25 Climate change impacts : Implications on marine resources and resource users

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Climate change

IPCC defines Climate change as "A change in the state of the climate that can be identified 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".

The warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. The Earth's average surface temperature has risen by 0.76° C since 1850. Most of the warming that has occurred over the last 50 years is very likely to have been caused by human activities. In its Fourth Assessment Report projects that, without further action to reduce greenhouse gas emissions, the global average surface temperature is likely to rise by a further 1.8-4.0°C this century, and by up to 6.4°C in the worst case scenario. Even the lower end of this range would take the temperature increase since pre-industrial times above 2°C – the threshold beyond which irreversible and possibly catastrophic changes become far more likely.

The present paper elucidates the impact of climate change on marine ecosystems, fish and fisheries and suggests various vulnerability assessment methods and adaptation options to cope up with climate change.

Climate change and marine ecosystem

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.

Understanding the importance and the implication of the climate changes on coastal areas may be one of the major issues for this and next centuries. Climate changes may, indeed, impact the nearshore marine ecosystem, as coastal areas are very sensitive to the strength and the variability of the meteorological forcings.

An increase of a few degrees in atmospheric temperature will not only raise the temperature of the oceans, but also cause major hydrologic changes affecting the physical and chemical properties of water. These will lead to fish, invertebrate, and plant species changes in marine and estuarine communities (McGinn, 2002). Fishes have evolved physiologically to live within a specific range of environmental variation, and existence outside of that range can be stressful or fatal (Barton *et al.*, 2002). These ranges can coincide for fishes that evolved in similar habitats (Attrill, 2002).

Estuarine and coastal regions are extremely productive because they receive inputs from several primary production sources and detrital food webs. Yet, these systems present the biota with a harsh environment, forcing organisms to evolve physiological or behavioral adaptations to cope with wide ranging physical and chemical variables (Horn *et al.*, 1999). Temperature, along with other variables, causes active movement of mobile species to areas encompassing the preferred range of environmental variables, influencing migration patterns (Rose and Leggett, 1988; Murawski, 1993; Soto, 2002).

The predicted increase in major climatic events, such as ENSO (Timmermann *et al.*, 1999; IPCC, 2001), may have drastic effects on fish stocks, especially when combined with other factors, such as overfishing (Pauly and Christensen, 1995). It has been suggested that reduced survival, reduced growth rate, and diversions of traditional migratory routes can all be caused by ENSO events, exacerbating the effects of intensive harvesting (Miller and Fluharty, 1992). The El Nino phenomenon generates substantial changes in oceanographic and meteorological conditions in the Pacific Ocean, with manifestations impacting the Peruvian coast (Zuta *et al.*, 1976); this has mainly affected pelagic resources, producing alterations in their biological processes, behaviour, and gradual decrease in their population levels (Valdivia, 1976).

a)Sea level rise in the Indian seas:

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. 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 7.2×1011m^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 sea level rise for Cochin (southwest coast) is estimated as 2 cm in the last one century The sea level would rise by 8 to 25 cm (Emery and Aubrey, 1989; Das and Radhakrishna, 1993). But the rate of increase is accelerating. It may rise at the rate of 5 mm per year in decades to come. This will accelerate erosion and increase the risk of flooding (Nicholls *et al.*, 1999). 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 106 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).

According to Unnikrishnan and Shankar(2007)sea-level-rise estimates for the Indian coast are between 1.06–1.75 mm yr− 1, with a regional average of 1.29 mm yr− 1, when corrected for GIA using model data. These estimates are consistent with the 1–2 mm yr− 1 global sea-levelrise estimates reported by the IPCC. The study also showed a large trend of 5.74 mm/ year for the record at Diamond Harbour (Kolkata), which is attributed partly to the subsidence of the Ganges-Brahmaputra delta. Model-based projections of global average sea level rise at the end of the 21st century (2090–2099) made for a number of climate scenarios indicate that the sea level may rise from a minimum of 0.18 m minimum to a maximum of 0.59 m. In the absence of availability of regional projections, global projections can be used as a first approximation of sea-level rise along the Indian coasts in the next few decades as well as towards the end of the 21st century.

The east coast is considered more vulnerable due to its flat terrain and the numerous deltas. Shetye *et al.* 1990 analysed the vulnerability of regions surrounding Nagapattinam, Kochi and Paradip for a one metre rise in sea level. The estimate shows that the inundation area will be about 4.2 km^2 for a 1.0 m rise in sea level in the region surrounding Nagapattinam. But for the same sea-level rise projections, about 169 km^2 of the coastal region surrounding Kochi will be inundated and in the case of Paradip, 478 km^2 may be inundated. Thus areas with large number of creeks and backwaters are likely to be at a higher risk of inundation.

Dineshkumar,2001 studied on the variations in monthly mean sea level at Cochin, southwest coast of India, over a period of 50 years (1949-1998). Analysis showed that there are strong seasonal variations in the monthly mean sea level. Contrary to expectation, sea level values were found to be the lowest during the south west monsoon months, though this is the period of maximum discharge from rivers which debouch in the region. This is explained in relation to the geographic setting and associated upwelling in the region. It is also indicated that large fluctuations due to weather conditions do tend to balance through the years, and the periodic seasonal changes are mostly eliminated when annual averages are calculated.

