IMPACT OF CLIMATE CHANGE ON FISHERIES SECTOR

Institute for Climate Change Studies

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Institute for Climate Change Studies (ICCS) Kottayam is a research institute which was established under the Department of Environment in 2014 with generous contribution from Government of Kerala. The primary goal of this institute is to understand climate variability, climate change and its impact on the environment. The institute is undertaking outreach activities to create awareness among the people and policy makers about climate change and its consequences. ICCS assists the Government of Kerala in the implementation of State Action Plan on Climate Change. Chief Minister of Kerala is the Chairperson of the Governing Body of ICCS, and the Minister for Environment is the Chairperson of the Executive Committee.

Institute for climate change studies

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CLIMATE CHANGE IMPLICATIONS ON FISH AND FISHERIES: AN OVERVIEW

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Fish serve as a primary source of protein for millions of people around the world, besides contributing to the livelihood of several millions directly or indirectly from activities within the inland and marine fisheries sector. In the recent past the concept of blue growth has gained momentum in many countries, the aim of which is to "secure or restore the potential of the oceans, lagoons and inland waters by introducing responsible and sustainable approaches to reconcile economic growth and food security with the conservation of aquatic resources" (Eikeset et al., 2018). At the same time, one of the major challenges before human societies is to provide food and livelihoods to a population of above 9 billion people by the middle of the twenty-first century, while addressing a series of environmental issues of the modern time, including climate change on the depleting resource base (FAO, 2018).

The global commitments to end poverty and hunger and to ensure, that economic, social and technological progress occur in harmony with nature, through the sustainable management of natural resources, as envisaged in the United Nations Agenda 2030 for Sustainable Development Goals (Barange et al., 2018). Climate change is one of the major challenges facing mankind today, in order to achieve the sustainability of dwindling natural resources that form part of fisheries. The Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC), which came into force on 4th November 2016, is one of the important steps towards addressing the issues of climate change on aquatic resources. The agreement, which aims at keeping the global temperature rise in this century well below 2°C above pre-industrial levels,

recognizes the fundamental priority of safeguarding food security and ending hunger (FAO, 2018).

One of the major challenges in the world, especially in developing countries like India, is to address the issue of sustaining the dwindling fisheries resources, while meeting the challenges posed by emerging external threats on resources such as climate change. In India, fisheries constitute an important economic activity contributing significantly to the national food security, income to the stakeholder community and for earning valuable foreign exchange. India is the second largest fish producing nation in the world and in aquaculture production the country ranks second in the world after China. The sector contributed about 0.9 per cent to the National Gross Value Added (GVA) and 5.43 per cent to the agricultural GVP (2015-16). In Kerala, fishing industry occupies a vital position in its economy. Though the state forms only 1.1 % of the geographic area of India, its long coastline of 590 km, highly productive coastal waters, 44 rivers, extensive backwaters, lakes and other wetlands contribute significantly towards fish production. The total fish production in Kerala during 2016-17 was 6.76 lakh tonnes, of which marine fish landings accounted for 4.88 lakh tonnes and inland fish production was 1.88 lakh tonnes (Economic Review, 2017) (Fig. 1).

