & Publishers, Kochi, 682 018.

FOREWORD

In recent years, climate change has emerged as one of the topics of topmost concern globally. India is no exception to this. The greenhouse gas emission is increasing rapidly, and if unchecked, is likely to reach unprecedented and irreversible levels in another three to four decades. It has been realized that the northern Indian Ocean is one of the hotspots of climate change. This region warms faster than 90% of global oceans. Hence, it is recognized that the northern Indian Ocean is a forerunner to changes in other regions. Needless to say that assessing the impacts and potential adaptation and mitigation options in the northern Indian Ocean is of paramount importance to India and to other parts of the world as well.

The problems for the fisheries sector is high, if not more compared to other sectors. In addition to the existing issues such as depleting fish stocks, competition among stakeholders for sharing the limited resources, and excess fleet capacity, the sector has to face the threat from climate change. Central Marine Fisheries Research Institute is one of the institutes that initiated research on climate change as early as in 2004 under the ICAR Network project "Impact, Adaptation and Vulnerability of Indian Agriculture to Climate Change". In the last six years, the institute has emerged as the nodal organisation on climate change research on Indian marine fisheries in the country. In addition to several interesting results on the impact of climate change on marine fisheries, the project has identified a few potential adaptation and mitigation options .

Emergence of well-informed institutions and societies is the first step towards evolving adaptation and mitigation measures for the fisheries sector. To achieve this and to create climate awareness among the scientists, managers, fishermen, NGOs and other stakeholders, Dr E. Vivekanandan, Principal Scientist & Principal Investigator, Network Project on Climate Change, CMFRI has reviewed the results of the Network project and has incorporated relevant information from other sources as well. This publication is expected to pave the way for formulating policies on climate change and marine fisheries in India.

Kochi-682 018
February, 2011 G. Syda Rao

ACKNOWLEDGEMENTS

I thank Dr. G. Syda Rao, Director, Central Marine Fisheries Research Institute, Kochi for encouragement and support to publish this Policy Brief. This Brief is a review of the publications from the ICAR Network project "Impact, Adaptation and Vulnerability of Indian Marine Fisheries to Climate Change" and relevant publications from other sources. I am grateful to Dr. P.K. Aggarwal, International Water Management Institute, New Delhi and Dr. G.G.S.N. Rao, Central Research Institute for Dryland Agriculture, Hyderabad for coordinating the Network project.

Dr. M. Rajagopalan, former Head, Fishery Environment Management Division, CMFRI initiated climate change research in CMFRI in 2004. I compliment his initiatives and acknowledge his leadership in climate change research. I thank my colleagues in CMFRI, Dr V.V. Singh, Dr J. Jayasankar and Dr Joe Kizhakudan for support. I also thank Dr. N.G.K. Pillai, Dr. E.V. Radhakrishnan, Dr. Sunil K. Mohammed and Dr. V. Kripa for reading the manuscript and offering suggestions. My grateful thanks are due to B. Jasper, M. Hussain Ali, U. Manjusha, R. Remya, A.K. Poonam and T.V. Ambrose, Senior Research Fellows and Sri. J. Narayanaswamy for assistance.

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SUMMARY

The marine fish production in India has increased by six times in the last six decades. However, there are sustainability concerns such as production approaching the potential yield, overcapacity in the fishing sector, open access to the fishery, degradation of habitats and trade-related issues. Climate change exacerbates this situation.

Sea surface temperature has increased by 0.2 to 0.3 °C along the Indian coast in the last 45 years, and is projected to increase by 2.0 to 3.5 °C by 2099. The projected sea level rise is 30 cm in 50 years. During the southwest monsoon, the wind speed and coastal upwelling has strengthened, resulting in higher concentration of chlorophyll *a* along the Kerala coast.

These changes are likely to influence the structure and function of marine ecosystems, on which evidences are accumulating. The phytoplankton grow faster at elevated temperature, but the decay sets-in earlier. Species response to elevated temperature is different, showing changes in composition and abundance at the base of the food web. Coral bleaching is likely to be an annual event in the future and the model shows that reefs would soon start to decline and become remnant between 2050 and 2060 in the Indian seas. Mangroves in tropical regions are extremely sensitive to global warming and the extent and composition of mangroves may undergo major changes. Occurrence of harmful algal blooms seems to have become more frequent, intense and widespread and cause considerable mortality of fish.

The small pelagics such as the oil sardine and Indian mackerel have extended their distributional boundary to northern and eastern latitudes contributing to fisheries in the last two decades. They have extended their distribution to midwaters as well. The threadfin breams are found to shift their spawning towards cooler months off Chennai. These distributional and phenological changes may have impact on nature and value of fisheries. 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 trends due to fishing and other non-climatic factors. Such

distributional changes would lead to novel mixes of organisms in a region, and result in considerable changes in ecosystem structure and function.

Small-scale fisheries will be the most vulnerable, eventhough it is not the cause to climate change. The sensitivity of this subsector to climate change threat is very high while adaptive capacity is low. Among the six marine fisheries regions in the Indian EEZ, it appears that the impact on southeast coast fisheries sets in faster than other regions.

Despite the uncertainties and potential negative impacts of climate change on fisheries, there are opportunities to reduce the vulnerability to climate-related impacts. As the first step, projections on fish distribution, abundance catches need to be developed for planning better management adaptations. For the fisheries sector, climate change notwithstanding, there are several issues to be addressed. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal means of reducing the impacts of climate change. Some of the most effective actions by which we can tackle climate impacts are to deal with the familiar problems such as overfishing, and adopt Code of Conduct for Responsible Fisheries and Integrated Ecosystem-based Fisheries Management.

The following measures could contribute to coping with climate change: (i) 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 and farming communities; (vi) establishing Weather Watch Groups; (vii) establishing effective coast protection structures; and (vii) evolving decision support systems for fisheries.

With increasing number and size of boats, CO_2 emission by fishing boats has increased in recent years. Although a small contributor to overall CO_2 emission, the sector has the responsibility to reduce the emissions as much as possible.

1. INTRODUCTION

There is now a widely-held consensus among scientists and policy-makers that human activities are increasing the levels of carbon dioxide and other greenhouse gases in the atmosphere, leading to a rise in temperature. In its Fourth Assessment Report (FAR), the Intergovernmental Panel on Climate Change (IPCC) (2007) stated that warming of the climate system is unequivocal and that emission levels of greenhouse gases such as carbon dioxide, methane and nitrous oxide have increased markedly in the atmosphere as a result of human activities. Since the year 1750, the level of atmospheric carbon dioxide has risen from 280 ppm to 380 ppm in 2005, and if unchecked, will be at around 560 ppm by the year 2050. Concentration of methane and nitrous oxide has also increased from 715 ppb to 1774 ppb, and from 270 ppb to 320 ppb, respectively in the last 250 years. This links, in turn, to changes in surface temperature, varying with latitude and topography, and to thermal expansion and melting of ice caps and sea level rise. It has been found out that the atmospheric temperature has increased by 0.74 °C between 1906 and 2005. Temperature differences between land and sea, and across latitudes, drive the world's weather and climate systems. This uneven warming is predicted to have important disruptive effects on weather and climate.

Using 35 emission scenarios, the IPCC (2007) has predicted that the global average temperature would rise between 1.4 and 5.8 °C between 1990 and 2100 with the most likely change between 2.0 and 4.5 °C. At a global level, water vapour, evaporation and precipitation are expected to increase, and at local levels, extreme events of drought, precipitation, storm surges and cyclones will increase. Average of seven climate models and 35 emission scenarios predicts increase in global sea level in the range of 15 to 25 cm in the next 50 years.

With global warming, the waters of oceans are also warming up though there are considerable variations in different geographical regions and at different times. Warming has been more intense in surface waters, and there are evidences for deepwater warming too. The world's oceans are also affected by changes in precipitation, wind and currents, which are the result of geographical differences in temperature and humidity of the atmosphere. Thus, important oceanic weather systems such as the *El Niño* Southern Oscillation (ENSO) and Indian Ocean monsoon will be affected by global warming. Other direct effects of warming on aquatic systems include changes in precipitation, evaporation, river flows, groundwater, lakes and sea levels. These changes have altered the energy balance in the atmosphere, resulting in a warming effect.

Marine ecosystems are not in a steady state, but are affected by the environment, which varies on many spatial and temporal scales. Changes in temperature are related to alterations in oceanic circulation patterns that are affected by changes in the direction and speed of the winds that drive ocean currents and mix surface waters with deeper nutrient rich waters (Kennedy *et al*., 2002). These processes in turn affect the distribution and abundance of plankton, which are food for small fish.

Besides, the rising acidity levels in the seas as a result of climate change have negative effect on coral reefs and calcium-bearing organisms. Global warming and the consequent changes in climatic patterns will have strong impact on fisheries with far-reaching consequences for food and livelihood security of a sizeable section of the population. The Food and Agriculture Organization (FAO) has pointed out that the responses of capture fisheries to climate change are fundamentally different from other food production systems (FAO, 2008). Unlike most terrestrial animals that constitute the livestock sector, aquatic animal species used for human consumption are poikilothermic. The report points out that any change in habitat temperatures significantly influences their metabolism, growth rate, productivity, seasonal reproduction, and susceptibility to diseases and toxins. This is likely to result in significant changes in fisheries' production in world oceans. However, the magnitude of impact would vary in different regions. For communities that heavily rely on fisheries, any decrease in the availability of fish will pose serious problems.

2. SUSTAINABILITY ISSUES IN INDIAN MARINE FISHERIES

In the last six decades, marine fish production in India has increased from 0.5 million tonnes (m t) in 1950 to 3.2 m t in 2009 (Devaraj and Vivekanandan, 1999; CMFRI, 2010). The decadal growth rate of production increased until the mid 1990s, but slowed thereafter. Nevertheless, marine fish production in India did not show consistent decline over the time scale. This trend is different from that of global decadal growth rate, which consistently decreased from the year 1970. However, there are several sustainability concerns that demand immediate as well as long-term solutions.

2.1 Production vis-à-vis Potential Yield

Potential yield estimates indicate that the annual harvestable potential yield from the Indian EEZ is 3.9 m t (Anon, 2000). As the production (3.2 m t in 2009) is approaching the potential yield, the country has reached a stage in which further increase in production may have to be viewed with caution. It would be difficult to achieve goals related to sustainability if more fish are continuously removed.

2.2 Fishermen population and livelihood

India is a country with a large number of fishermen harvesting multispecies resources with an array of craft-gear combinations. The livelihood of these fishermen directly depends on availability of natural resources. The number of fishermen involved in active fishing increased from an estimated 0.5 million in 1980 to 0.9 million in 2005 (CMFRI, 2006). This includes those involved in actual fishing on full-time and part-time basis. Irrespective of this near-doubling of the dependent-population, a fisherman in India produces only 3.5 t fish per year (in the last 25 years) as compared to > 100 t per year by his counterpart in several European Union countries. The population depending directly on fishing is so very great in India that there may not be any quick solution to the problem of overcrowding. At present, only 5.6% of fishermen are educated above secondary level of school education (CMFRI, 2006). Relocating a large number of fishermen with alternate employment is possible only by providing them higher education for highly skilled jobs and improve their societal status. This would be a long-term process.

2.3 Overcapacity

In the last 25 years, the number and efficiency of fishing fleet have increased. Following introduction of mechanisation in the mid-1960s, there were 18,790 mechanised boats in 1980 and 58,911 in 2005 (CMFRI, 2006). The efficiency of boats increased in terms of boat size, engine power, sea endurance etc. Motorisation of traditional boats was introduced in the mid-1980s, which became very popular immediately. In 2005, there were 58,911 motorised boats in addition to 75,591 non-motorised boats. Motorisation substantially increased the mobility of the small craft. These developments have helped extension of fishing to deeper waters as well into new geographical areas. At present, overcapacity is an issue in capital-intensive mechanised fishing sector as well as in the employment-oriented motorised sector. However, the effect of overcapacity of fleet and overfishing of coastal fish populations has been masked by increased landings of additional resources from distant water fishing grounds.

2.4 Coastal fishing

Fish resource is finite with a ceiling on productivity. There is intense competition for sharing the available fish stocks. Regions within the Indian EEZ are in different states of exploitation and in the same region, the resources are in different states of exploitation. It is extremely difficult to devise a common management strategy that would satisfy the interests of all sections of fishermen as well as sustain fish resources. Fishing closure for 45 to 60 days for mechanised fishing boats is being followed every year all along the coasts. However, fishing remains, to a large extent, open access. Inspite of promulgation of Marine Fishing Regulation Acts by maritime state governments, licensing of craft, mesh size regulation, catch declaration, ceiling on number and efficiency of fishing craft, monitoring, control and surveillance of fishing vessels remain as issues. Consequently, entry barriers and capacity controls are ineffective or are absent.

The situation exerts fish resources under pressure. The major dilemma is that if access to fisheries resources is restricted, it would affect livelihoods of coastal communities, while if the access is open, the resources will sooner or later decline beyond recovery. It has been reported that 60% of coastal fish stocks are in mature stage of exploitation and 30% are in senescence stage (Srinath *et al*., 2004). Fishing down the marine food web by 0.04 trophic level per decade has been detected along the Indian coast, especially along the southeast coast (Vivekanandan *et al*., 2005). These trends indicate the impact of fishing on fish stocks, and on the structure and function of marine ecosystem as well.

2.5 Trade

The demand for niche seafood products is increasing in international markets. Shark fins and tuna sashimi are some examples. As the tailfin of sharks fetches as high as US$ 200 per kg and sashimi US$ 20 per kg, target fishing for these resources has increased enormously in the last five years. This has induced a few hundred small and medium-size fishing boats to venture into high seas. These market-driven fishing activities are changing the face of India from a coastal fishing nation to that of ocean fishing nation. This would exert pressure on oceanic fish stocks, which are highly vulnerable to fishing. The sustainability issues of fisheries have to address growing removals and exports from the dwindling fish resources.

2.6 Other anthropogenic factors

One of the often-ignored factors that causes degradation of environment and depletion of fish stocks is the anthropogenic interference other than fishing. The man-induced alteration of the physical, chemical, biological and radiological integrity of air, water, soil and other media is causing, in several cases, irreversible damage to the marine ecosystems. Runoff from domestic, municipal and industrial wastewater discharges and agricultural fields, solid waste disposals, discharge from ships and oil spills from tankers are some of the major sources that cause deterioration of water quality, and cause damage to the aquatic organisms, from phytoplankton to mammals. Dams divert nutrient-rich water from entering into the sea, and obstruct the migratory path of some fishes. Pollutants such as trace metals and organochlorine pesticides enter the biological systems through food webs. Animals in higher trophic levels experience the effects of bioaccumulation and biomagnification. Depending on the intensity of damage, the interferences affect the physiological processes of growth and reproduction of aquatic organisms, mass kills, biodiversity loss and displacement of species.

Fisheries sustainability needs to be addressed in an integrated way by considering the issues of all the anthropogenic interferences such as increasing fishing intensity, damage to the physical, chemical and biological integrity of the ecosystems. As fisheries are impacted by the developmental needs of several other important prime sectors such as agriculture, industries, power generation etc, it is not possible to find solution to the issues from fisheries sector alone. For instance, issues such as water contamination, enforcement of standards for water discharge, maintaining the quality of river runoff, and reducing greenhouse gas emissions, have to be addressed by non-fisheries sector.

It has been recognised that Ecosystem-based Fisheries Management (EBFM) is a better option compared to single-species management. Declaration of Marine Protected Areas, sanctuaries and marine parks to the extent of about 3% of Indian coastline has served as areas banned from fishing. In a country with 3202 marine fishing villages, which are littered at a distance of about every two kilometers along the coastline, implementing EBFM is a challenge. Consensus of fishermen to implement no-fishing zones would be hard to arrive at, and implementing EBFM would be very expensive to governments. However, efforts should be initiated to move towards EBFM.

2.7 Climate change

Northern Indian Ocean has been identified as one of the 17 climate change hotspots among the world oceans (Hobday *et al*., 2008). These areas are recognised to warm faster than 90% of the oceans. These regions are expected to provide the potential for early warning and evidence of the response by natural resources to climate change. In theory, these regions at the frontline of climate change, should also be leading in assessing impacts and evaluating adaptation options. Ecological monitoring of hotspots provide us with one of the first opportunities to detect climate change induced impacts on our marine ecosystems in advance.

Long-term climate change will affect the ocean environment and its capacity to sustain fishery stocks and is likely to exacerbate the stress on marine fish stocks. The extent to which it will affect fisheries in different regions and species, is however not yet clear. Productivity might increase or decrease significantly. Ecosystem boundaries may be displaced and species composition may change remarkably. Fisheries infrastructures may have to be displaced, at high cost. Fisheries lacking mobility (e.g. small-scale traditional fisheries) might suffer the most.

3. IMPACT ON OCEANOGRAPHIC FEATURES

Changes in the important oceanic weather systems such as sea surface temperature, pH, salinity, *El Niño* Southern Oscillation (ENSO), precipitation, sea level, frequency and intensity of cyclones and droughts are becoming evident as a result of climate change (for example, see Prasannakumar *et al*., 2009, 2010).