Sanil Kumar *et al.*, 2011 studied the characteristics of tidal constituents along the near-shore waters of Karnataka, west coast of India. Analysis spectacles that astronomical tides are responsible for most of the observed sea level variability along the Karnataka coast. 97% of the variation in measured sea level at Honnavar and Malpe and 96% of the sea level variation at Kundapur was due to tide. The observed non-tidal sea levels were related to local wind forcing. The study shows that when the wind from south was strong, a rise in sea level was observed and when the wind from the north was strong, a fall in sea level was observed. Correlation between alongshore component of wind and non-tidal sea level was 0.54 at Malpe and 0.48 at Honnavar. The non-tidal sea level variation was found to vary according to the significant wave height. High residuals of sea level were found during high waves. Amplification of shallow water constituents were relatively high compared to other constituents from south to north along the study area.

b) Sea Surface Temperature

Prasanna Kumar *et al* (2009) examined the signature of global warming using various datasets for the Arabian Sea region and found that the disruption in the natural decadal cycle of SST after 1995 was a manifestation of regional climate-shift. They propose that upwelling driven cooling was maintained till 1995 despite oceanic thermal inertia and increasing CO_2 concentrations but this system broke down after 1995 though it is not known yet how long this process will continue. Vivekanandan *et al.* (2009a) found warming of the sea surface along the entire Indian coast. The SST increased by 0.2°C along the northwest, southwest and northeast coasts and by 0.3°C along the southeast coast during the 45-year period from 1960 to 2005. The team has predicted that the annual average SST in the Indian seas would increase by 2.0°C to 3.5°C by 2099. Upwelling in the waters of the southwest coast of India is restricted to 5 to 15°N, and the variability in physical parameters is manifested in the chlorophyll intensity (Smitha *et al.*, 2008). Remotely sensed sea surface temperature (SST) and ocean-colour images reveal eddies and fronts. These features frequently coincide with areas where fish species aggregate as a result of enhanced primary productivity and phytoplankton biomass, which in turn is linked with increased nutrient supply. Since, higher plant biomass is associated with zooplankton abundance, this could provide supplementary information on fish stock distribution from ocean-colour pigment fields.

Climate change and fisheries

Climate change will affect individuals, populations and communities through the individuals' physiological and behavioral responses to environmental changes (Boesch and Turner, 1984). Extremes in environmental factors, such as elevated water temperature, low dissolved oxygen or salinity, and pH, can have deleterious effects on fishes (Moyle and Cech, 2004). Suboptimal environmental conditions can decrease foraging, growth, and fecundity, alters metamorphosis, and affects endocrine homeostasis and migratory behavior (Barton and Barton, 1987; Donaldson, 1990; Portner *et al.*, 2001). These organismal changes directly influence population and community structure by their associated effects on performance, patterns of resource use, and survival (Ruiz *et al.*, 1993; Wainwright, 1994).

Particularly in northern high latitudes, large annual fluctuations in water temperature and sea ice cover can have dramatic effects on the distribution and abundance of fish populations (Murawski, 1993; Nye *et al.*, 2009). Fish stocks may compensate for annual temperature variations by changing location to maintain a desired temperature range (e.g. Mountain and Murawski, 1992; Overholtz *et al.*, 2011). Sixtyeight percent of the total production of fish, crustaceans, and molluscs come from capture fisheries most fishing depends on wild populations which may also be highly migratory (Allison *et al*, 2005).

Fish populations have been adapting to oceanic phenomena over evolutionary time scales, so that their survival rate should be high during an ordinary period. The episodic changes in climate/environments, however, result in changes in a population's survival, and in changes in productivity and species composition. Recruitment failure of fish populations caused by high mortality during the early life stages is detrimental in maintaining healthy stock conditions. Most hypotheses on recruitment processes are closely related to the plankton-based ecosystem, which largely depends upon oceanic variability (Cole and McGlade 1998). In order to delineate the effect of ecological interaction among fisheries resources, time-series data on production of fisheries resources and observation on the environment are required. The new paradigm of ecosystem response to environmental variability has become the main theme in marine ecology and fishery science. This type of research provides the understanding of cause and effect mechanisms, as well as prediction capabilities for fisheries recruitment related to climate changes. These in turn could eventually be used to establish appropriate fisheries resource management procedures (Kim *et al.* 2006; Kim and Lo, 2001).

Climate change may have a wide range of possible effects on ocean currents and processes that can affect fish resources (Everett 1996). Ocean fronts and eddies, that are determined by large scale and mesoscale current patterns, are the habitat and migratory pathways of oceanic pelagic fishes (Parin 1968, Olson and Podesta 1987). Changes in the location and/or strength of these oceanic features may affect the abundance of these fishes. However, changes in availability to the local fishing fleet are more likely to occur than are large scale changes in abundance.

Climate affects the distribution and abundance of species in ecosystems around the world. In the face of rising temperatures, the ocean may experience variations in circulation, water temperature, ice cover, and sea level (McCarthy *et al.*, 2001). Climate-driven fluctuations in regional temperature can further affect growth, maturity, spawning time, egg viability, food availability, mortality, and spatial distribution of marine organisms (Ottersen *et al.*, 2001; Perry *et al.*, 2005; Nye *et al.*, 2009). Also affected by climate change are the size and timing of plankton blooms, a major driver of marine ecosystem function with a direct impact on recruitment success and population sizes (Walther *et al.*, 2002; Fischlin *et al.*, 2007).

Kawasaki (1991) observed that three sardine populations in the Pacific Ocean and the European pilchard in the North Atlantic have undergone long-term coincident change in their abundance like the Pacific and Atlantic herrings with a phase different from that of the sardine populations. He also observed a high positive correlation between trends in abundance of the sardine populations and a secular change in anomaly of the global mean surface temperature. He concluded, "We are perhaps now standing at a turning point for the structural change in the pelagic fish community in the world ocean which may be caused by a global climatic change".

Marine pelagic systems are susceptible to climate change through extreme events and the contraction or expansion of oceanic zones. For example, sea temperature changes driven by variations in the North Atlantic Oscillation (NAO) have been linked to fluctuations in cod (*Gadus morhua*) recruitment and habitat shifts off Labrador and Newfoundland (Rose *et al.*, 2000).