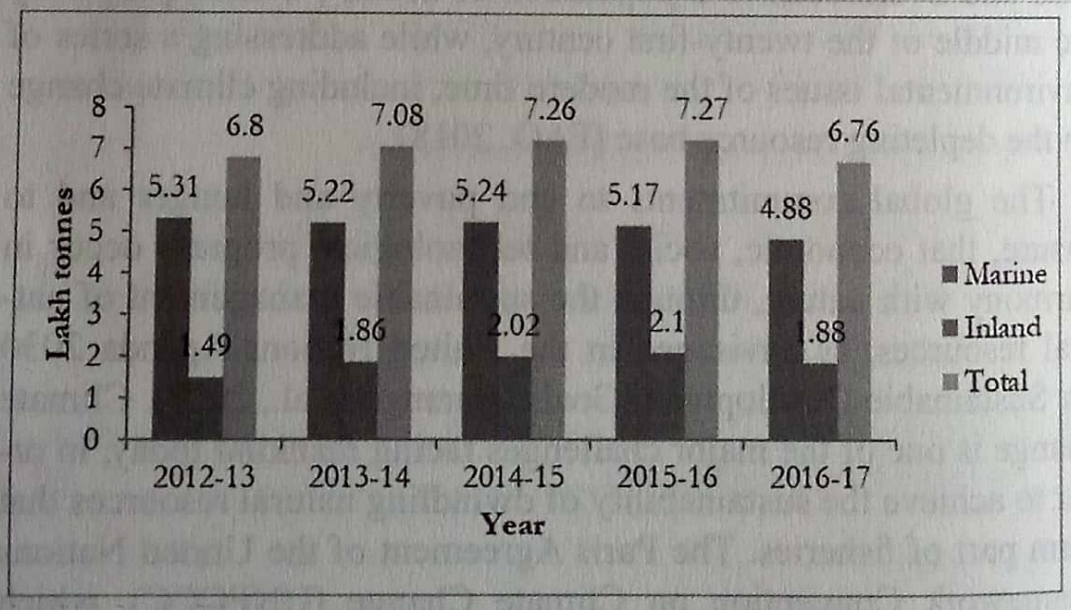

Fig. 1. Trends in fisheries production in Kerala (Source: Economic Review, 2017)

According to the Census of India 2011, the population of Kerala

was 33,406,061, or 2.76 per cent of India's population. The fish worker population of the State in 2016-17 is estimated to 10.29 lakh. Out of this, 7.92 lakh fish workers belong to marine sector while 2.37 lakh fish workers belong to inland sector. The fish worker population is estimated to be around 3.1 per cent of the State's population. They reside in 222 marine fishing villages and 113 inland fishing villages of the State. The number of active fish workers in the State during 2016-17 was 236,300 of which 89 per cent were males (Economic Review, 2017). Fisheries and aquaculture contribute around 8.5 percentage of the Gross State Value Added (GSVA) from the primary sector which is of significance to the State economy. The Gross State Value Added of the State has been increasing over years, but the share of primary sector and that of fisheries sector has been declining. The share of fisheries sector in the State Value Added has declined from 1.12 per cent in 2011-12 to 0.95 per cent in 2016-17 (Economic Review, 2017). Kerala has made vital contributions in the export of marine products from the country. During 2015-16, export of marine products from Kerala was 1,59,141 tonnes valued at 5008.54 crore. However, the share of Kerala in the total export of marine products from India has fallen both in terms of quantity and value in the recent past.

While the promise of fisheries sector towards strengthening economy, poverty alleviation and nutritional security are brighter, the issues of over exploitation, habitat degradation and fragmentation, invasive alien species, pollution and climate change have contributed to the decline in productivity in the sector. The contribution from capture fisheries (fisheries from natural water bodies) is reaching its limits, there is ample scope for expanding aquaculture, both in inland and coastal waters. Therefore, there is an urgent need to assess, to the extent possible, the potential impacts of climate change on fisheries and aquaculture and related well-being of the people who depend on these resources, not to speak of filling the knowledge gap available in the field through intensifying research and strengthening the database.