3.1 Sea surface temperature

Analysing the data set on sea surface temperature (SST) obtained from International Comprehensive Ocean – Atmosphere Data Set (ICOADS) (www.cdc.noaa.gov) and 9-km resolution monthly SST obtained from Advanced Very High Resolution Radiometers (AVHRR) satellite data (provided by the NOAA/NASA at http:/podaac.jpl.-nasa.gov/), it has been found that the sea surface temperature increased in the Indian seas, by 0.2°C along the northwest (NW), southwest (SW) and northeast (NE) coasts, and by 0.3°C along the southeast (SE) coast during the 45 year period from 1961 to 2005 (Fig. 1). The SST showed peaks at an interval of about ten years (1969-70, 1980, 1987-88, 1997-98) during 1961-2005, and the decadal number of SST anomalous (+ 1 or – 1 deviation from the 45-year mean) months increased. Off Kerala, for example, only 16% of the months were SST anomalous during 1961-1970, but 44% during 2001-2005 (Vivekanandan *et al*., 2009a).

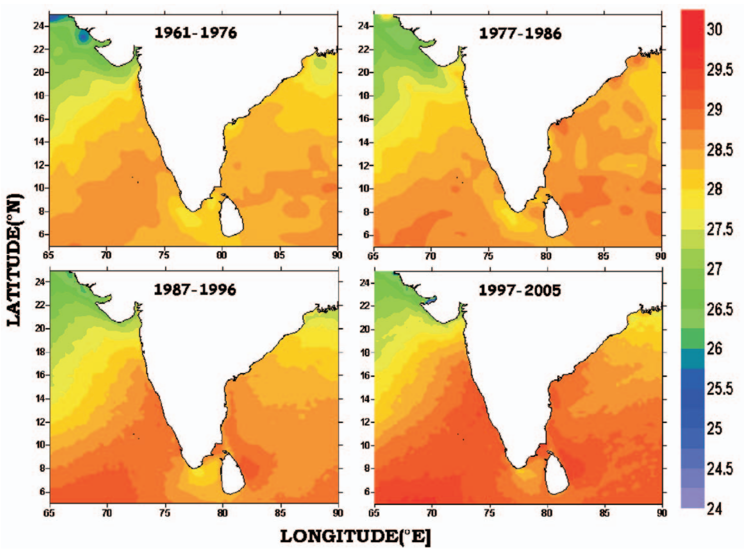


Fig. 1. Rise in sea surface (°C) temperature in the Indian seas

Vivekanandan *et al* (2009b) gathered monthly SST data for the years 1985-2005 from the 5-channel AVHRR on board the NOAA polar orbiting satellites (http://podaac.jpl.nasa.gov). By combining this with the projected monthly set of SST data for warming scenario of Special Report on Emission Scenarios (SRES) A2 from the UKMO HadCM3 model for the years from 2000 to 2099 for five different latitude-longitude positions in the Indian seas, they showed that the SST would increase in all the regions of the Indian Seas by 2.0° C to 3.5° C by 2099. In the Gulf of Kachchh, the annual average SST would increase from 27.0° C in 2000 to 30.5° C in 2099; and in the Lakshadweep Sea from 29.2° C to 32.2° C. The maximum SST in summer months may rise upto 34.0° C or more.

Temperature is one way we measure ocean variability, but temperature is also an indicator of more complex ocean processes. Changes in temperature are related to alterations in oceanic circulation patterns that are affected by changes in the direction and speed of the winds that drive ocean currents and mix surface waters with deeper nutrient rich waters.

3.2 Sea level rise, cyclones and storm surges

The current understanding is that ocean warming plays a major role in sea level rise, intensified cyclone activity and heightened storm surges. The mean global rate of sea level rise during the 20th century has been nearly 2 mm per year, which is 10-fold higher than the average of the past several millennia. The IPCC (2007) has projected that the global annual seawater temperature and sea level would rise by 0.8 to 2.5°C and 8 to 25 cm, respectively by 2050. The sea level rise for Cochin (southwest coast) is estimated as 2 cm in the last one century (Emery and Aubrey, 1989; Das and Radhakrishna, 1993). However, the rate of increase is accelerating, and it is projected that it may rise at the rate of 5 mm per year in the coming decades. Considering this, it is possible that the sea level may rise by 25 to 30 cm in 50 years (Dinesh Kumar, 2000). An increase in mean sea level will affect waves, currents and bottom pressure in the near shore region. In general, an increase in mean water depth will be accompanied by an increase in mean wave height, resulting in a more severe wave attack on the coast and a greater wave induced littoral drift. The erosion due to sea level rise for Kerala is estimated as 7125 m^3 per year, implying an erosion rate of -- 0.3 x 10^6 m^3-- per year, which could be attributed to the effects of wave attack. Using the extreme conditions of wave height and sea level rise, future erosion potential is expected to increase by 15.3% by the year 2100 (Dinesh Kumar, 2000). Besides destruction through increased rates of erosion, the sea level rise increases the risk of flooding. This will damage or destroy many coastal ecosystems such as mangroves and salt marshes, which are essential for maintaining many wild fish stocks, as well as supplying seed to aquaculture. Higher sea levels may make groundwater more saline, harming freshwater fisheries, aquaculture and agriculture and limiting industrial and domestic water uses.

The International Workshop on Tropical Cyclones (2010) has recently noted that if the projected rise in sea level due to global warming occurs, then vulnerability to tropical cyclone, storm surge and flooding would increase; and it is likely that increase in tropical cyclone, peak wind-speed and rainfall will occur if the climate continues to warm. Model studies and theory project a 3-5% increase in wind speed per degree Celsius increase of tropical sea surface temperatures. SST of 28^o C is considered an important threshold for the development of major hurricanes of categories 3, 4 and 5 (Knutson and Tuleya, 2004; Michaels *et al*., 2005).

Acidification of ocean waters (modified from Hobday *et al.*, 2006)

Two important parameters of the oceanic carbon system are the pH (i.e., level of acidity or alkalinity) and calcium carbonate ($CaCO_3$) saturation state of seawater. The pH of seawater is defined by the amount of H+ ions available. The calcium carbonate saturation state of seawater expresses the stability of the two different forms of calcium carbonate (calcite and aragonite) in seawater.

Oceans removed 25% of CO_2 emitted by human activities during 2000-2007. Increasing CO_2 concentrations in the surface ocean via anthropogenic CO_2 uptake will have two effects. First, it will decrease the surface ocean carbonate ion concentration (CO_3) and decrease the calcium carbonate saturation state. Second, when CO_2 dissolves in water, it forms a weak acid (H_2CO_3) that dissociates into bicarbonate-generating hydrogen ions (H+), making the ocean more acidic (pH decreases).

Using an ocean-only model forced with atmospheric CO_2 projections (IS92a), a 40% reduction in aragonite saturation in the world oceans is predicted by 2100 (Kleypas *et al*., 1999).

The coastal zone of India is densely populated and stretches over 8046 km. There are about 70 coastal districts, which occupy around 379,610 km^2, with an average population density of 455 persons per km^2, which is about 1.5 times the national average of 324 persons per km^2. In the coastal districts, 25% of the population lives within 50 km from the coastline. Kerala, with a narrow contiguous area extending along the coast, is dependent on coastal resources than any other state in the country. About 30% of the population lives in the coastal areas, resulting in a very high density of > 2000 persons per sq.km.

Among the coastal areas, the highwater marks and mean sea level are high along the Kachchh and Saurashtra coasts followed by West Bengal coast. Under the present climate, it has been observed that the sea level rise (0.4 to 2.0 mm per year) along the Gulf of Kachchh and the coast of West Bengal is the highest (Ministry of Environment and Forests, 2004). Future climate change in the coastal zones is likely to be manifested through worsening of some of the existing coastal zone problems. The Indian coast, in general, experiences seasonal erosion and some of the coastal areas regain their original profiles. Fifty per cent of areas, which do not regain their original shape over the annual cycle, undergo net erosion. At present, 23% of the shoreline along the Indian mainland is affected by sea erosion (Sanil Kumar *et al*., 2006). The large inflow of freshwater into the seas around India due to rainfall over the ocean and runoff from rivers, forces large changes in sea level especially along the coasts of Bay of Bengal. During June-October, the inflow of freshwater from the Ganges and Brahmaputra into the northern Bay Bengal is about $7.2*10^{11}m^3$, the fourth largest discharge in the world (Shankar, 2000). Increase in sea level, in addition to causing threats to human lives, will pose problems on freshwater availability due to intrusion of seawater and salinisation of groundwater. This would also result in loss of agricultural land. A rise in sea level is likely to have significant impact on the agriculture performance in India. A one metre sea level rise is projected to displace approximately 7.1 million people in India and about 5,764 km^2 of land area will be lost, along with 4,200 km of coastal roads (Ministry of Environment and Forests, 2004). Approximately 30% of India's coastal zones will be subjected to inundation risk with sea level rise and intensified storm surges (Dasgupta *et al.,* 2009). The Ministry of Environment and Forests, Government of India (2004) identified the coastal districts of Jagatsinghpur and Kendrapara in Orissa, Nellore in Andhra Pradesh, Nagapattinam in Tamil Nadu and Junagadh in Gujarat as highly vulnerable to cyclones.

4. IMPACT ON MARINE ECOSYSTEMS

Organisms interact directly or indirectly with each other through predation, competition, parasitism etc and are influenced by their physical environment. The various linkages among species may be altered because of rapid changes in the climate in this century. Changes in the habitats, species composition, diversity and abundance will result in ecosystems that function differently from the way they do now. Important ecosystem services such as food production may be altered either positively or negatively (Kennedy *et al*., 2002). In the terrestrial ecosystems, the physical boundaries are well marked and environmental variabilities are rather wide. The terrestrial organisms and ecosystems have developed internal mechanisms to cope up with variabilities. In contrast, in the marine ecosystems, the physical variability is small and extends over very long time scales due to the large thermal capacity of the ocean and the long periods of exchange between deep and near shore waters. The marine ecosystems are more vulnerable to large-scale environmental changes because they do not have the internal adaptability inherent in the terrestrial systems.

4.1 Changes in species composition of phytoplankton

Laboratory experiments on seven species of phytoplankton at lower (24°C) and higher (29°C) seawater temperatures showed that at higher temperature, the rate of multiplication was faster and cell density was higher (CMFRI, 2009). However, the decay set-in earlier and the cycle was completed faster at higher temperature. For instance, the decay of microalgae was on Day 12 at 24°C, but on Day 10 at 29°C. Moreover, the species dominance within the culture period was different between the two temperatures. This study indicates the potential response in the growth rate, species composition and longevity of phytoplankton to higher temperature. Other factors such as light, current and nutrient availability will also affect the amount and composition of phytoplankton. The availability of phytoplankton influences the food availability up through various trophic levels. The transport and abundance of zooplankton, the main consumers of phytoplankton, must synchronise with the phytoplankton bloom, or the zooplankton cannot survive, thus depriving food for organisms at higher trophic levels. In nature, the phytoplankton blooms, and the occurrence and abundance of zooplankton are always well timed. Any potential mismatch would offset the food web. Synchrony between timing and abundance of peak zooplankton determines the larval recruitment as well as the abundance of several adult fishes.

4.2 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 bleaching (Fig. 2) 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.

The Fourth Intergovernmental Panel on Climate Change (IPCC) Assessment Report (2007) states "Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1–3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatization by corals." The IPCC listed the following changes as pertinent to coral reefs:

Rising sea surface temperatures;

Increasing concentrations of CO_2 in seawater;

Sea level rise;

Possible shifting of ocean currents;

Associated rises in UV concentrations; and

Increases in hurricanes and cyclonic storms.

In the Indian seas, coral reefs are found in the Gulf of Mannar, Gulf of Kachchh, Palk Bay, Andaman Sea and Lakshadweep Sea. Indian coral reefs have experienced 29 widespread bleaching events since 1989 and intense bleaching occurred in 1998 and 2002 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) predicted that reefs should soon start to decline in terms of coral cover and appearance. The number of

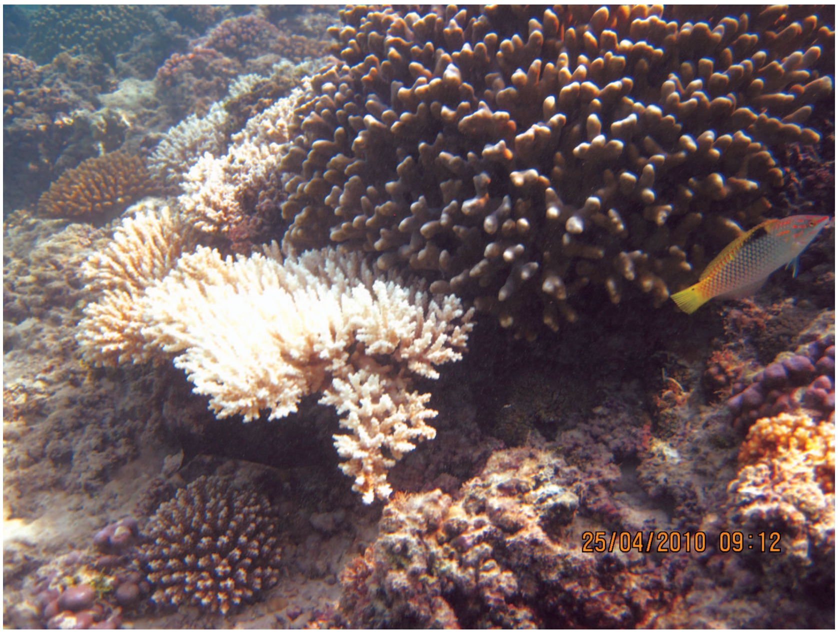


Fig. 2. Bleaching of corals off Androth, Lakshadweep Islands in April, 2010 (underwater photo courtesy: K.P. Said Koya)

decadal low bleaching events will remain between 0 and 3 during 2000-2089, but the number of decadal catastrophic bleaching events will increase from 0 during 2000-2009 to 8 during 2080-2089. 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 Sea 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 affect formation of exoskeleton of the corals. Scientists are of the opinion that if the acidification continues as it is now, the coral reefs in the world oceans would become remnant in 50 years (World Wildlife Fund, 2004). Given their central importance in the marine ecosystem, the loss of coral reefs is likely to have several ramifications.

It is necessary that coral reef protection and restoration programmes are initiated in the Indian seas by undertaking the following initiatives (see also Wilkinson, 2008):

- There is a continued need to strengthen coral reef monitoring and research in India to reinforce positive recovery trends and rectify particular gaps. Capacity needs strengthening for improving coverage of the vast reef areas in Indian seas. There is also a need for sound data management, analysis and reporting. Broader application of more comprehensive coral reef monitoring approaches, such as the Resilience Assessment methodology developed by the IUCN Climate Change and Coral Reefs Working Group, should be encouraged.
- For protection of coral reefs, Marine Protected Areas (MPAs) have become increasingly prominent. Management of MPAs should be strengthened; management effectiveness has to be reviewed in order to improve management decision making and strategies. The objectives of MPAs are both social and biological, including reef restoration, aesthetics, increased and protected biodiversity, and economic benefits. Conflicts surrounding MPAs involve lack of participation, clashing views and perceptions of effectiveness, and funding.
- Protecting the coral reef resources such as groupers, ornamental fish and crustaceans is essential. Careful management could prevent these from collapsing like many other reef resources elsewhere.
- More genuine and inclusive collaborative approaches in resource management are required. Increased collaboration between government, NGOs, and in particular, the empowerment of communities to participate meaningfully is necessary.

In the Great Barrier Reef, for restoration of coral reefs, low voltage electrical current is applied through seawater, which crystallises dissolved minerals on steel structures. The resultant white carbonate (aragonite) is the same mineral that makes up natural coral reefs. Corals rapidly colonise and grow at accelerated rates on these coated structures. The electrical currents also accelerate formation and growth of both chemical limestone rock and the skeletons of corals and other shell-bearing organisms. The vicinity of the anode and cathode provides a high pH environment which inhibits the growth of filamentous and fleshy algae, which compete with coral for space. The increased growth rates cease when the mineral accretion process stops (Sabater and Yap, 2004).

Concrete has also been used to restore large sections of broken coral reef. Finally, special structures as reef balls can be placed to provide corals a base to grow on.

4.3 Mangroves

Climate change components that affect mangroves include changes in sea-level, high water events, storminess, precipitation, atmospheric CO_2 concentration, ocean circulation patterns, health of functionally linked neighboring ecosystems, as well as human responses to climate change (Ellison and Stoddard, 1991; Clough, 1994). Of all the components, relative sea-level rise may be the greatest threat. Sea-level rise submerges the areal roots of the plants, and reduces mangrove sediment surface elevation. Rise in temperature and the direct effects of increased CO_2 levels are likely to increase mangrove productivity, change the timing of flowering and fruiting, and expand the ranges of mangrove species into higher latitudes (Gilman *et al.*, 2007). Changes in precipitation and subsequent changes in aridity may affect the distribution of mangroves.

Mangroves in tropical regions are extremely sensitive to global warming because strong temperature dependence of physiological rates places many tropical species near their optimum temperature. The extent (~ 6,000 km^2) and composition of mangroves in India may undergo major changes, depending on the rate of climate change and anthropogenic activities.