Fisheries form one of the means of sustenance for the coastal rural population in India [Thomson, 2009]. In India, about 12.5 lakh people are involved in active fishing in India while the postharvest sector including export and domestic marketing employs about 15 lakh and in tertiary sector there are around 2 lakh people. Among these, 71 percent of active fishers, 50 percent of secondary sector workers and 42 percent in the tertiary sector are inhabitants of coastalfishing villages. In the secondary sector, around 30 percent are women workers of which 81 percent are residents of fishing villages in the coastal belt (Sathiadas *et al.*, 2009).

The major share of fish landing in India comes from the west coast. The striking feature of the Malabar upwelling zone is the predominance of pelagic resources such as oilsardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*), which support the western Indian Ocean's largest coastal pelagic fishery (Vivekanandan *et al.*, 2005). Though this upwelling is less in intensity when compared to the other upwelling regions of the Arabian Sea (like those at Somalia and Oman), it has profound impact on the coastal fisheries of India. While the west coast of India accounts for 70% fish yield of the total Arabian Sea production (Luis and Kawamura 2004), the south-west coast alone accounts for 53% (Vivekanandan *et al.*, 2009a). Historically, the fishery for these small pelagics has shown wide fluctuations (Krishnakumar and Bhat, 2008). In the last 100 years, there have been several periods of relatively high abundance, and several major population crashes of oilsardine (Krishnakumar *et al.*, 2008).

Ocean colour patterns were useful in differentiating the relevance of food over other environmental factors like temperature in fish aggregation, offering better information regarding the location of Albacore tuna [Laurs *et al.*, 1984]. It was originally assumed that tuna prefers to reside within certain limited temperature ranges, which explains their tendency to aggregate at temperature fronts. In instances where colour and SST fronts were spatially separated, they found that tuna actually tend to aggregate on the clear side of a colour front. Ocean-colour pigments are relevant in detecting a bloom. Fragmented observations in the waters of the southwest coast of India hypothesized two seasonal blooms: (i) upwelling blooms in May-June coinciding with the arrival of pre-spawning adults and (ii) winter blooms in September-October coinciding with the main fishery for juveniles [Bensam, 1964]. For sardines, a planktivorous species, the amount of food ingested depends on chlorophyll concentration as well as copepods present in the ambient waters; better availability of food is expected in chlorophyll-rich waters. In the present study, variability in chlorophyll along the waters of the southwest coast of India had been quantified from satellite data and related to annual variability in the sardine landings. The synoptic scale spatial and temporal changes in chlorophyll-a are useful in explaining the appearance and disappearance of sardine shoals along the coastal waters.

Similar to SST, the capability of satellite remote sensing in providing global coverage snapshot has been an advantage to the measurement of Chl-a in the marine environment. In marine remote sensing, Chl-a has been used a proxy to the existence of phytoplankton. Butler *et al.* (1972) reported that the Chl-a above 0.2 mg/l indicate the presence of sufficient fish food to sustain a viable commercial fishery. In general term, chlorophyll-a can be described as a vital pigment for photosynthesis in phytoplankton.

Many researchers have tried to predict the availability of small pelagics in general, and oilsardine in particular, from the relationship between catches and climatic as well as oceanographic features such as seawater temperature, salinity, rainfall, upwelling and chlorophyll concentration along the south-west coast of India (Banse, 1959; Longhurst and Wooster, 1990; Madhupratap *et al.*, 1994; Yohannan and Abdulrahiman, 1998; Jayaprakash, 2002; Xu and Boyce, 2009).

There are various physical (driven by winds, tides and currents) and biological processes controlling the fisheries in an ecosystem [Dickey, 1990]. Seasonally changing monsoon is the major physical forcing which controls the biological abundance and fisheries along the west coast of India. There are excellent reports from this region not only on the variability of monsoon winds but also on their oceanographic and biological consequences in relationship to fisheries [Longhurst andWooster, 1990]. However, these seasonal changes in monsoon, reflecting in the abundance on fish, were not examined as a trophic response to the reproductive cycle of fishes [Madhupratap *et al.*, 1994]. This suspected trophic link for sardine fisheries forms part of the present study by exploring the remotely sensed chlorophyll as a putative trophic link to explain the survival of sardine larvae, their migration and aggregation pattern. The abundant Indian oil sardine along the west coast of India have strong interannual variability and their arrival and departure along the coastal waters coincides with the upwelling bloom [Grinson George *et al.*, 2011].

Sardines perform a normal migration from offshore to coastal waters and vice-versa coinciding with the customary wind conditions [Hornell, 1910b]. A gradual increase in temperature within the range of 26 to 28°C is favourable for the inshore migration of the juveniles, and during March to May they disappear to deeper waters due to increasing temperature (above 29°C) [Chidambaram, 1950]. The specific gravity of water (above 1.023) also promotes the disappearance of the shoals during the above period. The shoreward migration of spawners during SW monsoon season and their outward migration to deeper waters during postmonsoon months is for feeding [Nair, 1959] on phytoplankton that blooms up during the onset of monsoon and continues till post monsoon [Hornell and Nayadu, 1924b; Hornell, 1910b; Chidambaram, 1950; Nair, 1953]. The longitudinal migration either way is an excursion from offshore to inshore waters and vice-versa due to availability of food and favourable hydrographic conditions [Devanesan, 1943b]. The shoals start disappearing from the northern region first, and then from the southern Malabar area. From April to September, the shoals of spawners and juveniles migrate from offshore to inshore all along the west coast following the onset of bloom [Raja, 1943]. This observation suggests a northward migration of sardines steadily during SW monsoon season and retrogression from north to south in the NE monsoon season [Hornell, 1910a; Chidambaram, 1950; Panikkar, 1952].Lack of continuous seasonal information to characterize synoptic scale variability in chlorophyll concentration of the region was an impediment to verifying the food availability between different years and to explain the interannual variability in sardine landings. Also, it was not feasible to study the spatial and temporal variations in chlorophyll concentration in these areas because of nonavailability of *in situ* data. With the advent of remote sensing, however, this was possible with ocean-colour data. Platt *et al.* [2003] applied remotely sensed ocean-colour data as direct evidence for a putative trophic link, and suggested it as an important link in future analysis of dwindling fish stocks. Time series of phytoplankton cycle derived from satellite data can be used to construct a variety of ecological indicators of the pelagic system useful in ecosystem-based management [Platt *et al.*, 2009].