Impacts on fisheries

Studies around the world have proved unequivocally that aquatic systems that sustain fisheries and aquaculture are undergoing significant changes as a result of global warming and projections

indicate that these changes will be accentuated in the future (Bahri et al., 2018). The main risks of climate change for fisheries and aquaculture are relatively well understood through a series of studies in the west and a few studies done in India (Barange et al., 2018; Biju Kumar and Suvarna Devi, 2019; Krupa et al., 2019; Vivekanandan, 2013, 2019; Zacharia et al., 2019, in this issue). A number of marine species, depending on their mobility and habitat connection, are responding to climate impacts by shifting their distributions poleward and to deeper waters (FAO, 2018). Further, increased uptake of carbon dioxide by oceans may result in ocean acidification, which will of concern for all organisms with a calcareous exoskeleton (e.g. Planktonic forms such as cocolithophores, corals, molluscs) in both feral water bodies and in culture systems. The impacts of ocean acidification on ecosystem is still inconclusive and such studies are at its infancy in India. Competition for water, changes in the water cycle, increased frequency of storms and sea level are all expected to affect both inland fisheries and aquaculture industries (Seggel, De Young and Soto, 2016).

Climate change is projected to affect individual organisms, populations, species distributions, and ecosystem composition and function both directly (e.g., through vagaries in precipitation, temperature, sea level changes, ocean acidification, etc.) and indirectly (e.g., through climate changing the intensity and frequency of events such as forest fires, storms, etc.). Evidence of climate-change impacts is strongest and most comprehensive for natural systems and it impacts lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system (Field et al., 2014).

Changes in stream flow, floods, droughts, water temperature, and water quality have been observed and they have affected biodiversity and the goods and services ecosystems provided by the freshwater ecosystems (IPCC, 2002). Gosain et al. (2011) projected the impact of climate change on the 17 most important river basins in India up to mid-century and towards the end of the century. They estimated a decline in rainfall in 14 out of the 17 river basins towards the 2030's and the 2080's. In almost all river basins rainfall declines from 4% to 23%, following changes in precipitation, resulting in

decline in water yield in river basins. Rajendran et al. (2013) projects spatially heterogeneous increase in warm days and extreme hot events over India; projected changes in extreme rainfall events (above 95 percentile) show intensification of extreme rainfall over most parts of India by the end of the century with opposite change over the west coast. The reduction in surface water availability may influence hydropower generation and environmental flow in river basins (INCCA, 2010). All these would ultimately impact fisheries.

Altered water temperature due to global warming also impact water quality and in reservoirs and lakes it influences the potential for algal blooms, which can further reduce oxygen levels (IPCC, 2014). Climatic variables such as air temperature and precipitation affect environmental flows in rivers and the mobility and dilution of contaminants, affect concentrations of suspended sediment, and nutrients in rivers and lakes, hence affecting water quantity as well as the fishery resources therein. Increase in river water temperatures are likely to affect fish breeding, migration, and harvests, as many endemic species have restricted distribution, especially in biodiversity hotspots such as the Western Ghats.

Climate change may affect the hydrology and fisheries of inland waters through increased precipitation, air temperature, and decrease in water quality. Climate change will affect the productivity of the world's freshwater and marine fisheries, and the impacts on inland sector will be connected to the scarcity and quality of water of natural water bodies; in the aquaculture sector, the short-term climate change can include losses of production and infrastructure arising from extreme events such as floods, increased risks of diseases, parasites and harmful algal blooms, and the long-term impacts can include reduced availability of wild seed as well as reduced precipitation leading to increasing competition for freshwater (Barange et al., 2018). Fisheries and aquaculture too contribute to climate change by altering mangroves and coastal wetland ecosystems, and also consume energy required for the production of processed feeds and also to pump water.

The extreme climatic events such as the massive floods that happened in Kerala in 2018 would also impact fisheries and aquaculture. The flood has resulted in the massive spread of exotic species (including those cultivated illegally in the flood plains of rivers such

as the East African catfish), silting rivers and changes in the micro-environments which fish used to breed, huge losses in cage culture systems in rivers and lakes and mortality of clams in the estuarine and backwater areas due to severe freshwater runoff. Climate change would also affect inland fisheries which are artisanal fisheries due to changing water levels and increasing occurrence of dry spells as well as flooding. Climate change also causes increase in vaporization, turbidity, reduced solar radiation reaching water bodies resulting in plankton blooms leading to water pollution, run-off due to flooding creating damages to cages and loss of livelihood of fish farmers (Anyanwu et al., 2014). Rise in temperature due to climate change cause stress in fish and cause diseases.