Mangroves greatly help coastal protection. Mangrove loss will reduce coastal water quality, reduce biodiversity, fish and crustacean nursery habitats, adversely affect adjacent coastal habitats, and seriously affect human communities that rely on mangroves for numerous products and services.

To reduce the vulnerability of mangroves and increase resilience, non-climatic stresses such as filling, conversion for other human activities, pollution should be eliminated (Field, 1993). To augment mangrove resistance to sea-level rise, activities within the mangrove catchment can be managed to minimize long-term reductions in mangrove sediment elevation, or enhance sediment elevation. Mangrove enhancement (removing stresses that cause their decline) can augment resistance and resilience to climate change, while mangrove restoration (ecological restoration, restoring areas where mangrove habitat previously existed, development of inter-tidal mudflats) can offset anticipated losses from climate change (Field, 1993; McLeod and Salm, 2006). In India, the large expanse of inter-tidal mudflats (~ 25,000 km^2) may provide a scope of adjustment and adaptation in some areas, mostly in the semi-arid region.

Given uncertainties about future climate change and responses of mangroves and other coastal ecosystems, there is a need to monitor the changes systematically. Outreach and education activities can augment community support for adaptation actions.

4.4 Harmful algal blooms

Harmful algal blooms (HABs), in a strict sense, are completely natural phenomena which have occurred throughout recorded history. In the past three decades, (HABs) seem to have become more frequent, intense and widespread. In the Indian waters, HABs are increasing and cause considerable mortality of fish (Padmakumar *et al*., 2009). The southwest coast of India is particularly exposed in this respect. Among explanations proposed for the apparent increase of HAB in world oceans, it is suspected that changes in climate may be creating a marine environment particularly suited to HAB-forming species of algae (Hallegraeff, 1993). Factors such as temperature, stratification and nutrient supply are important for the occurrence of blooms. Global warming is predicted to make HABs larger and more numerous, as higher temperatures lead to more precipitation and a greater run-off of nutrient salts into the marine environment (http://www.sciencedaily.com- /releases/2010/05/100531082607.htm).

It is difficult to quantify the effect of climate change on the probability of an increase in harmful algal blooms. However, it is possible to assess the effect of an increased temperature on the growth of the algae, which cause fish mortality. Experiments conducted in Norway showed that growth rates of four harmful algae increased when a temperature scenario for the year 2100 (4°C increase) was used. The study concluded that due to climate change the risk of harmful dinoflagellate blooms in the Dutch and Norwegian coastal waters in the north Atlantic will increase (Edwards *et al*., 2006).

5. IMPACT ON MARINE FISH

Temperature is one of the single most important environmental variables affecting all aquatic organisms. Fish reproduction and other biological activities are mainly controlled by the temperature of water (Jorgensen, 1976). Food consumption of fish is a function of fish species, body mass, water temperature, salinity, and dissolved-oxygen concentration. Metabolic activity in fish increases by 10% for every 1^{o}C rise in the temperature of the aquatic environment, i.e., fish need 10% more oxygen for every 1^{o}C rise in temperature (Vivekanandan and Pandian, 1977). Rates and efficiency of conversion are also affected by water temperature (Table 1).

Table 1. Rates of food utilisation altered by water temperature in the freshwater fish *Channa striatus* (modified from Vivekanandan and Pandian, 1977); the values are g cal/g/day

Parameter	22°C	27°C	32°C	37°C
Feeding rate	79.8	144.2	180.4	150.5
Absorption rate	77.8	137.9	172.7	143.9
Metabolic rate	54.3	98.8	113.5	110.0
Conversion rate	17.4	28.2	46.6	21.9
Conversion efficiency (K_2)	22.4	20.4	27.4	15.3

Temperature is also known to affect fish distribution and migration. Many tropical fish stocks are already exposed to high extremes of temperature tolerance, and hence, some may face regional extinction, and some others may move towards higher latitudes (Perry *et al*., 2005). At shorter time scales of a few years, increasing temperature may have negative impacts on the physiology of fish because oxygen transport to tissues will be limited at higher temperatures. This constraint in physiology will result in changes in distributions, recruitment and abundance. Changes in the timing of life history events (phenological changes) are expected with climate change (Ahas and Aasa, 2006). 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 (Kennedy *et al*., 2002). At long time scales of multi-decades, changes in the net primary production and its transfer to higher trophic levels are possible. Most models show decreasing primary production with changes of phytoplankton composition with high regional variability.

The tropical fisheries are characterised by several fast growing (von Bertalanffy's annual growth coefficient: 0.5 to 1.0) and multiple spawning species. Low levels of spawning take place throughout the year for most of the species with one or two distinct spawning peaks in a year (Vivekanandan *et al*., 2010). The eggs of most of the species are pelagic, directly exposed to higher temperatures and currents. As temperatures increase, the development duration of eggs decrease, but the size of emerging larvae decreases (Vidal *et al*., 2002). In the warmer years, the adults may grow faster, but there will be a point where growth rates would start to decrease as metabolic costs continue to increase. In some marine organisms, it has been found that the average life-span will decrease as a function of increased growth rate, and the individuals will mature younger at a smaller size (Jackson and Moltschaniwskyj, 2001). This will in turn reduce the absolute fecundity, as smaller individuals produce lesser number of eggs. The scale of these organism-level changes on recruitment, biomass and fishery may depend on changes in the climatic parameters.

Generally, 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. The pathways by which climate change would impact marine fisheries are given in Table 2.

Table 2. Climate impact pathways on Indian marine fisheries

Climatic/ oceanographic variable	Observed & projected changes	Potential impact on fisheries
Sea surface temperature	Increase in SST by 0.2 to 0.3°C in 50 years; increase in SST anomalous months; increase in SST by 2.0-3.5°C by 2099	Physiological changes affect spawning and recruitment
	Faster rate of growth and decay of phytoplankton at higher SST; changes in plankton composition and primary productivity	May be beneficial to aquaculture; but mismatch of prey (plankton) and predator (fish) in wild populations
	Extension of distributional boundary of small pelagics to northern latitudes and depths; phenological changes in spawning season; changes in species mix, timing and success of spaw-ning, abundance, sex ratios, and timing and success of migration, enhanced metabolic and growth rates; altered ecosystems	Reduced production of high value, large fish; impacts on fisheries recruitment; loss of biodiversity; changes in regional craft-gear usage
	Frequent coral bleaching; corals may become remnant in 50 to 60 years	Loss of breeding habitats to coral fish; reduced recruitment to fisheries

pH	Frequent harmful algal blooms; reduction in DO, mass fish kills Increase in acidity of seawater; affect formation of exoskeleton of marine organisms such as corals, crustaceans and molluscs	Reduction in fish abundance; health risks to fish consumers Reduced habitats for coral-dependent biota; reduction in recruitment of crustaceans and molluscs into fishery
El Nino-Southern Oscillation	Increase in meridional wind speed by 0.5m/s; changes in direction of wind and current; seasonal deepening of thermocline by 60 m, contributing to mixed layer warming; changes in timing, strength and latitude of upwelling	Changes in larval distribution and abundance; reduction in food availability to larvae; changes in recruitment to fisheries; changes in regional & seasonal fish abundance; impact on ecosystems
Precipitation	Increase in extreme events; changes in onset of monsoon dates; changes in nutrient runoff and productivity of coastal waters	Effect on season and intensity of spawning, and prey availability; effect on production capacity of coastal ecosystems
Sea level	Rise in sea level by 2 to 5 cm in the last 100 years; projected rise by 0.3-0.5 m in 50 years; coastal erosion prominent along Kerala,	Shortage of freshwater; risks to properties of coastal fishing communities and infrastructure;

	Tamil Nadu, Andhra Pradesh and Orissa; loss of land; conversion of freshwater into brackishwaters; salt-water infusion into groundwater	Expenditure to governments on construction of coastal protection structures; changes in land use pattern; perhaps useful to coastal aquaculture, but not to freshwater aquaculture; migration of fishers
	Loss of coastal ecosystems such as mangroves	Loss of fish breeding habitats
Storm/ cyclone	Increase in frequency and intensity of storms and tidal waves	Damage to life and properties of coastal communities; to infrastructure such as harbours, craft and gear; increase in risks associated with fishing; loss of fishing days at sea; fishing would become less profitable; change in coastal profile
Drought	Increase in frequency and intensity; reduced runoff and enrichment of coastal waters; increase in salinity.	Reduction in productivity and fish abundance

The following responses to climate change by marine fishes are discernible in the Indian seas: (i) Extension of distributional boundary of small pelagics; (ii) extension of depth of occurrence; and (iii) phenological changes. Some evidences for the responses are given below:

5.1 Extension of distributional boundary of small pelagics

Oil sardine: The oil sardine *Sardinella longiceps* and the Indian mackerel *Rastrelliger kanagurta* are tropical coastal and small pelagic fish, forming massive fisheries (21% of marine fish catch of India). 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. These small pelagics, especially the oil sardine, 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

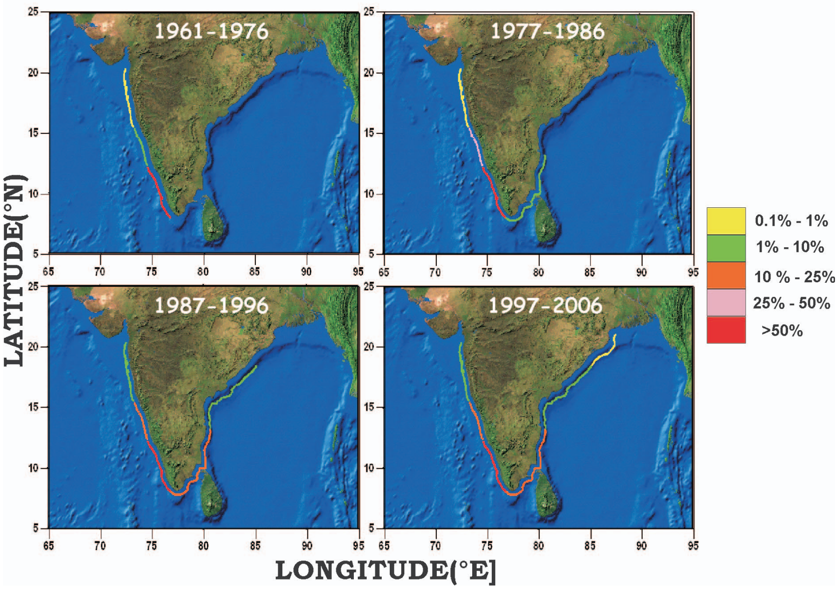


Fig. 3. Extension of distributional boundary of oil sardine along the Indian coast; the coloured lines indicate the percentage contribution of catch by each maritime state to the all India oil sardine catch during the corresponding time-period (from Vivekanandan et al., 2009c)

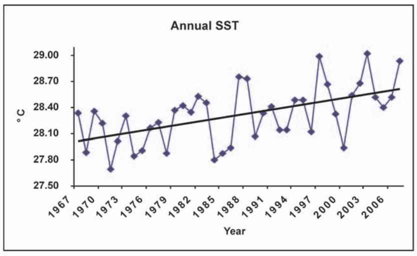
of oil sardine was from the Malabar upwelling zone and the catch was either very low or there was no catch from latitudes north of 14°N along the west coast (Fig. 3). In the last two decades, however, the catches from latitude 14°N - 20°N are consistently increasing, contributing about 15% to the all-India oil sardine catch in the year 2006 (Vivekanandan *et al*., 2009c). 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 is expanding to latitudes north of 14°N, enabling the oil sardine to extend their distributional range to northern latitudes. Another notable feature is the extension of oil sardine distribution to the east coast of India as well. Until the mid 1980s, the oil sardine did not form fishery along the southeast coast. In the 1990s, oil sardine emerged as a major fishery along the southeast coast, with the annual catch recording more than 1 lakh tonnes (Fig. 4).

It is also found that the catches from the Malabar upwelling zone has not decreased indicating distributional *extension* and not distributional *shift*. These observations indicate that the abundance of oil sardine has increased over the decades. Being an upwelling system, the southwest ecosystem is highly productive. The catch of small

Fig. 4. Bumper catch of oil sardine along Tamilnadu coast

pelagics, especially that of the oil sardine has increased from 1,554 tonnes in 1994 to 2,50,469 tonnes in 2007 in the upwelling zone off Kerala. Time series data on different climatic and oceanographic parameters gathered from different sources show that, corresponding to the annual SST (Fig. 5a), the annual average scalar wind speed increased from 3.58 m/s to 6.05 m/s (Fig. 5b) during the years 1967 – 2007 off Kerala (Manjusha *et al*., 2010). The zonal wind speed during southwest monsoon season (June-September) increased from 3.34 m/s in 1967 to 5.52 m/s in 2005, with speed exceeding 5 m/s in several years during 1992-2005. The monsoon CUI increased by nearly 50% from 485 to 713 m^3/s during 1997-2007 (Fig. 5c). This substantial increase in CUI elevated the chlorophyll *a* concentration from 4.54 mg/m^3 (1997) to 13.85 mg/m^3 (2007) during monsoon (Fig. 5d). The high concentration coupled with increasing trend of Chl *a* during the monsoon resulted in increase of over 200% in annual average Chl *a* concentration. The increasing CUI and Chl *a* during monsoon sustained an increasing catch of oil sardine especially during post-monsoon season (Fig. 5e). The peak spawning activity of oil sardine is during the southwest monsoon. If the direction and speed of wind are ideal, the larvae are dispersed to favourable destinations where they find enough food and fewer predators. Egg development and growth of post-larvae are rapid, and the fish reach 10 cm length in about three months. Thus the individuals, which spawn during the southwest monsoon are recruited to the fishery during the post-monsoon period. It may be concluded that elevated SST, favourable wind (and perhaps current) and increasing CUI have induced higher Chl *a* concentration during southwest monsoon, which has resulted in increasing the recruitment and catches of oil sardine during post-southwest monsoon season along the Kerala coast (Fig. 6). This trend indicates that the current warming is beneficial to herbivorous small pelagics.

5a



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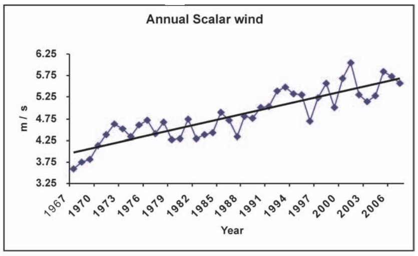

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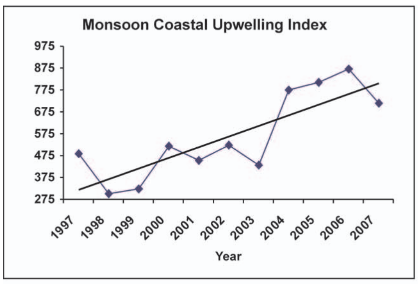

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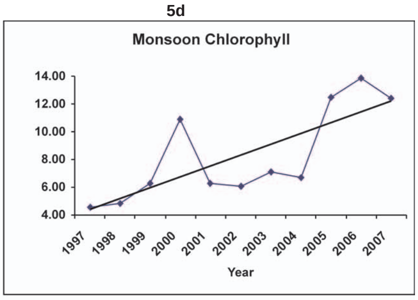

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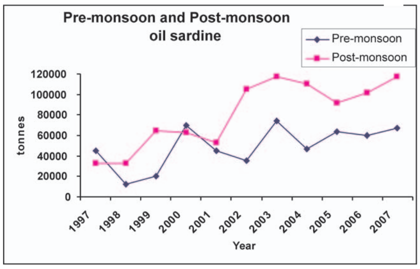

Fig. 5. Changes in oceanographic parameters off Kerala during 1967-2007; and their effect on chlorophyll concentration and oil sardine catch

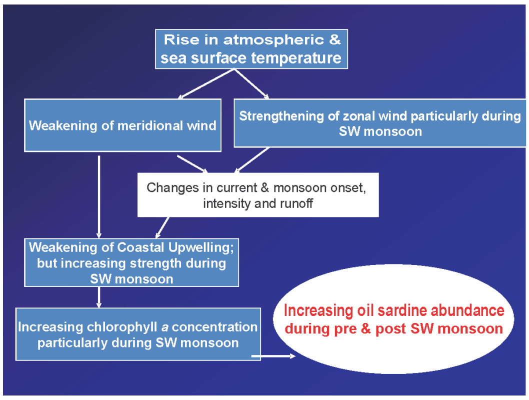

Fig. 6. Climatic and oceanographic events responsible for increased oil sardine abundance along Kerala coast during 2000-2007

Indian mackerel: The Indian mackerel *Rastrelliger kanagurta* are also found to extend their distribution to the northern latitudes of the Indian seas in a similar way. Compared to the oil sardine, the Indian mackerel had wider distribution along the Indian coast, but the catches and abundance were predominantly along the southwest coast. The annual production of mackerel in India is about 1.4 lakh tonnes (5% of the total marine fish production). It has a crucial role in marine ecosystems as a plankton feeder and as food for larger fishes and also a staple sustenance and nutritional food for millions.