Murty and Edelman (1970) investigated the relationship between the intensity of the southwest monsoon and the oil sardine fishery. They contended that the field of pressure would reflect the monsoon intensity to the utmost degree of accuracy than the amount of rainfall. The pressure gradients at the surface during the monsoon, according to them are better indicators of monsoon intensities for the different years. Their analysis also revealed that there was a critical value of monsoon intensity above which the catches improve with increasing monsoon activity. They also offered an explanation to this characteristic influence of the monsoon.

Longhurst and Wooster (1990) gave a detailed account of oil sardine fishery and the literature related to the effect of fishery independent factors on the oil sardine catch variability. They observed that oil sardine landings data clearly indicated decadal trends. According to them the cyclic pattern of oil sardine probably reflected density dependence rather than response to fishing. While explaining the environmental variables which could have caused the variations in the oil sardine landings they have established a relationship of variations in the mean sea level with fluctuations in the abundance. According to them oil sardine fishery mainly comprised of 0-year class only. Thus fluctuations in the landings could be ascribed to recruitment variability. The success or failure of the recruitment in pelagic stock by and large is governed by the environmental factors, the air sea interactions and the ocean dynamics. They also have reported that the success in recruitment of oil sardine fishery is very much dependent on the intensity of upwelling (derived from sea level) along the south-west coast of India

Kumaran *et al.* (1992) observed that even though the rainfall and oil sardine landings at Calicut during different seasons did not show any direct relationship, the oil sardine landings were better two or three months after fairly heavy rains. The analysis of oil sardine landings and rainfall data at Cochin showed that fairly good rain during the monsoon probably had some positive impact on the abundance of juvenile oil sardine during the succeeding post-monsoon months. They inferred that the reduced rainfall intensity might have an adverse impact on the shoal formation at the surface.

Antony Raja (1969) had also studied the effect of monsoon on the spawning success and the fishery. Madhupratap *et al.* (1994) questioned the validity of the precision of the data of the earlier period and also the observed relationship. They also stressed the importance of impact of climatic and other ocean related parameters on the oil sardine stock.Murty (1965) envisaged the possibility of evolving a prediction system for forecasting the trend of pelagic fisheries of the west coast based on their relationship with the coastal current patterns. He also observed that changes in oil sardine landings seemed to be related to the long-term changes in the wind drifts. Manjusha *et al* (2013), studied the impact of the interannual changes of upwelling on the small pelagics of Kerala, the average chlorophyll a concentrations were compared with the fishery. The catch of small pelagics, especially that of the oilsardine in the Malabar upwelling zone off Kerala, India. The coastal upwelling index (CUI) during south-west monsoon increased by nearly 50% during the period 1998 to 2007. This substantial increase in coastal upwelling index elevated chlorophyll a concentration during monsoon which resulted in an increase of over 200% in annual average chlorophyll a concentration. The increasing coastal upwelling index and chlorophyll a during monsoon sustained an increasing catch of oilsardine during postmonsoon season. The responses of lesser sardine and Indian mackerel, which are midlevel carnivores, were different. The population increases of the oil sardine appear to replace decreases in the lesser sardines and Indian mackerel during the postmonsoon season.

Madhupratap *et al* (2001) addressed the seasonal and spatial variability of the processes controlling the physical, chemical and biological properties of the waters of the west coast of India for the year period 1992-1997, their influence on fish composition, changes in feeding habits between south and north, and speculated on the productivity and its relation to fisheries in the Arabian Sea was studied.A correlation between available environmental datasets (SST, sea bottom temperature, surface salinity, surface dissolved oxygen, bottom dissolved oxygen, pH, nutrients, chlorophyll, zooplankton, rainfall, multivariate El Nino Southern Oscillation index, coastal upwelling index, and derived SST) and sardine catch from the study area vividly segregate the significance of chlorophyll from other environmental factors in explaining the sardine catch from the Malabar upwelling area (Krishnakumar and Bhat, 2008).

Studies on the impact of climate change on fisheries (fish species, stock distribution etc) have been carried out mainly by the CMFRI, Kochi. Investigations carried out by the CMFRI show that different Indian marine species will respond to climate change as follows: (i) Changes in species composition of phytoplankton may occur at higher temperature; (ii) Small pelagics may extend their boundaries; (iii) Some species may be found in deeper waters as well; and (iv) Phenological changes may occur.

a) ***Indian mackerel is getting deeper***: Besides exploring northern waters, the Indian mackerel *R. kanagurta* has been descending deeper as well during the last two decades (CMFRI, 2008). The fish normally occupies surface and subsurface waters. During 1985-89, only 2 percent of the mackerel catch was from bottom trawlers, the remainder was caught by pelagic gear such as drift gillnet. During 2003-2007, however, an estimated 15 percent of the mackerel has been caught by bottom trawlers along the Indian coast. It appears that with the warming of sub-surface waters, the mackerel has been extending deeper and downward as well.