Nemipterus japonicus : Change in spawning season off Chennai

N. mesoprion: Change in spawning season off Chennai

During 1961-76, the mackerel catch along the northwest coast of India contributed about 7.5% to the all India mackerel catch, which increased to 18% during 1997-2006 (Fig. 7). In the northeast coast, the mackerel catch contributed 0.4% to the all India mackerel catch during 1961-76, which increased to 1.7% during 1997-2006. Similarly along the southeast coast the mackerel catch during 1961-76 was found to be 10.6% of the all-India mackerel catch, which increased to 23.2% during 1997-2006. Along the southwest coast, the mackerel catch contributed about 81.3% to the all India mackerel catch during 1961-76, which decreased to 56.1% during 1997-2006 (CMFRI, 2009).

The Indian mackerel, in addition to extension of northern and boundaries, are found to descend to deeper waters in the last two decades. The fish normally occupy surface and subsurface waters. The mackerel was conventionally caught by surface drift gillnets by artisanal fishermen. In recent years, however, the fish is increasingly caught by bottom trawlnets operated by large mechanised boats at about 50 to 100 m depth. During 1985-89, only 2% of mackerel catch was from bottom trawlers (Fig. 8), 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 was contributed by bottom trawlers along the Indian coast.

There could be two explanations to this: (i) The mackerel are being displaced from the pelagic realm due to warming of the surface waters. (ii) Global climate change models have shown that sea bottom temperatures are also increasing. The mackerel, being a tropical fish, are expanding the boundary of distribution to depths as they are able to advantageously make use of increasing temperature in the sub-surface waters. The latter explanation appears more reasonable as the catch quantities of the mackerel from the pelagic gear such as drift gillnet and ringseine are also increasing. It appears that the distribution of mackerel in the subsurface has increased, and hence the recent trend may be a vertical *extension* of distribution, and not a distributional *shift*.

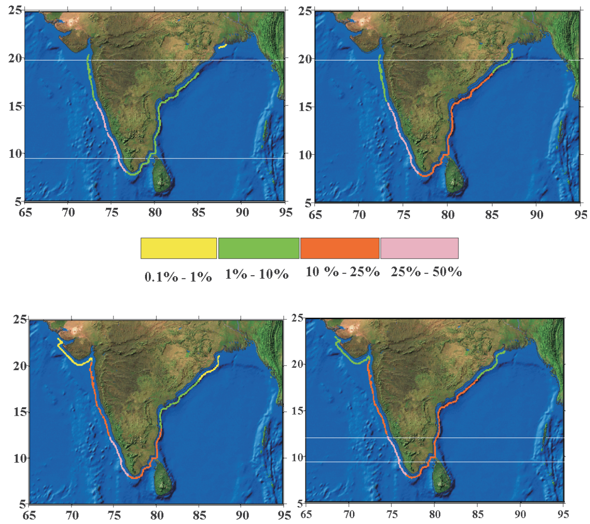

Fig. 7. Extension of distributional boundary of Indian mackerel along the Indian coast; the coloured lines indicate the percentage contribution of catch by each maritime state to the all India mackerel catch during the corresponding time-period

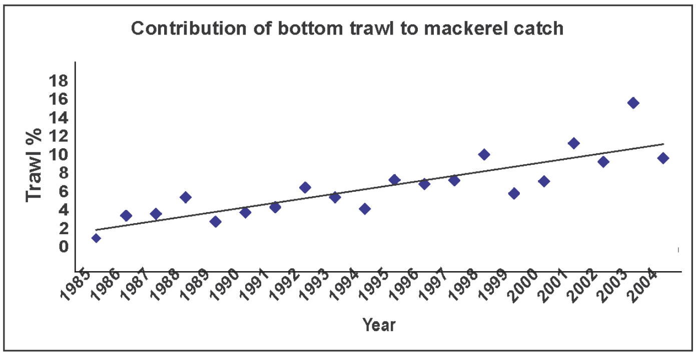

Fig. 8. Increasing contribution of bottom trawlers to Indian mackerel catch during 1985 – 2004 along the Indian coast

Considering the catch as a surrogate of distribution and abundance, it is found that the two most dominant fish are able to find temperature to their preference especially in the northern latitudes and deeper waters 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, it should be cautioned that if the SST in the Malabar upwelling zone increases beyond the physiological optimum of the fish, it is possible that the populations may shift from the southern latitudes in the future.

5.2 Phenological changes in threadfin breams

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 of fish 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 and medium-sized fishes (maximum length: 30 to 35 cm). Data on the number of female spawners collected every month off Chennai (southeast coast of India) from 1981 to 2004 shows that the percent occurrence of spawners of the two species decreased during the warm months of April-September, but increased in the relatively cooler months of October-March (Vivekanandan and Rajagopalan, 2009). In the early 1980s, about 40% of the spawners of *N. japonicus* occurred during April-September, which gradually reduced to 15% in the early 2000s (Fig. 9). On the other hand, 60% of the spawners occurred during October-March in the early 1980s, which gradually increased to 85% in the early 2000s. Data collected from ICOADS show that the annual average sea surface temperature off Chennai increased from 29.0° C (1980-1984) to 29.5° C (2000-2004) during April-September and from 27.5° C (1980-1984) to 28.0° C (2000-2004) during October-March. It appears that SST between 27.5 and 28.0°C may be the optimum and when the SST exceeds 28.0°C, the fish are adapted to shift the spawning activity to seasons when the temperature is around the preferred optima.

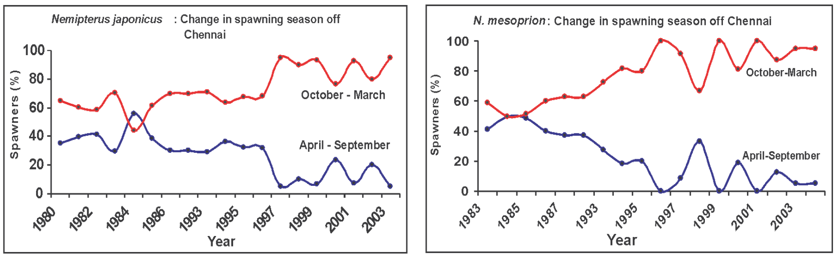

Fig. 9. Change in spawning season of Nemipterus japonicus and N. mesoprion off Chennai (from Vivekanandan and Rajagopalan, 2009)

These distributional and phenological changes may have impact on nature and value of fisheries. 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 trends due to fishing and other non-climatic factors. 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, and result in considerable changes in ecosystem structure and function.

Currently, it is difficult to find out how much of catch fluctuation is due to changes in fish distribution and phenology. A time series analysis on stock biomass of different species does not exist along the Indian coasts. Long-term records of abundance are limited to historical commercial landings. Availability of time series data on climatic and oceanographic parameters and fish catches in India may be too short to detect displacements of stocks or changes in productivity. Moreover, these records are often influenced by economic factors such as the relative price paid for different types of fish, and changes in fishing methods or fishing effort. For instance, introduction of mechanised craft in the 1960s, motorised craft, high opening trawlnet, minitrawl and ringseine in the 1980s, and large trawlers for multiday fishing in the 1990s substantially increased the fish catch. These non-climatic factors often obscure climate related trends in fish abundance. Hence to know the influence of climate change, the impact of non-climatic factors should be removed by de-trending analysis.

6. EVOLVING MODELS TO UNDERST;AND IMPACTS OF CLIMATE CHANGE

In India, marine fish catch and effort data are available for the last five decades. However, a synergy between climatic and oceanographic data and fisheries data does not exist. Projections on climate change impact on fish populations have not been performed so far. Such projections need to be developed as the first step for future analytical and empirical models, and for planning better management adaptations.

Biswas *et al* (2005) developed a method for forecasting fish catch of the major fishing areas in the world oceans under higher temperatures. This method predicts the tendency (increase or decrease) for fish catch, with quantitative predictor's power, if the temperature is known. This method has been applied to the Indian Ocean to assess the climate-change impact on fish catch. Based on the temperatures predicted using the CLIMate-BiospheRE model for the years 2000–2100, a decrease of fish catch in the Indian Ocean, with the confidence of the predictor's power at ≥90%, has been predicted.

Cheung *et al* (2008, 2010) developed a computer model that predicts what might happen under different climate scenarios to the distribution of commercially important species. Using a model that tracked a range of habitat conditions, including water temperature and depth from sea ice, to predict which habitats would be most impacted by climate change, they found that around 50 species of commercial fishes living near or at the poles will go extinct within the next 4 decades. Those species that can survive will try migrating toward the Arctic and Southern oceans or end up trapped in closed seas. While fisheries species in colder waters succumb to climate change, those living in tropical waters will be stressed by overfishing.

6.1 Mass-balance models – Ecopath, Ecosim and Ecospace

Many climate change impacts on individual populations will have cascading effects throughout the ecological communities in an ecosystem. The broad ecological impact of climate change can be estimated using the whole food web trophodynamic modelling suite Ecopath with Ecosim and Ecospace. This modelling tool has three complementary modules (www.ecopath.org): (1) Ecopath is a static mass-continuity description, or accounting, of trophic flows in any given ecosystem and time period using biomass as a currency. It is a food web model in which all species in the system are aggregated into functional groups whose biomasses, production rates, consumption rates, physiological efficiencies, and diet compositions are estimated and specified, and includes flows to and from fisheries. (2) Ecosim uses information in Ecopath dynamically so that temporal changes in mortality or other physiological rates can be specified to simulate impacts of changes in fisheries exploitation or environmental changes, or both simultaneously. Ecosim allows physiological rates to be changed with climate change. (3) Ecospace enables the expression of Ecosim in a spatially explicit form for the spatial exploration of biological impacts of an environmental or fisheries change. Ecospace can be used to explore impacts of changes in the distribution of biomasses of each functional group based on how they interact with each other spatially.

There are four approaches that are fruitful for characterising climate change impacts using the Ecopath with Ecosim modelling approach (Richardson and Okey, 2006): (1) constructing and balancing future Ecopath models using estimated biomasses and physiological rates for a future scenario, information from climate envelope and other biophysical models, and comparing the projected to the present day system; (2) producing a time series of fitting error terms that represent non-fisheries impacts (e.g. environmental change) for comparison to integrated ocean climate indicators; (3) forecasting change using Ecosim based on estimated responses of functional groups to particular scenarios of change; and (4) explicitly integrating functional response models within the Ecopath with Ecosim modeling approach.

However, Ecopath has not been extensively used for understanding the impact of climate change as it is not directly connected to hydrodynamic models.

6.2 Ecosystem models

With technological advancement of computing and numerical techniques, it has been possible in recent years to model some of the complexity in marine ecosystems. Recently, ecosystem models have been coupled to hydrodynamic general circulation models, capturing the high spatial and temporal variability of ecosystem dynamics (Skogen and Moll, 2000; Zavatarelli *et al*., 2000). Ecosystem models represent our best understanding of how marine systems as a whole function and coupling these with output from climate system models is likely to provide our best understanding of system response. Developments in process-based ecosystem model simulations will enable us to better understand the effects of climate changes on biodiversity and assess the effectiveness of adaptation and management strategies (Richardson and Okey, 2006).

6.3 SEAPODYM

Spatial ecosystem and population dynamics model (SEAPODYM) is a model developed initially for investigating spatial tuna population dynamics under the influence of fishing and environmental effects. It is possible to investigate the impact of global warming on tuna populations with SEAPODYM using forcing datasets of economic conditions under IPCC scenarios for the 21st century. The model includes detailed relationships between population dynamics and basic biological ecological functions, including a more realistic representation of the vertical oceanic habitat, both in terms of physical and foraging conditions (Lehodey *et al.*, 2008)

Climate change and marine fisheries

India has to improve research on establishing relationships between climatic & oceanographic variables and fish abundance.

The relationships will be different between the ecological regions. For example, the ecological setting of southwest coast and southeast coast is different. The climate change impacts will differ between these regions.

Prediction models by developing scenarios do not exist for Indian marine fisheries.

Adaptation plans should take into consideration the predictions and uniqueness of each region.

7. ADAPTATION OPTIONS FOR FISHERIES

For the fisheries and aquaculture 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.

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). 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 addressing the concerns arising out of climate change, and evolve adaptive mechanisms and implement action across all stakeholders at national, regional and international levels (Table 3; Allison *et al*., 2004; Handisyde *et al*., 2005; Leary *et al*., 2006; WorldFish Center, 2006; FAO, 2008). In response to shifting fish population and species, the 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 analyse 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. Action plans at regional level need to be taken by

- strengthening regional organisations and place climate change agenda as a priority;
- addressing transboundary resource use; and
- evolving common platforms and sharing the best practices.

Action plans at international level also need to be taken by

- linking with mitigation activities;
- enhancing co-operation and partnerships; and
- applying international fishery agreements.

Table 3. Options for adaptation with climate change in fisheries (after Allison *et al*., 2004; Handisyde *et al*., 2005; FAO, 2008)

Concerns	Adaptive mechanisms
Uncertainties in fish availability and supply	i) Develop knowledge base for climate change and fisheries and aquaculture; ii) Predict medium and long term probabilistic production iii) Assess the adaptation capacity, resilience and vulnerability of marine production systems; iv) Adjust fishing fleet and infrastructure capacity; v) Consider the synergistic interactions between climate change and other issues such as overfishing and pollution.
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; iv) consider gender and equity issues.
Complexities of climate change interactions into governance of frameworks to meet food security	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 approach to 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 organisations and place climate change agenda as a priority (b) addressing transboundary recourse use, (c) evolving common platforms and sharing the best practices; iv) Action plans at international level by (a) linking with mitigation activities (b) enhancing co-operation and partnerships, (c) applying international fishery agreements.
Fisheries and aqua-culture 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 and aquaculture need to be reviewed and further developed by considering climate change.
Financing climate change adaptation and mitigation me-asures	i) Fishermen, 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) Incentive for reducing the sector's carbon footprint and other mitigation and adaptation options.

7.1 Code of Conduct for Responsible Fisheries

Fishing and climate change are strongly interrelated pressures on fish production and must be addressed jointly. Moderately-fished stocks are likely to be more resilient to climate change impacts than heavily-fished ones. Reducing fishing mortality in the majority of fisheries, which are currently fully exploited or overexploited, is the principal means of reducing the impacts of climate change (Brander, 2007). Reduction of fishing effort (i) maximises sustainable yields, (ii) helps adaptation of fish stocks and marine ecosystems to climate impacts, and (iii) reduces greenhouse gas emission by fishing boats (Brander, 2008). 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). Hence, some of the most effective actions which we can tackle climate impacts are to deal with the familiar problems such as overfishing (Brander, 2008), and adopt Code of Conduct for Responsible Fisheries and Integrated Ecosystem-based Fisheries Management (FAO, 2007). In India, mechanisms for managing large-scale commercial fisheries such as total allowable catch (TAC) or total allowable effort (TAE) do not exist. Hence, it is a challenge to fully comply with the CCRF. The challenge becomes severe considering the poverty prevalent among the coastal communities involved in traditional fishing methods, and the lack of suitable alternate income generating options to them. These factors make these communities highly vulnerable to climate change, as their capacity to adapt is limited. Effort to reduce dependence on fishing by these vulnerable communities is important. It is essential to adopt Ecosystem-based Fisheries Management by integrating fisheries management into coastal areas management.

7.2 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). It is estimated that macrophytes contribute 10% to global aquatic carbon uptake in coastal areas. The emission of CO_2 through their respiratory activity is very low as they are capable of reutilizing the respiratory release of CO_2 within their cellular interspace for subsequent photosynthesis (Kanwisher, 1966). Large biomass sea plants such as *Kappaphycus, Gracilaria, Gelidiella, Sargassum* and *Ulva* are available in the Gulf of Mannar and Palk Bay. From their laboratory studies on the CO_2 sequestration potential of four species of macrophytes, namely, the red algae *Gracilaria corticata* and *G. edulis*, brown alga *Sargassum polycystum* and green alga *Ulva lactuca,* Kaladharan *et al* (2009) estimated that the standing stock (2,60,876 t) of all marine macrophytes in the Indian seas is capable of utilizing 9,052 t CO_2 per day (Table 4). The carbon sequestering efficiency was found unaltered even in high levels of dissolved CO_2. Green algae were found to have better CO_2 sequestering ability than the red and brown algae.

Table 4. Estimated CO_2 absorbed (t/day) and emitted (t/day) by seaweed biomass along the Indian coasts (from Kaladharan *et al.*, 2009)

Macro-algae	Standing crop (t)	Absorption efficiency (mg/g/h)	CO_2 absorption (t/day)	CO_2 emission (mg/g/h)	CO_2 emitted (t/day)
Red	36,523	1.6	584	1.0	365
Brown	41,740	2.3	981	0	0
Green	82,613	4.1	7,487	0	0
Total	260,876	8.0	9,052	1.0	365

Mass cultivation of these plants will help reducing the CO_2 concentration from seawater. 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.

7.3 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 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 photosynthesiser 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* may be an opportunity. A 2000 hectare farm would yield biomass of 30,000 tonnes and 2,500 t of seeds (Stanley, 2008). It suits small, labour-intensive farms as well as highly mechanised farms. The Seawater Foundation, Arizona is advocating diversion of flow of inundating seawater inland through ocean canals in the northern Mexican State of Sonora to nourish commercial fish and shrimp aquaculture operations, mangrove forests and crops such as *Salicornia* that produce food and fuel (www. seawater foundation.org).