b) ***Small pelagics extend their boundaries***: The oil sardine *Sardinella longiceps* and the Indian mackerel *Rastrelliger kanagurta* accounted for 21 percent of the marine fish catch in 2006. These small pelagics, especially the oil sardine, have been known for 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 SST ranges from 27 to 29°C. Until 1985, almost the entire catch was from the Malabar upwelling zone, there was little or no catch from latitudes north of 14°N. During the last two decades, however, catches from latitude 14°N - 20°N are increasing. In 2006, catches in this area accounted for about 15 percent of the all-India oil sardine catch. The higher the SST, the better the oil sardine catch (Vivekanandan *et al.*, 2009a). The surface waters of the Indian seas are warming by 0.04°C per decade. Since the waters in latitudes north of 14°N are warming, the oil sardine and Indian mackerel are moving to northern latitudes. It is seen that catches from the Malabar upwelling zone have not gone down. Inference: The sardines are extending northward, not shifting northward. The Indian mackerel is also found to be extending northward in a similar way. According to CMFRI, the catch of oil sardines along the coast of Tamil Nadu has gone up dramatically, with a record landing of 185 877 tonnes in 2006. The presence of the species in new areas is a bonus for coastal fishing communities. Assessing their socio-economic needs will greatly help in developing coping strategies for adaptation to climate impacts. WWF is currently documenting community perceptions and experiences in relation to the oil sardine fishery of the eastern coasts.

c) ***Spawning: threadfin breams like it cool***: Fish have strong temperature preferences so far as spawning goes. The timing of spawning, an annually occurring event, is an important indicator of climate change. Shifts in the 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: 35 cm). Data on the number of female spawners collected every month off Chennai from 1981 to 2004 indicated wide monthly fluctuations. However, a shift in the spawning season from warmer to relatively cooler months (from April- September to October-March) was discernible (Vivekanandan and Rajagopalan, 2009). These changes may have an impact on the nature and value of fisheries (Perry *et al.*, 2005). If small-sized, low value fish species with rapid turnover of generations are able to cope up with changing climate, they may replace large-sized high value species, which are already declining due to fishing and other non-climatic factors (Vivekanandan *et al.*, 2005). Such distributional changes might lead to novel mixes of organisms in a region, leaving species to adjust to new prey, predators, parasites, diseases and competitors (Kennedy *et al.*, 2002), and result in considerable changes in ecosystem structure and function.

d) ***Vulnerability of corals***: 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) projected the vulnerability of corals in the Indian Seas. They believe that the coral cover of reefs may soon start declining. The number of decadal low bleaching events will remain between 0 and 3 during 2000-2089, but the number of decadal catastrophic 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. 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 take into consideration only the warming of seawater. Other factors such as increasing acidity of seawater are not considered. If acidification continues in future as it does now, all coral reefs would be dead within 50 years. Given their central importance in the marine ecosystem, the loss of coral reefs is likely to have several ramifications.

Climate change and fishers

In general fisher communities are emotionally attached to their living environment as their livelihood is heavily dependent on sea .The impact of climate change in marine resource users includes, displacement of family members, food security issues, Migration of fisherfolk, fall in income level, seasonal employment, change in employment pattern, increased fishing cost, reduction of fishing days etc.

a) **Demography and Social standards:** Displacement of family members increased over the years, the young generation has a tendency to move out of fishing, Food security issues increased rapidly in recent years. Disguised unemployment is rampant in all sectors since earnings from marine fisheries are not proportionate to the increase in fishers. This has instigated labour migration induced by the earning potential in the distant waters coupled with limited resources in their vicinity.

b) **Infrastructure sensitivity:** Increased frequency and severity of storms or weather, and sea conditions are , unsuitable to fishing as well as damaging to communities on shore through flooding, erosion, and storm damage. There is proximity to hazard areas the fisher household are highly prone to disaster dwellings and the property loss increased over the years.

c) **Income Effect:** The income levels of fishers decreased substantially over the years. The employment pattern has been mostly seasonal, and alternate avocation options are minimal, there is also economic loss due to loss in number of fishing days. Changed fishing ground caused increased cost of fishing and fish storage. The fuel cost, the cost of fishing gear and boat are increasing significantly over the years.

Climate change and displacement

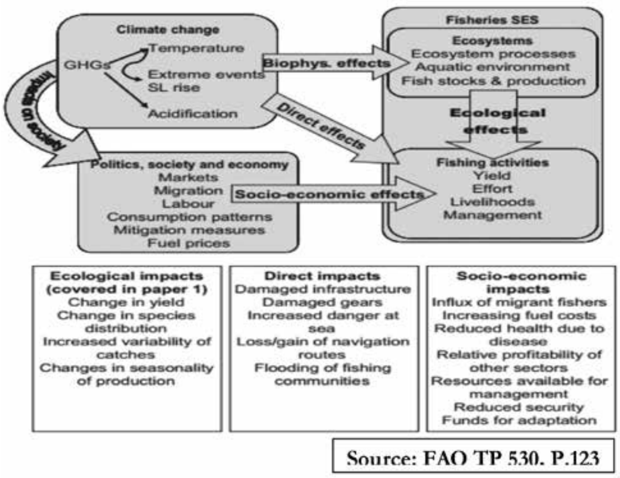

Fig1. Ecological, direct and socioeconomic impacts of climate change on fisheries

The international community now increasingly recognizes that environmental degradation and climate change could potentially result in population displacement on a scale the world is presently ill-equipped to prevent or address in an effective manner. Gradual processes of degradation as well as extreme environmental events can cause migration. Environmental migrants are understood to be those individuals, communities and societies who choose, or are forced, to migrate as a result of damaging environmental and climatic factors. This broad and diverse group ranges from people forced to flee disasters such as flooding to impoverished farmers abandoning degraded land and migrating to urban centres in search of alternative livelihoods.