7.4 Artificial reefs for coast protection

Coastal areas along Gujarat and Kerala (west coast of India), Tamil Nadu and Orissa (east coast of India) and Sunderban (West Bengal in northeast coast of India) are facing serious threats of sea erosion, risking the lives and properties of millions of people. One of the structures advocated as an opportunity for multipurpose use including coast protection is the Artificial Surfing Reef, which are constructed in the coastal waters. The reefs are constructed using sand-filled geotextile bags or containers, or rocks (granite). The structures have slopes, which increase the reef's volume. The back gradient of the reef is as steep as possible (for example, 1:1) whereas the face gradient is gentle (for example, 1:20). The opportunities of the Artificial Surfing Reef are projected as follows:

- The upper part of the slope of the reef affects wave break. The coast protection function is largely derived from the widening of the beach in the lee of the reef due to sheltering and wave rotation caused by the reef. Although the shoreline oscillates back and forth due to storms and swell conditions, the shoreline remains further seaward than adjacent coast unprotected by the reef (Black, 2000).

- The reef provides habitat for colonisation and occupation by many marine fauna that would otherwise be unlikely to persist at that location due to high-energy hydrodynamic conditions and sand-dominated substrate. It has the potential to increase local biodiversity and may contribute to biological productivity and fisheries at a regional scale.

- The reef can be used for promoting surfing, which is not popular in India. The reefs can deliver tourism and amenity facilities with a range of socio-economic benefits (Arup, 2001).

Some sites of Artificial Surfing Reefs construction are at Boscombe (Bournemouth), Borth (Ceredigion), Newquay (Cornwall) and Opunake (New Zealand). Government of Kerala has recently deployed a reef in the south Kerala coast.

7.5 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, the marine algae may be a potential alternative fuel source. Marine 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 the algal farms (www.greencarcongress.com). The production of biodiesel complements ethanol as an alternate renewable fuel.

7.6 Understanding the Indigenous Technical Knowledge

Fishing communities have often developed adaptation and coping strategies to deal with fluctuating environmental conditions. Greater understanding of how communities cope with and adapt to fisheries with extreme natural variations would assist in developing adaptation strategies for climate change. Fishermen in India are generally able to track seasonal and spatial variations in fish stock availability and relate it to climatic and oceanographic variabilities. They are able to detect some of the variables such as speed and direction of wind and current, watermass movement and upwelling, and make short-term predictions on fish distribution, spawning and abundance. This knowledge enables them to switch their fishing activities with respect to species exploited, location of fishing grounds and gear used. Gaining an insight into this and advantageously use their ITK to evolve coping mechanism will be useful.

Climate change literacy among fishermen

Fishermen have excellent knowledge on the relationship between climatic factors and fish catch. Their knowledge should be utilised for scientific understanding on climate change.

Most Indian fishermen are aware of climate change, but are confused with annual climate variabilities and climate change. Partnership between fishermen and scientists will be a win-win combination for a better understanding on climate impacts on fisheries, and to evolve adaptation options and mitigation measures.

Fishermen are of the opinion that fisheries dependent activities, rather than climate change, are responsible for decline in fish catches. While this may be true for now, awareness building is necessary to educate the fishermen on the future impacts of climate change on fisheries.

7.7 Develop knowledge-base for climate change and marine fisheries

Considerable effort should be made for gathering historic climatic and oceanographic data in addition to monitoring these key parameters to suit climate change research. It is also necessary to recognise the importance of changes in these parameters as drivers of change in marine communities including fish. Initiating a commitment on long-term environmental and ecological monitoring programmes is important as such data cannot be collected retrospectively. These programmes should develop fisheries models and lead into risk assessment of future fish stock variations and likelihood of resource collapses; and evolving sectoral and food security plans.

7.8 Climate change risk assessments

It is important to conduct climate change risk assessments to estimate the cost of adaptation of fisheries sector under different climate scenarios. The current and future risks and mechanisms within communities may be identified. The communities should be engaged together with governmental and non-governmental agencies in preparedness planning.

In India, 458 (of the total 2132) coastal fishing villages with a population of one million are located within 100 m from the high tide line (CMFRI, 2009). Risk reduction initiatives such as early warning systems, disaster recovery programmes and reducing risk exposure by enhancing coastal defences are in place. Along the east coast where storms and floods are relatively regular, the governments take preparative action and organise sufficiently to relocate the people temporarily and to restore key services and economic functions. Fishermen receive up-to-date weather forecasts and weather warnings through television, radio and print media, thereby reducing the number of boats caught at sea by cyclones. Along 400 km of Kerala's 590 km coastline, coast protection structures such as sea walls and gyrones are in place. However, coastal communities often complain intrusion of sea through the open, undefended coast. Cost-effective engineering solutions for conservation of erodable shorelines to prevent damage to properties and human life need to be put in place. Risk reduction plans concerning coastal and flood defences should be linked with disaster management.

7.9 Increase awareness on the impacts of climate change

Being a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), India has submitted the first National Communication to the UNFCCC in 2004. The second National Communication is under preparation for submission in 2011. National climate change response strategies are under preparation on a sectoral basis. Specific policy document with reference to the implications of climate change for fisheries needs to be developed for India. This document should take into account all relevant social, economic and environmental policies and actions including education, training and public awareness related to climate change. Effort is also required in respect of raising awareness of the impact, vulnerability, adaptation and mitigation related to climate change among the decision makers, managers, fishermen and other stakeholders in the fishing sector. Resilience of fishing communities needs to be enhanced by supporting existing adaptive livelihood strategies. The relative risk of climate change also needs to be understood in the context of impacts on other hazards such as poverty, food insecurity, epidemic diseases, inequity and intrasectoral conflicts.

7.10 Aquaculture

Aquaculture is an alterative option to cope with climate change. It has considerable adaptation potential via selective breeding, regulating the environment, and resilient species opportunities. Moreover, with increasing inundation of coastal areas with seawater, the areas available for shallow water mariculture will increase. However, if not planned properly, aquaculture will also have impacts. The predicted direct impacts are

- changes in water availability, temperature and salinity;
- damage by extreme climatic events such as storms, floods and droughts;
- availability of seed at the right time as seasons of natural seed are likely to change due to shift in spawning seasons; and
- adaptability of the candidate species to the changes.

The indirect impacts are

- availability of fishmeal and its cost; and
- increased frequency of disease outbreaks.

The impact on aquaculture and related livelihoods will be linked to the type, scale and intensity of the aquaculture production system and the location and environment in which it is being carried out.

8. IMPACT AND ADAPTATION POTENTIAL OF MAJOR COMMERCIAL FISHERIES

Marine fisheries of India is characterised by multispecies and multiple craft-gear combinations. CMFRI has recognised 83 species/ groups, which contribute fisheries in one region or the other in all the seasons. The dominant fisheries groups are the clupeids such as the oil sardine, lesser sardines, whitebaits, shads, and *Thyrssa*; elasmobranchs such as the sharks, rays and guitarfish; scombrids such as the Indian mackerel, tunas, seerfish; major perches such as the groupers, lethrinds and lutjanids; minor perches such as the threadfin breams and goatfishes; the catfish, sciaenids, carangids, ribbonfish, bombayduck, lizardfish, barracudas, pomfrets, mullets; crustaceans such as the penaeid and non-penaeid prawns, crabs and lobsters; cephalopods such as the squids, cuttlefish and octopus; gastropods and bivalves. These species/groups have different levels of adaptive capacities to climate change. Fisheries will be impacted differently according to the physical changes in the regional environment and the ability of the species/ groups to cope up with the changes. Some may be in the threshold of extremes of climatic variabilities whereas some others may not be. More than 25 craft-gear combinations exploit these resources, but the dominant ones are the trawls, gillnets, lines, seines and bagnets operated from mechanised, motorised and non-motorised (traditional) boats. Despite lack of empirical evidences for climate relationships in major commercial fisheries of India, we can make some preliminary statements on the impacts and adaptation options (Table 5).

Table 5. Adaptation options for a few major commercial fisheries

Fisheries	Impact	Adaptation research	Socioeconomic adaptation
Small pelagic fisheries (gillnet, purseseine, ringseine)	SST and current are main drivers of distribution and abundance of plankton and small pelagics; subjected to interannual climate variabilites; non-availability of right kind of plankton food to fish	Periodic abundance estimates by acoustic methods; monitoring biological response and changes in species mix in ecosystems; prediction modeling focusing on climatic change	Relocation of some fishing operations; changes in craft-gear combinations depending on changes in fish distribution; changes in economic value of fishes; artisanal fishermen with low mobility will be affected the most, and their adaptive capacity to be enhanced

Large pelagic fisheries (gillnet, hooks & line, longlines)	Removal of large predators by fishing causing serious concern. Temperature and ENSO have strong influence on migration and distribution of tunas, billfishes and pelagic sharks	Contribution of warming on migration of yellowfin tuna and several pelagic sharks into Indian seas needs investigation. It is to be determined if the change in abundance is likely to be sustained	Rapid adaptation by fishing industry exemplified by introduction of longliners for yellowfin tuna and pelagic sharks. Decrease in abundance would result in heavy investment losses on craft and gear and perhaps relocation of fishing operations. Management measures are necessary when fishing intensity increases.
Trawl fisheries	Warming of ocean depths predicted; recruitment associated with bottom currents; descend of pelagic fish to deeper waters; increased cost of operation and fuel consumption, adding to CO_2 emission	Impact on benthic biota and pelagic-demersal species mix; assessment of positive and negative impacts on growth and reproduction; developing fuel efficient vessels	Several demersal stocks already fully exploited; trawling operation may have to shift to deeper waters; dependence on stationary gear may have to increase
Dolnet fisheries	Distribution of bombayduck and *Coilia* stocks restricted with no scope for shifting distribution further north, which is landlocked;	Ecosystem research with simulations to assess availability of fish to each fleet; suggest fleet regulatory measures for optimum utilization of resources	Competition from active gear may increase; changes in tidal amplitudes may affect availability of fish to gear; dominance of existing craft-gear may have to undergo changes

	competition from fish extending/ shifting distribution from southern latitudes		
Small-scale traditional fisheries	Availability of fish will reduce; competitive capacity with other fleet in sharing fish stock will reduce; may shift to estuarine fishing	Technical improvement of craft and gear for stability and greater mobility; stock-taking on prevalence of new diseases among fishing communities	Most vulnerable; already under poverty; no alternate income and poor literacy; government schemes for rehabilitation necessary; coast protection should be a priority
Oceanic fisheries	Migratory path of tunas, which is driven by temperature, may change; distributional areas, abundance and fishery will be affected; some regions may benefit, others may lose; target fishing for pelagic sharks already causing concern	Newly emerging oceanic fisheries for tunas and sharks to be monitored; potential yield and maximum fleet size for sustainability to be estimated by following regional approach	Risk if migratory path of tunas changes; large investments in harvest and post-harvest will incur huge losses; dialogues and agreements with neighbouring countries through IOTC and other regional bodies should be initiated.

8.1 Small pelagic fisheries

The small pelagics of the Indian seas are comprised of different taxonomic groups and contribute to rich species diversity, abundance and fisheries. Clupeids such as sardines and whitebaits, which attain a maximum body size of only about 20 cm, contribute a major portion to the small pelagics. With advantageous biological characteristics such as small size, short life, low trophic level, fast growth, quick turnover of generations and high fecundity, the small pelagics such as the oil sardine, lesser sardines, anchovies and Indian mackerel are high volume fisheries, contributing > 35% to the total marine fish catch along the Indian coasts. The distribution and abundance of small pelagics are driven mostly by a combination of several climatic and oceanographic features such as sea water temperature, current, rainfall, upwelling and chlorophyll concentration. Relatively low-priced, they form staple food for millions of coastal people. The small pelagics are exploited by drift gillnets, ringseines and purse seines. In recent years, a substantial portion of the catch is contributed by the trawlers.

As pelagic species are typically mobile and wide-ranging, species' ranges and distribution are most likely to be impacted by climate change. Research indicates that the small pelagics advantageously make use of increasing sea surface temperature and chlorophyll concentration (Fig. 6) by increasing their biomass and area and depth of distribution (Fig. 8). As the biomass increases, efficient gear are introduced (for example, ringseine in Kerala), and as the area of distribution increases, the fish are caught by introducing hitherto under-used gear (for example, small-mesh drift gillnet in Maharashtra). This trend is likely to have an impact on the types and economics of fishing operations along the coasts.

In the last two decades, the oil sardine has emerged as the most dominant resource along the southeast coast and as a minor fisheries along the northeast coast. The long-term impact of proliferation of small pelagics on ecosystem structure and function of new distributional regions is not clear. The possibility of these fish gradually driven northwards from southern latitudes, and their abundance increasing in the northern latitudes replacing large predatory fish could be the potential changes. Laboratory studies show that phytoplankton, the primary producers, are sensitive to seawater warming (CMFRI, 2009). This will lead to possible non-availability of right type of food in adequate quantities to next level consumers, namely zooplankton and small pelagics. A major component of fisheries management plan (FMP) for the small pelagics is a harvest policy that accounts for environmental conditions, the biological status of the resource, harvesting capacity of the fishing fleets and acceptable biological catch. For small pelagics, the fishing activities should be restricted when the stocks are on the decline, due to fishing or environmental factors. If warning of population decline is timely, more effective and economically efficient conservation and management can be implemented, industry overcapitalisation can be avoided, and a smoother transition to other fisheries or other industries is possible.

8.2 Large pelagic fisheries

The large pelagic fisheries target the tunas, sharks, seerfish, barracudas, sailfish etc. Vivekanandan *et al* (2005) have detected that removal of large pelagics is leading to fishing down marine food web in the Indian seas. With the expansion of fishing to oceanic regions, target fishing for tunas and sharks is on the rise. In recent years, several trawlers are converted into tuna longliners. Consequently, the catches of the yellowfin tuna *Thunnus albacares,* and oceanic and deepsea sharks such as *Alopias* spp and *Echinorhinus brucus* are increasing.

The large pelagics, especially the tunas are driven by seawater temperature and ENSO events for their migration and distribution. Tropical tunas, including skipjack (*Katsuwonus pelamis)*, yellowfin (*T. albacares*) and bigeye (*T. obesus*) tend to be fast growing and relatively short lived. Tunas are fast swimming top predator species whose high metabolic requirements must be supported by ready access to rich food sources. Their migratory patterns are closely governed by ocean processes that create a conjunction between suitable physical habitat (in terms of temperatures and adequate oxygen) and adequate food sources (Miller, 2007). In describing the basis for tuna migrations, Sharp (1992) noted that as tunas are so energy-consuming, they are dependent on ocean processes and features which promote aggregation of prey resources. They must find suitable areas in the oceans within finite time periods, or die. In the Indian Ocean, skipjack and yellowfin tunas tend to concentrate near the surface in areas in which there is a shallow mixed layer and strong stratification, making them more vulnerable to capture. Two distinct monsoon periods drive seasonal shifts in the location of convergence and divergence zones across the Indian Ocean, as well as changes in the intensity of coastal currents, and local variations in the depth and gradient of the thermocline (Sharp, 1992). The location of convergence zones determines where tuna will be found. Climate variability, thus, has demonstrable impacts on the abundance, concentration, location and catchability of tropical tuna stocks. There is evidence that operators of modern tuna fleets in India and elsewhere are actively using the available information on climatic/oceanographic impacts on tuna stocks to guide their harvesting operations.

However, there are no studies in India on the impact of climate variability on changes in tuna migration or phenology or physiology. It is not clear whether the recent increase in the catches of yellowfin tuna and several oceanic sharks is due to expansion of fishing operations to offshore waters or due to changes in oceanographic features in the Indian seas or a combination of both the factors. The impact of climate change on the skipjack tuna, *K. pelamis*, which is the mainstay of pole and line fishery in Lakshadweep Sea, remains unknown. Exploring climate relationships in these offshore regions will be a challenge, due to the short and patchy time-series data on pelagic species catches.

In the case of increased abundance, a rapid adaptation by fishermen is likely. This is evidenced by introduction of longliners and conversion of large number of trawlers into tuna longliners in recent years in the Indian seas. It will be a challenge to determine if the change in abundance is likely to be sustained, or is due to interannual variability. This distinction is crucial for long-term decisions on fishing, such as increasing fleet capacity or making technological investments. In the case of declining abundance, additional management measures may be necessary. Electronic satellite tagging and remote-sensed data would enable development of predictive habitat models for large pelagics.

Pelagic squids, such as *Sthenoteuthis oualanensis* have more flexible life history strategies and greater tolerances to environmental change than large pelagic fishes (Pecl and Jackson, 2005). They could perhaps benefit from climate induced changes in the regional oceanography. There has been an expansion in the range and increase in abundance of the coastal squids as well. A minor fishery exists for the last three years along the Saurashtra coast. Although the cause of increase of squids along the Indian coast is unclear, warming of the regional oceanography has been implicated elsewhere (Olson and Young, 2007). The potential increases in squid abundance may induce large-scale jigging operations in Indian waters, where hitherto only hand jigs are operated.

8.3 Trawl fisheries

In the last three decades, bottom trawlers have emerged as the major contributor to the marine fish catches along the Indian coast. During 2000-08, the trawlers contributed 50 to 60% to the total landings. Due to high value realised from the trawl catches, the economic contribution by the trawlers is substantial. The number and efficiency of trawlers have increased over the years. Single-day small trawlers have been replaced by multiday larger trawlers with sea endurance of 7 days or more since early 1990s. Trawling is restricted to depths upto 100 m, but extends up to 300 m during specific seasons to catch deep sea shrimps. The trawlnets are of high-opening type with small codend mesh size (15 to 20 mm). In general, shrimps are the target for the trawlers, but being non-selective, the trawlers catch bulk quantities of other commercially important (finfish and cephalopods) and unimportant groups as bycatch. Recently, high-speed trawling with powerful engines (~ 400 hp) has been introduced in conventional trawlers (overall length: ~ 15 m) along the Kerala coast. These boats target bulk fisheries in the subsurface waters. The bycatch of trawlers includes juveniles of commercially important fishes, which are often discarded at sea. A single trawl haul, on an average, catches about 40 species of edible and non-edible biota and it is likely that the trawlers may catch more than 700 species along the coastal areas across the coastal regions. Following declining catch rate, it has been realised that demersal stocks, which contribute to the trawl fisheries are heavily exploited and are rapidly declining across the coastal regions of the Indian EEZ. Climate change is likely to exacerbate this situation.

Consequences may arise for species that rely on inshore habitats such as estuaries. Flushing of estuaries may impact breeding migrations, spawning habitats, nursery areas, and the suitability of those habitats to support existing commercial species. Fisheries that may be affected include those based on shelf species that use inshore areas and estuaries as nurseries, such as shrimps. Thus variation in shrimp recruitment either positively or negatively is possible depending upon the strength and timing of precipitation. Climate change may lead to additional changes in the alternative species harvested when the primary species is less available. The catches of several low-value groups such as pufferfish and jellyfish are increasing in the trawlers in the last ten years. Thus, the robustness of the trawl fishery sector may decline in the future if climate variability increases. In the case of declining abundance of shrimps, the trawl sector may be forced to adopt additional management measures. Improvements in bycatch reduction and improved targeting practices will have the dual benefit of minimising impacts on non-target species, and provide potential alternatives to spatial closures to protect particular species. Multi-species fisheries should continue to develop species-specific fishing gears, which will allow individual species to be targeted, without impacting other species that may decline due to climate change, and protect from fishing.

Trawl is an active gear and trawlers use mechanisation for fishing as well as propulsion. Hence, fuel consumption and CO_2 emission by trawlers is higher than that of fleet using stationary gear such as gillnet (see section 10 on Mitigation). Considering the decline in demersal stocks, destruction of bottom habitats and higher CO_2 emission, it appears that restrictive measures on trawl fisheries are essential.

8.4 Small-scale traditional fisheries

The small-scale traditional fisheries will be the most vulnerable to climate change. In India, there are more than 1,04,270 fishing boats without any form of mechanisation or motorisation, and depend on wind power for propulsion. With no alternate income and with poor literacy, the fishermen who depend on traditional type of fishing are under poverty. With restricted mobility, the competitive capacity of this fleet with other fleet is likely to reduce. The availability of fish to this fleet is also likely to reduce.

The sector has demonstrated considerable resilience to climate variability in the past. However, any objective assessment of small-scale fisheries in India would conclude that exposure and sensitivity to climate change threat are high, while adaptive capacity is low (for example FAO, 2005). Among the reasons for this conclusion are:

- The negative impacts on the sector, e.g. through habitat and ecosystem damage such as bleaching of corals, additional stress on mangroves and seagrasses;
- proliferation of harmful algal blooms and various diseases, which will result in mass fish kills in nearshore waters;
- full dependence on fishing and related activities for livelihood;
- many fisherfolk reside in vulnerable, low-lying coastal areas which exposes their physical assets (e.g. boats, gear, homes) and

put their lives at great risk due to climate-related events such as cyclones, sea level rise and sea erosion;

- lack of insurance and sea safety mechanisms to protect from extreme events, which are projected to become more frequent and/or intense in the future; and
- factors such as lack of consistent access to capital on reasonable terms, weak fisherfolk organisations and consequently low bargaining with governments and other sectors.

While the list of factors presented above is not exhaustive, it provides a reasonable indication of the issues confronting the small-scale fisheries sector in India. It is widely anticipated that climate change will amplify these challenges, and hence, appropriate and timely interventions are required in order to minimise the adverse effects.

While small-scale fisheries are not the cause for climate change and can do little to reverse the trend of global greenhouse gas emissions and higher sea water temperatures, actions can be taken to improve the resilience of the sector to the adverse effects of climate change. Such actions may include (see also McConney *et al*., 2009): (i) strict enforcement of existing marine pollution control protocols and abatement of contamination from land-based sources, (ii) reactivation and expansion of habitat protection and restoration programmes, and (iii) control of non-sustainable practices such as overfishing, and the use of inappropriate fishing methods. Technical improvement of craft and gear for greater mobility is necessary. Government schemes for safety at sea, coast protection and rehabilitation should be a priority. The benefits of applying good governance and co-management principles in the small-scale fisheries sector are well known (FAO, 2005). Governance and co-management systems that are based, *inter alia*, on an understanding of ecosystem health and thresholds, partnerships, stakeholder inclusiveness, equity and sustainable livelihoods should also be regarded as vital elements of climate change adaptation planning for small-scale fisheries (McConney *et al*., 2009).

8.5 Oceanic fisheries

Oceanic fisheries is emerging in India in the last five years. The fisheries is concentrating on the yellowfin tuna and pelagic sharks. Government of India has given Letter of Permit to engage 162 foreign tuna longliners under Indian license for operation in the Indian EEZ. In addition to this, several trawlers are being converted into tuna longliners. These newly emerging oceanic fisheries for tunas and sharks need to be properly monitored and potential yield and maximum fleet size for sustainability need to be estimated by considering regional approach. If the migratory path of tunas changes, large investments in the harvest and post-harvest sectors will incur huge losses.

The effects of changed fish migrations and distribution caused by climate variability and climate change are likely to be most difficult to deal with for oceanic fisheries, especially for highly migratory species. The challenge is to devise institutions and treaties with built-in mechanisms to handle such changes. The management of transboundary oceanic stocks by the regional organisations should consider climate variability. Dialogues and agreements with neighbouring countries through Indian Ocean Tuna Commission (IOTC) and other regional bodies should be initiated. Miller (2007) suggests making allocation of catches among nations independent of climate variability, but allowing flexibility to respond to changing stock distributions by trading fish catch quotas or fishing effort quotas. While this could work well for recurrent, if irregular changes, it is less clear how it would cope with secular displacements where stocks might disappear entirely from some areas (Hannesson, 2007).

It is believed that the impact of climate change on oceanic regions would be the least among other aquatic systems. However, it is difficult to understand the potential impacts on oceanic systems as the availability of data is patchy. Therefore, predicting even simple overall trends of how the climate variability could impact the oceanic pelagic ecosystem would be of major interest. Scenarios of climate change due to greenhouse warming used in several coupled atmosphere-ocean simulations have suggested that changes in the mean state of the tropical oceans would result in climate conditions similar to present day *El Niño* conditions with an increased interannual variability (Meehl *et al*., 2006). Resulting scenarios could include increasing temperature, changes in the illumination of the surface layer where photosynthesis takes place, increasing stratification of the upper ocean, and changes in the oceanic circulation, reducing the nutrient input in the euphotic layer. This should lead to an understanding how greenhouse warming will affect, at the ocean and global scales, the abundance and productivity of marine populations in the pelagic ecosystem.

Production at higher trophic levels (usually exploited species) depends on the production at lower levels (bottom-up control) and may be modulated by the physical forcing and the structure of the marine food webs. Ecological concepts suggest that the structure of the food web can be controlled by the biodiversity within the system and/or by higher predators (top-down control). However, concerning pelagic ecosystems, there is very little observation to illustrate such controls. It is essential for modelling the oceanic pelagic ecosystem to identify the functional groups, how energy and matter flow through these groups and how they are affected by physical and biological changes as well as by human activities (fisheries) (Lehodey *et al.*, 2008).

9. IMPACT AND ADAPTATION POTENTIAL OF REGIONAL FISHERIES

The ability to adapt to climate change rests on a mechanistic understanding of the interactions between global change events and regional disturbances. Adaptation strategies are location and context specific. Hence, strategies for adaptation must begin with the identification of ecosystems and populations that are vulnerable to change.

The Indian Ocean is the warmest ocean in the world. Indian seas extend to a vast area in the tropical zones from latitude 8^o N to 23^{o}N, and from longitude 69^o E and 90^o E. The physical, chemical and biological oceanographic features differ within this vast expanse. The climate is affected by tropical monsoon. Strong northeast winds blow from October until February, and from May until October southwest winds prevail. When the monsoon winds change, cyclones strike the coasts of especially Bay of Bengal. The Bay of Bengal and Arabian Sea occupy the same latitudinal range, but the oceanographic characteristics exhibit wide differences. These marginal seas are forced by the above wind systems, solar heating owing to lower latitudes, immense evaporation, precipitation, and huge river runoff particularly in the Bay of Bengal. The western Bay of Bengal, bordered by 2656 km-long east coast of India, receives minerals and nutrients from several east-flowing rivers and two large brackishwater lakes. The major rivers, *viz*., the Ganges, Mahanadi, Godavari and Krishna drain 200 km^3 of water and 12 x 10^9 tonnes of silt during monsoon, which influence the ecosystem dynamics (Dwivedi and Choubey, 1998). The area of continental shelf of east coast of India is about 1,14,000 km^2. The northern subsystem (northeast coast of India) consists of the maritime states of West Bengal and Orissa, which is dominated by estuarine influence, caused by addition of freshwater and silt (Reemtsma *et al*., 1993). The shelf is wide (>100 km in the Sunderban area), characterised by low saline, low O_2 and low temperature waters (Dwivedi, 1993). The southern subsystem (southeast coast of India) consists of the maritime states of Andhra Pradesh and Tamil Nadu, and the Union Territory of Puducherry and has a narrow shelf (as narrow as 10 km off Cuddalore) with little estuarine influence and higher salinity. In the extreme south, the Palk Strait is extremely shallow, having a depth of only about 10 m. The overall nutrient levels are generally high, particularly along the northern subsystem, but this is not reflected in high primary and secondary production as in the case of upwelling areas of eastern Arabian Sea (southwest coast of India) (Dwivedi and Choubey, 1998). However, the productivity along the east coast is sufficient to support a large subsistence and industrialised fishing sector.

The eastern Arabian Sea, bordered by 3341 km-long west coast of India, has a continental shelf area of about 3,51,000 km^2. The continental shelf widens from south to north, reaching about 300 km between latitudes 18°N and 23°N. The inner shelf off the alluvial coast of Kerala (8 to 12°N) is a mobile mud regime, with inshore bank (*chakara*) formation during the southwest monsoon, when upwelling occurs. The onset of southwest monsoon occurs first in the south in May and June, then spreads northward, and continues through October. From November to February, the province is influenced by lighter, drier northeast winds. During this season the cyclonic circulation causes downwelling of isopleths near the coast especially along the northern subsystem (consisting of maritime states of Maharashtra and Gujarat and Union Territory of Daman & Diu) of the west coast of India. The upwelling period of the southwest monsoon along the southern subsystem (consisting of maritime states of Kerala, Karnataka and Goa) is associated with algal blooms reaching 8 mg chlorophyll concentration per m^3. The favourable productivity factors support large fisheries along the west coast, which contributes 60% to the total fish catches along the Indian coast.

Thus the climatic and oceanographic settings in the four subsystems, namely southwest, northwest, southeast and northeast coasts along the mainland, and the two island systems, namely Andaman & Nicobar and Lakshadweep differ between each other, resulting in large innate regional differences in volume and composition of fisheries. Changes in climatic and oceanographic settings, which occur due to man-made climatic changes, are likely to impact regional fisheries in different ways. By nature, each marine ecosystem is unique, and the information derived from each location is often relevant only to that location. Moreover, the status of fish stock exploitation and fisheries development are different between the six regions. Hence adaptation measures suitable for one region may not be applicable to the contiguous region. The map showing the six regions in the Indian EEZ is shown in Figure 10 and the potential adaptation options for the six coastal regions are given in Table 6.

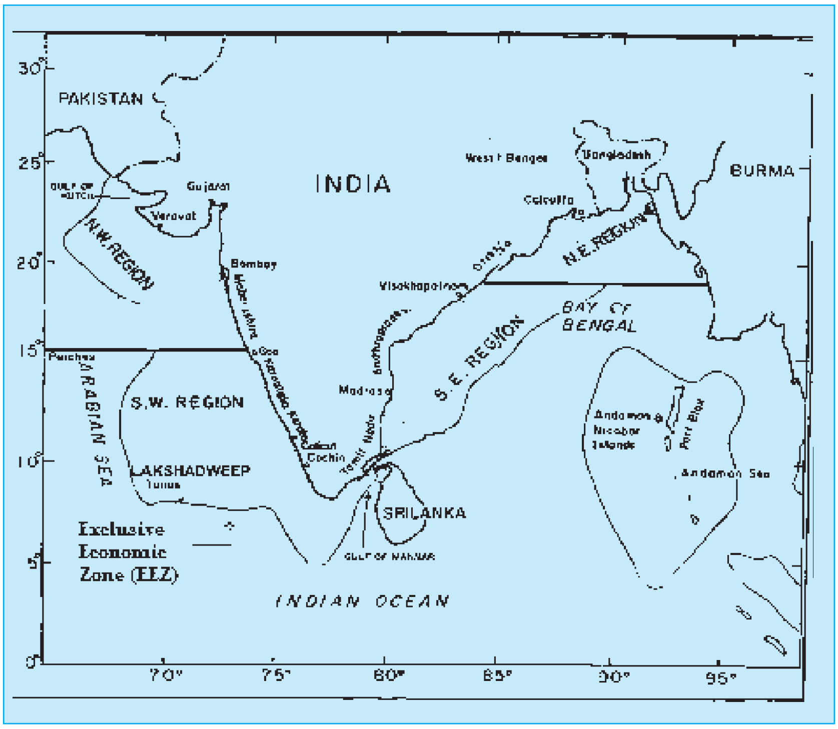

Fig. 10. Map showing the Indian EEZ and six marine regions

Table 6. Adaptation options for six regions

Region	Impact	Adaptation research	Socioeconomic adaptation
Northwest coast (Gujarat, Maharashtra, Daman & Diu)	Largely positive impacts; new fisheries may emerge; biomass of a few existing fish populations may increase; however, stress may be on Bombay duck and *Coilia*	Assessment of potential positive and negative impacts of additional species entering into fisheries; suggest additional postharvest infrastructure requirements; monitor invasion of new fish parasites and diseases from southern latitudes	Potential dominance of small pelagics may lead to changes in craft-gear combinations. Entrepreneurship of fishermen may increase with the availability of additional fish species in greater abundance.
Southwest coast (Goa, Karnataka, Kerala)	Positive impacts may not last long as fish may gradually shift to northern latitudes; likely entry of species from equatorial regions; changes in oceanographic settings may affect fish stocks.	Relationship between climatic and oceanographic variables, and fish distribution, abundance and biological characteristics to be monitored continuously. Value addition of present and new resources to be given priority.	Potential for partially diverting fishing communities into ecotourism. Scope for brackishwater aquaculture. Engineering solution needed to reduce sea erosion and increase beach area.
Southeast coast (Tamilnadu, Andhra Pradesh, Puducherry)	SST increase faster than in other regions; impact of warming on fish stocks may be severe; several stocks on threshold of thermal tolerance and overexploitation;	Relationship between climatic and oceanographic variables, and fish distribution, abundance and biological characteristics to be monitored continuously. Research on adaptive capacity, and	Reducing fishing mortality by regulating/restricting fishing effort; ecosystem-based fisheries management inclusive of MPAs and no-fishing zones should be adopted for sustaining fisheries; community participation in fisheries management,

	coastal fishermen population is prone to cyclones and sea erosion.	spatial & employment relocation of fishing communities should be intensified.	natural calamity forewarning and disaster management mechanisms should be put in place with finance allocation. Investments on fisheries infrastructure should consider climate change
Northeast coast (Orissa, West Bengal)	Benefits may outweigh losses initially; new fisheries may emerge; increased river runoff may be beneficial to coastal fisheries; however, extreme precipitation events may not favour recruitment to *Hilsa* fishery. Sea level rise may reduce area of Sunderban mangrove coverage	Need to quantify fish stocks and understand exploitation status to arrive at conclusions on fisheries management.	Changes in projected species mix and increased climatic variability stress the need for flexible fisheries policies.
Andaman & Nicobar Islands	Decrease in coral and mangrove cover will reduce nursery areas for fish, which in turn will affect recruitment. Extreme cyclone events, sea erosion and inundation will be major threats.	Marine fisheries research relatively weak; need to quantify fish stocks and arrive at conclusions on exploitation status.	Scope for open sea mariculture in select lagoons. Plans for adapting to sea level rize should be devised on a priority. An integrated Plan of Action to adapt to climate change with all sectors and stakeholders should be developed.

Lakshadweep Islands	Spawning and recruitment strength of skipjack tuna may change. Coral reefs likely to lose dominance in 50 years. Major threat would be sea level rise.	Potential changes in tuna abundance in relation to climatic variables to be assessed. Coral restoration programmes to be initiated. Vulnerability indices for sea level rise should be developed for inhabited islands.	Value addition and better marketing infrastructure for fish to be developed. Plans for adapting to sea level rise should be devised on a priority. An integrated Plan of Action to adapt to climate change with all sectors and stakeholders should be developed.