Poverty, failing ecosystems, vulnerability to natural hazards and gradual climate-driven environmental changes are all linked to environmental migration. The degradation of ecosystems, and/or all evidence points towards climate- and environmentally induced migration becoming one of the major policy challenges of this century. Adequate planning for and management of this phenomenon will be critical for human security. Human security policy challenges demand for resources in excess of available supply, can lead to chronic poverty and hunger, high levels of communicable diseases, conflict and adaptation, or to coping strategies that include temporary or permanent migration.

While natural hazards such as hurricanes and floods can affect entire nations or regions, the most dramatic impacts typically fall disproportionately on the most vulnerable (in terms of location and socio-economic status). In addition, when natural hazards abruptly destroy livelihoods, return, recovery and reintegration are not always possible (http://www.fmreview.org/FMRpdfs/FMR31/FMR31.pdf).

Climate Change and Coastal Communities –Need for awareness

Coasts are experiencing the adverse consequences of hazards related to climate and sea level, extreme events, such as storms, which impose substantial costs on coastal societies. The coastal regions around globe are more prone to the impacts of climate change than the inlands, fishing being one of the primary occupations of the coast, the fishermen community is the most vulnerable group to be affected by the Climate change. Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity. Climate change has the potential to affect all natural systems thereby becoming a threat to human development and survival socially, politically and economically. Beyond basic findings about levels of concern, awareness and belief in human impact on the climate, some recent studies have attempted to delve deeper into public attitudes about climate change. Furthermore, awareness on climate change is a prerequisite to kick start any adaption and mitigation plans and programs in any community. In addition, it is quiet relevant to take advantage of the key informants within the community to disseminate the need for long term and short term adaptation and mitigation options to combat the climate change impacts and thereby making the community more resilient to climate change issues.

Community Perception on climate change

A study was carried out assess the level of awareness of vulnerable fishing communities of Ernakulam district of Kerala, about climate change and to identify the level of adaptation and mitigation strategies available and adopted by them. This was done by carrying out Vulnerability assessments- by employing vulnerability indices and preparing awareness schedules. Across the villages it was found that 98% of the respondents have heard about climate change at a time or the other but however it was found that awareness about climate change was less than 40 percent. There is discrepancy between hearing and awareness about climate change stems from the fact that hearing means it is only superficial knowledge about climate change. The major sources of information about hearing climate change could be different media, friends, relatives etc but awareness involve an in depth understanding about climate change which indicate that the people know the causes , impacts, consequences, the society need and commitment towards its preparedness, adaptation measures etc

The perception of the visible features consequent to climate change is the extent of their agreement to the variables such as Sea level rise, Temperature increase, Change in wind pattern, Extreme weather events, Sea water intrusion, Water scarcity, Property loss, Erratic weather, Diseases etc affected them.

72 percent of the respondents strongly believed that climate change is due to the aftermath of industrialization which can be attributed to urbanization, habitat destruction, pollution and transportation, which they held as equally important sources of causes of climate change.

Respondents' perception on the major impact of climate change on resources including catch reduction, increased efforts in fishing, migration of fishes, varied catch composition, shift in spawning seasons, temporal shift in the species availability, loss in craft and gear, occurrence of invasive species, alterations in fishing seasons, depletion of farm and inventories, non-availability of regular species etc. In the context of the study, resources indicate the fisheries sector and allied activities and the inventories involved. Climate change in every fisherman has a feeling that the fish catch has abridged.

Fisher households are dependent on coastal and marine goods and services to a great extent, which serve as an important indicator as to how sensitive they could be in relation to climate events. There is a close association between climate change issues affecting the fishery resources and resource users. Respondents' perception on major impacts of climate change on resource users include displacement of family members, increase in food security issues, migration of people, substantial reduction in income, seasonality in employment, shift in employment pattern, increased cost of fishing, reduction in fishing days, shift in agriculture crops.

The knowledge on climate change among the respondents of both these villages was very shallow and pertained to short term happenings. Awareness on climate change is a

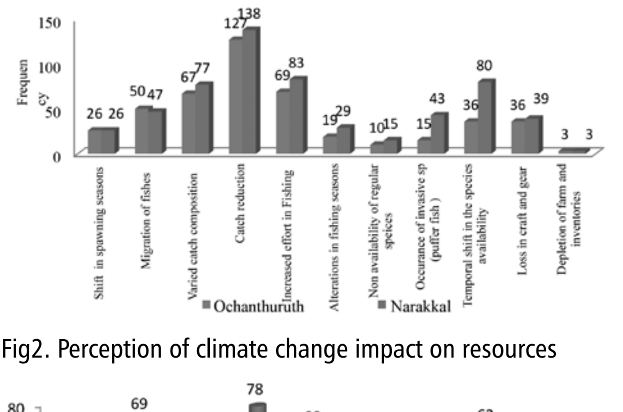

Fig2. Perception of climate change impact on resources

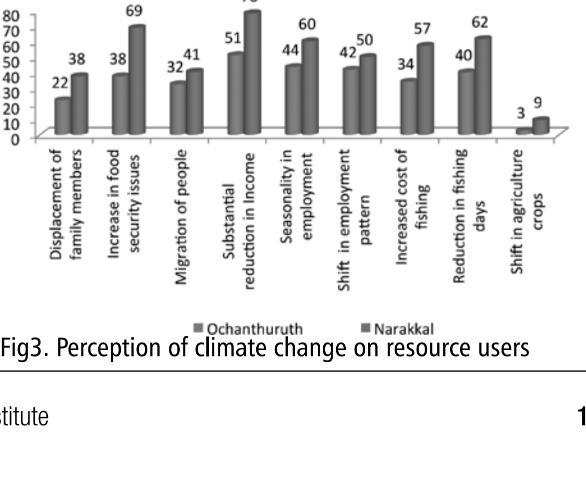

Fig3. Perception of climate change on resource users

prerequisite to initiate steps in combating negative impacts of climate change. Though changing climatic condition is a global concern, the possible mitigation options for improving adaptive capacity needs to be local. An integrated approach comprises of actions for addressing long term and short term concerns of the community, through grass root level actions which would have to be initiated in materializing local solutions to compact the cumulative impact of climate change.