9.1 Northwest coast fisheries

The northwest coast is the domain of Bombayduck- *Coilia - Acetes* complex harvested by dolnetters. Major trawl fisheries exist for demersal finfish such as sciaenids, threadfin breams, lizardfish; crustaceans such as penaeid and non-penaeid prawns; and cephalopods. The annual landings along the northwest coast were 8,42,508 tonnes during 2007-2009, contributing 28.1% to the landings along the Indian coast.

The annual mean SST trend shows that the northwest coast has warmed marginally from 26.04°C in 1985 to 26.10°C in 2005, at the rate of 0.03°C per decade. The annual average maximum SST was around 28.9°C through the two decades and did not increase. The SRES A2 scenario prediction generated by the IPCC shows that the annual average SST along the northwest coast may increase from 26.05°C in the year 2000 to 29.5°C in 2099. By the turn of this century, the annual average SST in the northwest coast, which is located between 16 and 23° N, will be higher than the current SST in the southern latitudes (8-12° N).

As the southern latitudes are warmer, the northwest coast fisheries may be benefited by positive impacts for several years. Movement of fish from southern latitudes, as is happening with the oil sardine in the last two decades, would be an additional resource to the northwest coast.

The oil sardine catch increased from zero in the 1980s to 25,000 t in 2005 along Maharashtra coast where it is found that the fish has an established resident population now. Preliminary ecosystem analysis using the mass-balance trophic model Ecopath shows that incursion of oil sardine into the northwest coast would not immediately affect abundance of other fish stocks in the region (CMFRI, 2009). The model also shows that the abundance of several other stocks would increase. However, stress may be on the dominant species, the Bombayduck and *Coilia.* With distribution restricted to northern latitudes, these two species have no option to move further north, which is land-locked. The region experiences a large tidal variation of 9 m in Gulf of Khambhat at latitude 22^{o}N. It is not known how the complex physical forcing of sea level rise will impact tide levels, which may affect the tide-dependent dolnet fisheries for Bombay duck. The whale shark *Rhincodon typus*, which is a protected species, migrate from southern latitudes and aggregate off Saurashtra during December - March every year. Studies conducted elsewhere indicate that the migratory pattern of large marine organisms will be altered due to warming and acidification of the oceans.

In the long-term, there would be changes in the ecosystem structure and function and predator-prey relationships. There is a need to make an assessment of potential positive and negative impacts of additional species entering into the region and fisheries by employing mass balance analysis models. We need to establish prediction models on fish abundance for different emission scenarios, which is essential to suggest additional post-harvest infrastructure requirements, changes in craft-gear combinations and to increase entrepreneurship of fishermen. It is also important to monitor invasion of new fish parasites and diseases from southern latitudes to understand changes in host-parasite specificity.

9.2 Southwest coast fisheries

Data on sea surface temperature collected from ICOADS for the years

1961 – 2009 off Kerala show that the number of decadal SST anomalous months increased from only 19 during 1960-1969, to 53 during 2000-2009. The anomalies in the Multivariate ENSO Index (MEI) also increased over the decades. SRES A2 scenario prediction generated by the IPCC shows that the annual average SST along the southwest coast may increase from 28.5^{o}C in the year 2000 to 31.5^{o}C in 2099.

The annual average fish landings along the southwest coast was 9,71,500 t during 2007-2009, contributing 32.2% to the landings along the Indian coast. The fishery is supported by a large number of ringseiners, gillnetters and trawlers. The southwest coast fisheries is a typical tropical upwelling regime with high productivity. This subsystem characteristically supports the pelagic clupeid fish, the oil sardine *Sardinella longiceps* that primarily depend upon diatoms for food, obtained by active filtration on gill-rakers. It is an extremely abundant small pelagic fish and supports a fishery since the mid 19th century. The Indian mackerel *Rastrelliger kanagurta* is another small pelagic fish, which contributes the second largest fishery. The region supports several other fisheries such as anchovies, soles, penaeid prawns and cephalopods.

For the southwest coast, the relationship between climatic and oceanographic variables, and fish distribution, abundance and biological characteristics has to be monitored continuously. If the SST increases in the southern latitudes beyond the physiological optimum of the fish, and if other oceanographic variables also change unfavourably, it is possible that the populations may not be able to adapt and may move towards northern latitudes. The region may experience entry of non-conventional resources from equatorial region.

As anomalies in oceanographic variables are increasing, partnership between climate modellers, biologists and socio-economists, is required to develop scenarios for climate change and impacts. Utilisation of non-conventional resources and value addition of present and new resources should be a priority area of research.

9.3 Southeast coast fisheries

Decadal trends along the southeast coast shows that the annual average fish landings increased from 0.14 million tonnes during 1950-59 to 0.57 m t during 1990-99, but increased only marginally to 0.59 m t during 2000-09. The region is rich in biodiversity and commercial fisheries target a wide variety of marine organisms. The catch composition has shifted from predominantly predatory fish high in trophic level to small pelagics such as clupeids and Indian mackerel in the last five decades. Oil sardine, lesser sardines, *Hilsa* shad and Indian mackerel, which contributed 13.4% to the total landings of the region during 1960-69, increased to 25.5% during 2000-09. During the corresponding period, the contribution of sharks, rays, catfish and ribbonfish decreased from 20.1% to 8.6%. Oil sardine, which did not form a regular fishery before mid-1980s, has emerged as the single largest fishery in the last two decades. Vivekanandan *et al* (2005) have found out that fishing down marine food web persists along the southeast coast. A large fishing fleet consisting of 10,879 mechanised craft, 38,896 motorised craft and 50,141 non-motorised craft operates along the coast.

Among the four regions, the increase in SST is highest in this region. In the last 45 years, the annual average SST has increased from 28.7°C to 29.3°C, an increase of 0.6°C. The IPCC-predicted SST at the end of this century is 32.0°C, *i.e.*, 2.7°C increase. The productivity of the region is relatively low and the maximum chlorophyll concentration is around 1 mg per m^3. The ecological consequences of upwelling during the southwest monsoon in the Bay of Bengal are in no way comparable to that of Arabian Sea. Upwelling on the east coast is suppressed by warm, low-saline surface water. Biological impacts of regional warming due to global climate change are likely to be substantial in the southeast region, and indeed may well be the most pronounced in any marine region in India, for three reasons: 1. Fishing has affected the ecosystem structure and function, which is reflected as fishing down the marine food web. 2. A number of stocks in this region are fully exploited; the additional impact of climate change is of concern to future sustainability. 3. The productivity and system throughput of the region is relatively low, and hence, the stability of the ecosystems in the region will be affected at a faster rate by climate change. Relationship between climatic and oceanographic variables, and fish distribution, abundance and Biological Reference Points need to be monitored continuously. Reducing fishing mortality by effectively regulating/restricting fishing effort should be initiated. Because of the diversity of species harvested along the southeast coast, it is relevant to consider the ecosystems in which the exploited species occur and the potential climate impacts on biodiversity. Adopting ecosystem-based fisheries management assumes importance to sustain biodiversity and fish stocks as well. Marine Protected Areas and large no-fishing zones should be adopted by community participation.

The region is prone to cyclones during northeast monsoon, which causes severe damages to human life and properties in the coastal areas. Their destructive forces include strong winds, intense rainfall, extreme waves and currents and storm surges. Where cyclones encounter coastlines, their effects on seagrass (especially in Palk Bay and Gulf of Mannar) and mangrove habitats (Pichavaram and Corringa Bay) can be severe. Sea erosion is emerging as a major concern in several coastal areas. Taking into account the adaptive capacity of fishing communities, measures for relocation of fishing communities should be planned. Weather forecast systems and disaster management need to be strengthened. Future investments on fisheries infrastructure should consider climate change.

9.4 Northeast coast fisheries

Compared to other three coasts along the mainland, the development of fisheries along the northeast coast is relatively recent. The number of mechanised boats increased from a mere 65 in 1961 to 10,406 in 2005. The annual average landings increased from 84,000 tonnes during 1950-59 to 2,85,000 t during 2000-08. The hilsa shad, *Tenualosa ilisha* has remained as the major contributor to the landings for decades. Though separated by the huge north Indian landmass, in many ways, the fish fauna of northeast coast is almost similar to that along the northwest coast. The hilsa shad, together with the bombayduck, *Coilia*, sciaenids, catfish, ribbonfish and non-penaeid prawns contribute 58.0% to the total landings. However, the oceanographic features are different between the two regions. Due to large quantities of runoff from the Ganges, the region is unique with very high sedimentation and broad continental shelf area. It is characterised with low salinity, extensive estuarine system and mangrove cover.

In the last 45 years, the annual average SST along the northeast coast has increased from 27.5^{o}C to 27.8^{o}C. Similar to the northwest coast, benefits derived from climate change may outweigh losses initially. It is possible that new fisheries may emerge due to movement of fish from southern latitudes. Increased river runoff due to glacier melt may be beneficial to coastal fisheries. However, extreme precipitation and cyclone events may not favour recruitment to *Hilsa* fishery. The region is projected to be vulnerable to sea level rise, which may cause inundation of coastal areas and reduce area of Sunderban mangrove cover.

Changes in suspended sediment and nutrient loads resulting from altered runoff will affect marine and brackishwater fisheries. Organisms, such as penaeid prawns, which are dependent on estuaries to complete their life cycle may have potential positive and negative impacts. Extreme temperatures in the shallow nursery habitat of penaeid prawns may be the characteristic effect of climate warming. Extended periods of elevated temperatures in shallow estuarine waters might considerably affect the distribution of prawn nursery habitats. High inorganic sediment loads can reduce or arrest the filtration rates of bivalves.

The understanding on the marine fisheries status along the northeast coast is relatively poor. Nevertheless, it is believed that many stocks are underexploited and there is scope for increasing fishing effort. In this regard, the fisheries situation is different from that of southeast coast, and the west coast as well. There is a need to quantify fish stocks and arrive at conclusions on exploitation status. Changes in projected species mix and increased climatic variability stresses the need for flexible fisheries policies. In future, information on the biological relationships with climate variability must be collected to give an insight into the impacts of climate change on fisheries. With additional information, assessments of future impacts can be made with greater confidence and management responses can be justified. Retrospective analyses will be crucial in resolving physical-biological relationships, with ocean models providing previously missing or unattainable environmental data. Immediate progress with maximum reward can be made by undertaking focused regional studies.

9.5 Andaman and Nicobar Island fisheries

The coastal length of the islands is 1962 km, which is 25% of the coastline of India. The EEZ is 0.6 million km^2. There are no perennial rivers except Galathia in the Great Nicobar and Kalpang in North Andaman. The area is regionally outstanding in terms of both species diversity and intact corals. The Andaman and Nicobar islands are the country's most important coral reef resources and the largest block of coral cover in South Asia. Fringing reefs dominate, surrounding most of the 500 islands, although isolated outcrops and extensive communities growing on rocky shores and vertical granite walls are also frequently found. Approximately 200 coral species and 400 fish species have been recorded to date. Dugong is found in shallow waters and dolphins and whales in oceanic waters of the islands. Four species of turtles frequent the sandy beaches for nesting. The mangroves serve as nursery for coastal species of fish and shellfish. Mangroves in Andaman and Nicobar Islands may come under stress or may not persist in moderate to high rate of sea level rise (Singh, 2003). As about 260 km of the coast of Andaman and Nicobar Islands are lined with mangroves and they have restricted scope of adjustment in response to sea level rise, the impact of climate change on the extent and species composition of mangroves may be devastative when the sea level rise exceeds about 10 cm in 100 years.

Fish is one of the major natural resources of the islands. There are 45 fishing villages and 57 fish landing centres serving as base for 1568 non-mechanised craft, 102 motorised and 140 mechanised craft. The main fishing gear used is drift gillnet, which contributes over 40% to the marine fish landings. The fishery is dependent on fish around the coral reefs. The present annual production is about 30,000 tonnes, which is only about 20% of the estimated potential. This indicates that there is great scope to develop marine fisheries. Of the estimated potential of 1,50,000 tonnes, the potential of oceanic tunas and tuna-like fishes is 67,300 tonnes.

The mean SST trend shows that the reef area in the Andaman Sea has warmed from 28.40^{o} C in 1985 to 28.70^{o} C in 2005 *i.e.*, at the rate of 0.15^{o} C per decade. The annual average maximum SST increased from 30.10^{o} C to 30.48^{o} C, *i.e.*, at the rate of 0.19^{o} C per decade. The SST increased above the monthly mean of 30.9^{o} C on 25th March 1998, and remained high for nearly two months until 23rd May except for one week in April (Vivekanandan *et al*., 2009b). High coral bleaching (as reported in *www.reefbase.org*) occurred in May 1998 as the ambient SST exceeded thermal threshold of coral bleaching. As the SST is predicted to increase by 2.5^{o} C by the end of this century, Vivekanandan *et al* (2009b) projected that corals in the Andaman Seas would become remnant by 2050-2060. The decline in coral cover will have serious impact on the organisms, which take shelter and use the reefs for breeding and feeding purposes.

Ubiquitous practices need to be initiated for restoring the reefs and for sustaining the dependent flora and fauna. An Action Plan is required for the restoration of coral reefs with the following three objectives (see also Great Barrier Reef Marine Park Authority, 2007 and section 4.2 of this publication):

1. Targeted Science: Address critical knowledge gaps on impacts of climate change on coral reefs; identify thresholds, improve monitoring and predictions; evaluate strategies and translate strategies into active management responses
2. Resilient coral reef ecosystem: Maximise resilience by protecting species and ecosystems, regulate fishing; minimise impacts through local management actions
3. Adaptation of communities: Involve all stakeholders in coral restoration programmes; increase their knowledge on climate change impacts.

9.6 Lakshadweep Island fisheries

Lakshadweep Islands consist of 11 inhabited and 25 uninhabited islands and are distributed between 8°00′ N and 12°30′N latitudes and 71°00′E and 74°00′ E longitudes in the Arabian Sea. The archipelago consists of 12 atolls, three reefs and five submerged banks. The life of Lakshadweep Islanders is interwoven with the skipjack tuna *Katsuwonus pelamis.* They have considerable skill in pole and line fishing. In addition to the skipjack tuna, other tunas, barracuda, seerfish, sailfish, snappers and sharks form fishery. About 601 species of fishes have been recorded in the Lakshadweep waters by the CMFRI. It is estimated that the annual harvestable potential of tunas is about 50,000 tonnes and equal quantity of other fishes. The annual landing is about 10,000 tonnes, which is only about 10% of the estimated potential yield.

The mean SST trend shows that the reef area in the Lakshadweep

Sea has warmed from 28.50^{o}C in 1985 to 28.92^{o}C in 2005 *i.e.*, at the rate of 0.21^{o}C per decade. The annual average minimum SST increased from 27.20^{o}C to 27.80^{o}C, *i.e.*, at the rate of 0.30^{o}C per decade. The effect of *El Nino* on SST was evident in 1998 and 2002 when the maximum SST exceeded 31^{o}C, which caused the corals to bleach. The SST increased above the monthly mean of 30.9^{o}C for 80 days from 22nd March 1998 to 10th June 1998. High coral bleaching (as reported in *www.reefbase.org*) occurred in May 1998 as the ambient SST exceeded thermal threshold of coral bleaching. As the SST is predicted to increase by 3.0^{o}C by the end of this century, Vivekanandan *et al* (2009b) projected that corals in the Lakshadweep Seas would start declining by 2030-2040, much ahead of other coral regions in the Indian seas.

Seawater temperature is implicated as the main driver in the distribution and abundance of tunas. As the tunas are typically mobile and their distribution is wide-ranging, they are likely to move from the southern latitudes towards Lakshadweep Seas and further north. Monitoring the movement of tunas by electronic tagging will enable developing predictive habitat models for tunas including the skipjack tuna.

Climate change is identified as the foremost future threat to the island chain (Anon, 2005). The low level of these islands makes them very sensitive to sea level rise. The open sea coral islands of Lakshadweep are one of the low lying small group of islands in the world. Considering the geographical position of the islands, the islands face the risk of inundation of sea water due to anticipated sea level rise and storm surges.

Coastal erosion is one of the serious problems being faced by the Lakshadweep group of islands. Erosion takes place on account of natural causes like wave action as well as due to destruction of coral reefs. Similarly, the high-speed wind and huge waves hitting the seashore lead to sea erosion resulting into reduction of the size of the islands.

Even otherwise, during southwest monsoon season, sea erosion takes place and many low-lying foreshore regions of the islands are washed out.

10. MITIGATION

It is important to remember that the oceans are likely to respond more slowly to climate change than the atmosphere. Although this means that climate impacts on biology may be slower to manifest, it also implies that the ecological response to any mitigation strategies that can be implemented will be slower. For example, it has been understood that ocean acidification is essentially irreversible during our lifetimes and it will take tens of thousands of years for ocean chemistry to return to a condition similar to that occurring at pre-industrial times (about 250 years ago) (Royal Society of UK, 2005).