Vulnerabilty assessment , Adpations and Mitigations

Shyam *et al*., 2014 constructed the vulnerability indices using parameter, attribute, resilient indicator and score (PARS) methodology, a conceptual framework developed for assessing the climate change vulnerability of coastal livelihoods.

Vulnerability model

In general the fisher folk of Kerala are emotionally involved in their livelihood activities pertinent to their homestead habitat and are sensitive to the changes in their surroundings. Due

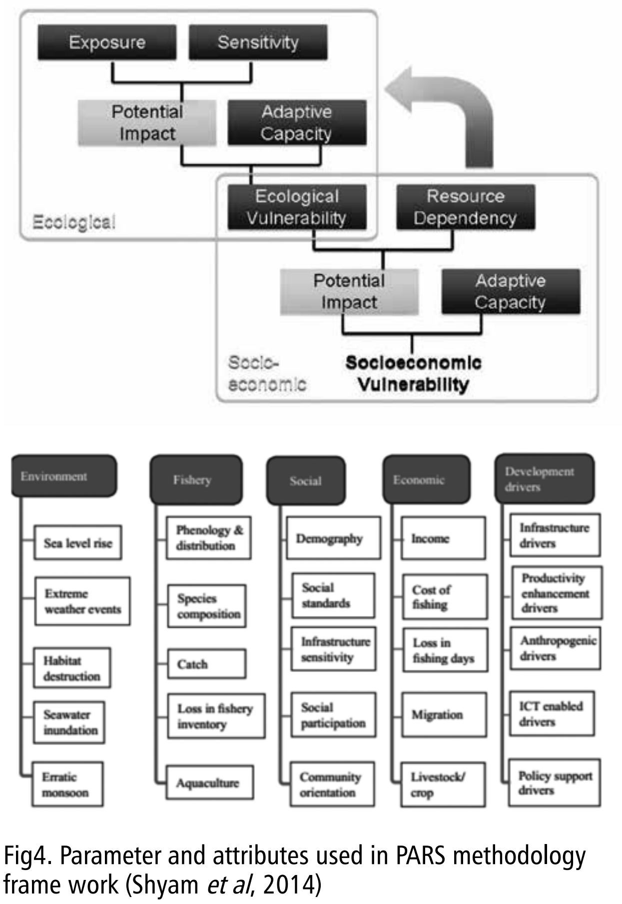

Fig4. Parameter and attributes used in PARS methodology frame work (Shyam *et al*, 2014)

to the lack of awareness about the big picture – The climate change, the fisherfolk are naïve in context to the source of the problems including temperature rise, extreme weather events, reduction in fish catch over years, change in fish composition over years and sea level rise. The process of providing right and comprehensive knowledge on climate change is the need of the hour; this can be achieved through a bottom up approach involving the primary stakeholders along with the community which will eventually position them to adequate climate change adaptation and mitigation by augmenting their traditional knowledge (Shyam S Salim *et al*, 2014).

Adaptation

Options for adaptation are limited, but do exist. The impact of climate change depends on the magnitude of change, and on the sensitivity of particular species or ecosystems (Brander, 2008).

- ***Adapt the Code of Conduct for Responsible Fisheries (CCRF)***:Fish populations are facing the familiar problems of overfishing, pollution and habitat degradation. 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) maximizes sustainable yields, (ii) helps adaptation of fish stocks and marine ecosystems to climate impacts, and (iii) reduces greenhouse gas emission by fishing boats. Some of the most effective actions which we can take to tackle climate impacts are to deal with the old familiar problems such as overfishing (Brander, 2008), and adapt the CCRF and Integrated Ecosystem-based Fisheries Management (FAO, 2007).
- ***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. A specific policy document on 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 to raise awareness of the impact, vulnerability, adaptation and mitigation related to climate change among all stakeholders.
- ***Strategies for evolving adaptive mechanisms***: In the context of climate change, the primary challenge to the fisheries and aquaculture sectors will be to ensure food supply, enhance nutritional security, improve livelihoods and economic output and ensure ecosystem safety. These objectives call for identifying and addressing the concerns arising out of climate change and evolving adaptive mechanisms and implementing action across all stakeholders at national, regional and international levels (Allision *et al*., 2004; Handisyde *et al*., 2005; World Fish Center, 2007; FAO, 2008).
- ***Ecosystem restoration***: A study on the potential impact of climate change on mangroves in India pointed out

hta the large extent of inter-tidal mudflats (about 23,620 km2) in the country may provide a scope of adjustment and adaptation in some areas, mostly in the semi-arid region as in Gujarat. It is expected that the diversity in mangroves may improve at higher latitudes like the Gulf of Kachchh; latitudinal range extension may occur at the expense of salt marsh communities; adaptation and survival chance of mangroves in deltaic region like Sundarbans will be higher than mangroves on Andaman and Nicobar Islands (Singh, 2003).