The primary mitigation potential of fisheries sector lies in its energy consumption through fuel, raw material use and production. As with other food sectors, distribution, packaging and other supply chain components also will contribute to the sector's carbon footprint. Net mitigation contributions of fisheries, aquaculture and related supply chain features are small in overall terms, but can be improved. There also may be valuable interactions for the sector with respect to environmental services such as maintaining the quality and function of coral reefs, coastal margins, inland watersheds, potential carbon sequestration and other nutrient management options, but these will need further research and development (FAO, 2008).

10.1 Footprint of fishing operations

Fisheries activities contribute to GHG emissions during capture operations and subsequently during the transport, processing and storage of product. Industrial fisheries have much greater emissions than small-scale fisheries. Fuel efficiency is defined primarily by motor propulsion and gear characteristics, but is substantially affected by fisheries management and practice. Any management measure that encourages a "race to fish" creates incentives to increase engine power (FAO, 2008). Overfished stocks at lower densities and smaller individual sizes require vessels to exert more effort, catch greater numbers of individual fish, travel to more distant or deeper grounds or fish over a wider area, all of which would increase fuel use per tonne of fish catch. The estimated fuel consumption by global capture fisheries operations ranges from 14 to 42 million tonnes equivalent to CO_2 emission of 43 to 134 Tg (1 Tg (teragram) = one million tonnes) (Tyedmers *et al*., 2005; FAO, 2007). It is estimated that global fisheries account for about 1.2% of the global oil consumption.

There are 58,911 mechanised and 75,591 motorised marine fishing boats in India. All these boats use diesel for propulsion, and among these, trawlers use diesel for propulsion as well as fishing. By undertaking survey on diesel consumption by 1332 mechanised boats and 631 motorised boats operating from major fishing harbours in Kerala, Tamil Nadu, Maharashtra and Gujarat, CMFRI (2009) has estimated that annual fossil fuel consumption by marine fishing boats in India is around 912 million liters per year, which is equivalent to CO_2 emission of 2.4 million tonnes per year during 2005-2007. CO emission is generally considered as 10% of CO_2 emission, which is equivalent to 0.24 million tonnes per year. It was found that the mechanised boats emitted 1.10 tonnes of CO_2 per tonne of fish catch, and the motorised boats with outboard engine emitted 0.48 t CO_2 per t of fish catch (Table 7). Among the mechanised craft, the trawlers emitted more CO_2 (1.18 t CO_2 /t of fish) than the gillnetters and dolnetters (0.93-0.96 t CO_2/t of fish). Based on the data available on the number and size of fishing boats in India in the past years, it is estimated that CO_2 emission by the marine fishing sector has substantially increased from 0.51 t CO_2 per tonne of fish catch in 1980 to 0.83 t CO_2 per t of fish during 2005-2007 (Fig. 11), *i.e.*, 64% increase in CO_2 emission per tonne of fish caught in a period of 25 years.

Table 7. Ratio of CO_2 emission (tonnes per tonne of fish catch) by marine fishing boats during 2005-2007

Fleet	CO_2 emission ratio
Mechanised boats	1.10
Trawlers	1.18
Gillnetters	0.93
Dolnetters	0.96
Motorised boats	0.48

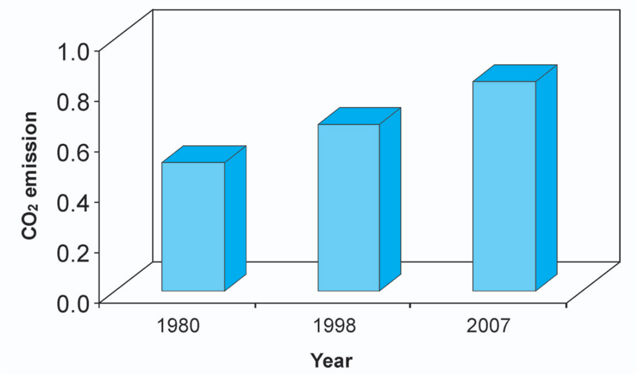

Fig. 11. CO_2 emission ratio (tonnes of CO_2 per tonne of fish catch) by marine fishing boats in India during 1980, 1998 and 2007

Though marine fishing boats contribute only about 0.3% to the total CO_2 emission by India, there is scope to reduce the carbon footprint by the marine fishing boats by setting emission norms and improving the fuel efficiency of engines. Conservation measures such as (i) reducing and regulating the fishing effort, (ii) use of engine with appropriate horsepower, (iii) proper maintenance of engines and (iv) reducing fish scouting time by using fish finding equipments would reduce CO_2 emission by marine fishing boats.

A significant reduction of green house gas emissions can be achieved by switching from fuel-intensive techniques such as bottom trawling and beam trawling, to alternative techniques that use less fuel. It is estimated that the fuel needed to catch and land one kilogram of Norway lobster can be reduced from 9 litres to 2.2 litres by switching from conventional trawl fisheries to trap fisheries (Ziegler and Valentinsson, 2008). Such a switch would also signicantly reduce the by-catch of non-target species and impacts on the seabed. In the Danish fishery, it is found that the amount of fuel per kg of fish caught could be reduced by a factor of 15 by switching from beam trawling to the Danish seine. The Danish seine is a semi-passive gear, which has less impact on the seabed than beam trawling.

10.2 Footprint of post-harvest sector

As in all food production sectors, post-harvest activities entail stocking, packaging and transporting and they create post-consumption waste, all linked with CO_2 emissions. Of special note are those related to air transport. Intercontinental airfreight may emit 8.5 kg CO_2 per kg of fish shipped, about 3.5 times the levels from sea freight, and more than 90 times those from transport of fish consumed within 400 km of its source (FAO, 2008). Product form will also have an important effect, including energy embodied in packaging, and can influence options for maintaining quality and value with respect to transport method. There are important implications for fish trade, upon which India depends for export earnings. In order to understand the carbon footprint of fishery products and define comparative performance and areas for potential improvement, emissions need to be traced through the entire supply chain, using a full life-cycle analysis (LCA) from pre-harvest to post-consumer wastes.

LCA is an environmental assessment tool to quantify environmental impact throughout the entire life cycle of a product or process. The life cycle of a product means from raw material extraction over production, transportation and use phases to waste treatment. Entrepreneurs can use LCAs internally to improve their own environmental performance (i.e. decrease use of energy or water, change the type of energy, refrigerant or packaging material used) or to make sure their sourcing strategy for raw materials is an environmentally sound one.

Although a relatively small global contributor, capture fisheries have a responsibility to limit GHG emissions as much as possible. For example, eliminating inefficient fleet structures (e.g. excessive capacity, over-fishing), improving fisheries management, reducing post-harvest losses and increasing waste recycling will decrease the sectors' CO_2 emissions and improve the aquatic ecosystems' ability to respond to external shocks. Other technical solutions to reduce fuel use might include shifting towards static fishing technologies and to more efficient vessels and gears. In some cases, win-win conditions could be identified, where reduced fuel-use strategies would link with reducing fishing effort, improving returns to vessels, safeguarding stocks and improving their resilience to climate change (FAO, 2008).

GLOSSARY

Abrupt climate change: The nonlinearity of the climate system, which leads to abrupt climate change; often refers to time scales faster than the typical time scale of the responsible forcing (source: IPCC).

Adaptive capacity: Ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (source: IPCC).

Anthropogenic: Resulting from or produced by human beings.

Aridity: Lacking moisture, especially having insufficient rainfall.

Biological Reference Points: Biological Reference Points (BRPs) are widely used to define safe levels of harvesting for marine fish populations. Most BRPs are either minimum acceptable biomass levels or maximum fishing mortality rates. The values of BRPs are determined from historical abundance data and the life-history parameters of fish species.

Climate: Average weather; statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period of averaging these variables is 30 years, as defined by the World Meteorological Organisation. The relevant quantities are most often surface variables such as temperature, precipitation and wind (source: IPCC).

Climate change: Change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (source: IPCC).

Climate prediction: A climate prediction or climate forecast is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or long-term time scales (source: IPCC).

Climate projection: A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases. Climate projections are distinguished from climate predictions in order to emphasise that climate projections depend upon the emission/concentration/radiative forcing scenario used, which are based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realised and are therefore subject to substantial uncertainty (source: IPCC).

Climate variability: Natural variability of the climate system, in particular on seasonal and longer time scales, which predominantly occurs with preferred spatial patterns and time scales (source: IPCC).

Communities: Ranging from local fishing communities to large-scale fishing production systems, from suppliers to consumers, and from those who manage to those who are managed.

Coral bleaching: The paling in colour which results if a coral loses its symbiotic, energy-providing organisms.

Demersal: Bottom or near-bottom of the sea; inhabiting species living at the bottom or in near-bottom waters in the commercial fishing grounds include flatfish, threadfin breams, silverbellies and shrimps.

Downscaling: Downscaling is a method that derives local- to regional-scale (10 to 100 km) information from larger-scale models or data analyses (source: IPCC).

Downwelling: Movement of water from the surface to depth. Downwelling can occur at the coast, or in the open ocean. Downwelling regions are typically low productivity (source: IPCC).

Ecopath with Ecosim (EwE): An ecological/ecosystem modeling software suite. EwE has three main components: *Ecopath* - a static, mass-balanced snapshot of the system; *Ecosim* - a time dynamic simulation module for policy exploration; and *Ecospace* - a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas.

Ecosystem-based Fisheries Management (EBFM) or Ecosystem Approach to Fisheries (EAF): Assesses the impacts of removing fish both directly on their population and indirectly on other living organisms, such as predators that eat the fish. This approach allows managers to account for potential tradeoffs among species. Many scientists, policymakers and environmentalists recommend that ecosystem-based management replace single-species fisheries management in order to maintain healthy ocean environments.

ENSO (*El Nino*-Southern Oscillation): A set of interacting parts of a single global system of coupled ocean-atmosphere climate fluctuations. The Pacific Ocean signatures, *El Niño* and *La Niña* produce large temperature fluctuations in surface waters of the tropical Pacific Ocean. ENSO is the most prominent known source of inter-annual variability in weather and climate around most parts of the world (~3 to 8 years).

Euryhaline: Tolerant of a wide range of salinity.

Exclusive Economic Zone (EEZ): This zone typically extends offshore to a distance of 200 nm from the coast, and surrounds most countries.

Extreme weather event: An event that is rare at a particular place and time of year.

Fisherman: A person who is engaged in fishing as a owner or labourer, and in activities related to fishing, processing and marketing at primary (landing centre) level.

Greenhouse effect: Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system (source: IPCC).

Greenhouse gas (GHG): Gaseous constituents of the atmosphere, both natural and anthropogenic that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere (source: IPCC).

International Comprehensive Ocean-Atmosphere Data Set (ICOADS): ICOADS is a major update of an extensive surface marine meteorological data collection. It is maintained as a cooperative effort between National Center for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA).

Inter-governmental Panel on Climate Change (IPCC): The Intergovernmental Panel on Climate Change is the leading body established by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) for the assessment of climate change, to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socio-economic consequences.

Life Cycle Assessment (LCA): The term 'life cycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence. The sum of all those steps - or phases - is the life cycle of the product. The goal of LCA is to compare the full range of environmental and social damages assignable to products and services, to be able to choose the least burdensome one.

Mechanised craft: A fishing boat with inboard engine.
Meridional wind (V): Relative to lines of longitude (meridians: north-south direction); the opposite is zonal.

Mitigation: An anthropogenic intervention to reduce the anthropogenic forcing of the climate system. It includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks (source: IPCC).

Mixed layer: Upper portion of the ocean (typically 20 - 100 metres in thickness) where the wind mixes constituents (e.g. nutrients, salts) to give constant concentration within this layer and where there is relatively constant temperature with depth compared with deeper waters.

Motorised craft: A fishing boat with outboard motor.

Multivariate ENSO Index (MEI): Composite index of six observed variables, *viz*., sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. The MEI is calculated as the first unrotated Principal Component (PC) of all six observed fields combined. Positive MEI values are related to warm phase or *El Nino* events and negative values to cool phase or *La Nina* events.

Oligotrophic: Low nutrient environment or region where the lack of nutrients such as nitrate restricts biological productivity.

Pelagic: Surface and subsurface of the sea; inhabiting species living at the surface or in upper ocean waters, include tunas, anchovies and sardines.

Phenology: The timing of events in an animals' life, such as when it lays eggs, migrates, or hibernates. As these events may be sensitive to climate, phenological studies may provide indirect evidence of climate impacts on biology.

Resilience: The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

Salinisation: The accumulation of salts in soils.

Scalar wind (W): Describes the speed or magnitude of the wind.

Scenario: A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios can be very simple (e.g. CO_2 increasing at 1% per year) or more realistic (e.g. SRES scenarios developed by the Intergovernmental Panel on Climate Change). Which scenarios should be considered most realistic is currently uncertain, as the projections of future CO_2 emissions are uncertain.

Sea level pressure: The atmospheric pressure at mean sea level, either directly measured or, most commonly, empirically determined from the observed station pressure.

Sea level rise: An increase in the mean level of the ocean. Eustatic sea level rise is a change in global average sea level brought about by an alteration to the volume of the world ocean. Relative sea-level rise occurs where there is a net increase in the level of the ocean relative to local land movements.

Sea surface temperature: Water temperature close to the sea surface.

Sea wall: A human-made wall or embankment along a shore to prevent wave erosion.

Sequestration: Carbon storage in terrestrial or marine reservoirs. Biological sequestration includes direct removal of CO_2 from the atmosphere through land-use change, afforestation, reforestation, carbon storage in landfills and practices that enhance soil carbon in agriculture.

Southern Oscillation Index: A measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific Ocean during *El Nino* and *La Nina* episodes. Traditionally, this index has been calculated based on the differences in air pressure anomaly between Tahiti and Darwin (Australia).

Special Report on Emission Scenarios (SRES): IPCC has generated 40 special reports on emission scenarios based on emission estimates for radiatively important gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluoro-carbons (CFCs). Emission estimates span the period from 1990 to 2100 at the global level and at the level of four macro-regions. One of the primary reasons for developing emissions scenarios is to enable coordinated studies of climate change, climate impacts, and mitigation options and strategies.

Stakeholder: A person or an organisation that has a legitimate interest in a project or entity, or would be affected by a particular action or policy.

Stenohaline: Tolerant of a narrow range of salinity.

Storm surge: Temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions such as low atmospheric pressure and/or strong winds. The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.

Thermocline: Depth at which the water temperature changes most rapidly, typically at the base of the mixed layer.

Threshold: The level of magnitude of a system process at which sudden or rapid change occurs. A point or level at which new properties emerge in an ecological, economic or other system, invalidating predictions based on mathematical relationships that apply at lower levels.

Traditional craft: A boat without any mechanical device for propulsion and fishing.

United Nations Framework Convention on Climate Change (UNFCCC): Support cooperative action by countries to combat climate change and its impacts on humanity and ecosystems. Guided by the Parties to the Convention, UNFCCC provide organisational support and technical expertise to their negotiations and institutions and facilitate the flow of authoritative information on the implementation of the Convention.

Upwelling: Movement of water from depth to the surface, usually enriching the upper waters with nutrients from the deeper waters.

Vulnerability: Degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes (source: IPCC).

Zonal wind (U): Along lines of latitude (i.e. east-west direction); the opposite of meridional.

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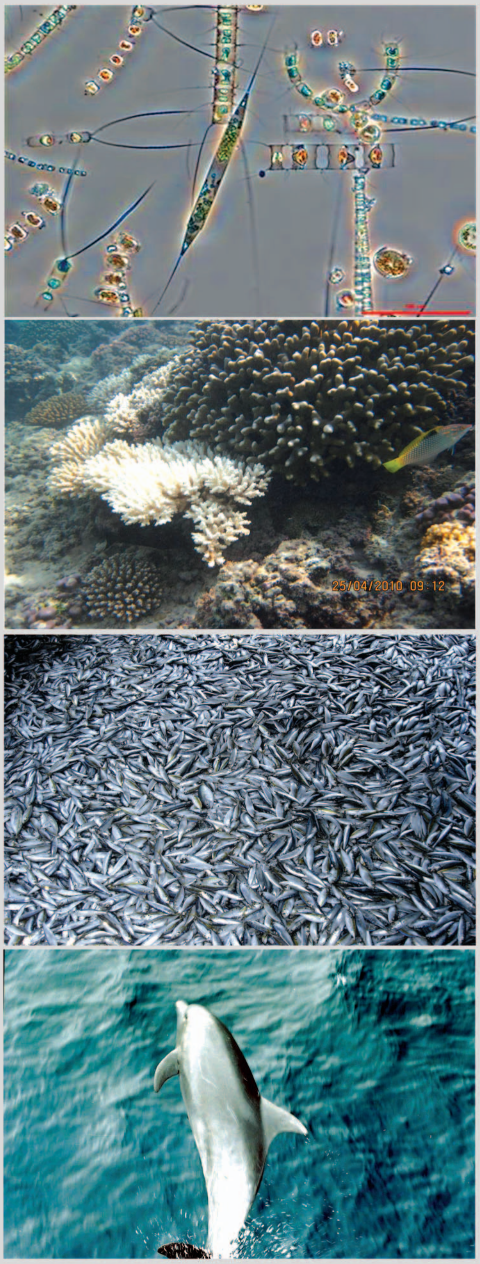
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