- Strategies to promote sustainability and improve supplies should be in place before the threat of climate change assumes greater proportion. While the fisheries sector may strive to mitigate climate change by reducing CO2 emissions, especially by fishing boats, it could reduce impact by following effective adaptation measures. There should be fiscal incentives for reducing the sector's carbon footprint, and for following other mitigation and adaptation options.

I)Climate change research - A GULLS initiative

The CMFRI research project on "Global understanding and learning for local solutions: Reducing vulnerability of marine-dependent coastal communities" (GULLS) under the theme on Coastal Vulnerability was sanctioned under an MoU of Belmont Forum and G8 Research Councils International Opportunities Fund. Focus areas of GULLS project include Southern Africa, Southern Australia, Western Australia, Mozambique channel, Southern India and Brazil . The GULLS project will address the Belmont Challenge priorities in the area of coastal vulnerability – specifically the challenges that arise in food security and sustaining coastal livelihoods as a result of global warming and increasing human coastal populations. The project will contribute to improving community adaptation efforts by characterizing, assessing and predicting the future of coastal-marine food resources and identification of suitable adaptation options.

Rationale for selection of the focus area includes Impacts are likely to be observed early, Incentives to initiate adaptive strategies will be strong, Models developed for prediction can be validated early, Adaptation options can be developed, implemented and tested allowing for challenges to be met efficiently and effectively.

Identification of climate change hot spots

Since hot spots in climate change parlance has not been identified yet in Indian context, it is high time to define and identify climate change hot spots in India to initiate comprehensive planning for adaptation and conservation measures. In this context Climate change Hot spots –can be defined as the ''live labs' where the manifestation of the climate change impacts are observed "first ". The identification of the climate change hot spots will help policy makers in priority setting and in planning adaptation and conservation measures

The coastal vulnerability assessment in GULLS project underlines, a demarcation between fishery hotspots (based on fish abundance, phenology, distribution, range shifts, recruitment success etc.) and social hotspots (determining vulnerability, displacement, marginalization of traditional community) would be a novel idea to have representation of diverse factors in the project. Consistent with the objectives of GULLS, the activities will be aiming at assessing the current status of the fishery resources and ecosystem services and would attempt at predicting the future impacts of climate change on these resources and services apart from identification of key vulnerable marine species to climate change and assessing the community vulnerability.

The review done in addition to the discussions with the Belmont team resulted in boiling down the hotpsot region to (South West and South East Region of India).The South East India encompassing Ramanathapuram and Tuticorin districts of Tamil Nadu could be one of the Hotspot and the other be South West India(coastal districts of Kerala including Ernakulum, Alappuzha, Kollam and Trivandrum) with fisheries abundance and distribution shifts.

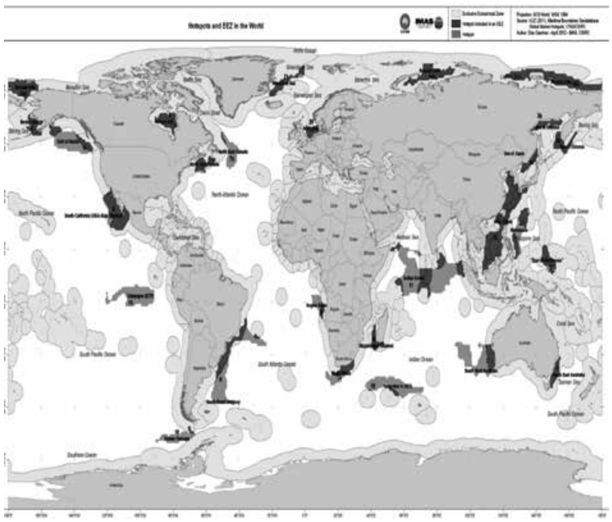

Fig.5. Hemisphere hotspots ocean regions experiencing fast warming and those with heightened social tensions as a result of change.

Vulnerbility Assessment(Modified form IPCC climate change vulnerability frame work)

Vulnerability of coastal regions will be characterized using a linked socio-economic and ecological vulnerability model .The project will be in operation in the different hotspots and will lead to build regional skill-sets that can reduce coastal vulnerability by evaluating and characterizing likely impacts, create predictive systems that will inform decision makers about the expected consequences of coastal changes; deliver alternative options in terms of adaptation and transformation within coastal communities; and to define the long-term implications of selecting a particular option in terms of

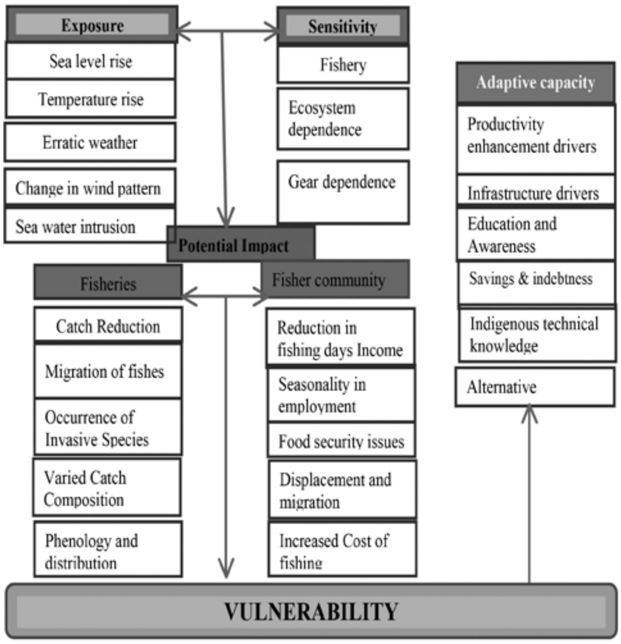

Fig 6 . Conceptual Frame work of GULLS Fisheries Climate Change

economic, social and environmental outcomes.

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