In the marine environment, the impacts of climate change on productivity is an area of concern. Primary production of the global ocean, on which the marine food web and ultimately fish rely, is expected to decline by 6 percent by 2100 and by 11 percent in tropical zones (Kwiatkowski et al., 2017). Diverse models predict that by 2050, the total global fish catch potential may vary by less than 10 percent (Barange et al., 2014; Cheung et al., 2010), under various climate change scenarios, and the impacts will be predominantly negative in the many fisheries-dependent tropical regions (Barange et al., 2014)

Changes in precipitation frequency and intensity coupled with variations in pH, water temperature, wind, dissolved oxygen, dissolved CO_2, salinity variations and pollution may lead to poor water quality of marine ecosystems. Human activities, particularly increased nutrient stacks that set in motion a cascading chain of events identified with eutrophication, accelerate development of hypoxia (lower down oxygen concentration) in numerous territories of the world's coastal oceans. The changed environmental conditions could favour the growth of Harmful Algal Blooms (HABs). Increase in HABs may negatively impact the environment, human health, and economy of the communities (Wells et al., 2015). Occurrence, increase in frequency, intensity and spatial coverage of harmful algal blooms in the EEZ of India indicated a sharp increase, with the frequent contribution of toxic species such as *Alexandrium spp., Gymnodiniumspp., Dinophysis spp., Coolia monotis, Prorocentrum lima, and Pseudonitzschia spp.* (Padmakumar et al., 2012).

It was generally held that there is an increase in the biomass of

phytoplankton during the recent decades in western Indian Ocean as a result of climate change and global warming. However, the current study points out a disturbing decrease of up to 20 percent in phytoplankton in this area in the course of recent 6 decades and these trends in chlorophyll are driven by enhanced ocean stratification because of quick warming in the Indian Ocean, which suppresses nutrient mixing from subsurface layers. Future climate projections suggest that the Indian Ocean will continue to warm, driving this productive region into an ecological desert (Roxy et al., 2016). Coastal freshwater wetlands may be vulnerable to saltwater intrusion with rising sea-levels, but in most river deltas local subsidence for non-climatic reasons will be more important (Syvitski et al., 2009). Humans have been the primary drivers of changes in coastal aquifers, lagoons, estuaries, deltas and wetlands and are expected to further exacerbate human pressures on coastal ecosystems resulting from excess nutrient input, changes in run-off and reduced sediment delivery (IPCC, 2014).

Studies on the impact of climate change on fisheries carried out by the Central Marine Fisheries Research Institute (CMFRI) show that different Indian marine species respond to climate change as follows: (i) Small pelagic fishes may extend their boundaries, (ii) Some species may migrate to deeper waters as well, and (iii) Phenological changes. The major pelagic species that represent major portion of marine fish landings in Indian coast are the oil sardine *(Sardinella longiceps)* and the Indian mackerel *(Rastrelliger kanagurta)*, contributing up to 40 % marine fisheries. The oil sardine is restricted in 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. While almost the entire catch of oil sardine was from the Malabar upwelling zone till 1985, their landings from latitude 14°N - 20°N are consistently increasing in the last few decades (Vivekanandan et al., 2009).

The cyclone Ockhi devastated the life of fishermen in Kerala, killing over 350 people from southern Tamil Nadu and Kerala between 30 November and 3 December 2017. The causalities and the impact of livelihoods of fisher folks in the state due to extreme climate events like Ockhi points towards the need to improve

disaster risk management and disaster risk reduction framework to reduce the vulnerabilities of coastal fishing communities (Lakshmi, 2018). Further, such studies reiterate the need for a multiprolonged approach to reduce economic and social damages including the loss of human life.

The general implications of climate change on coastal and marine ecosystems are represented in Fig. 2.

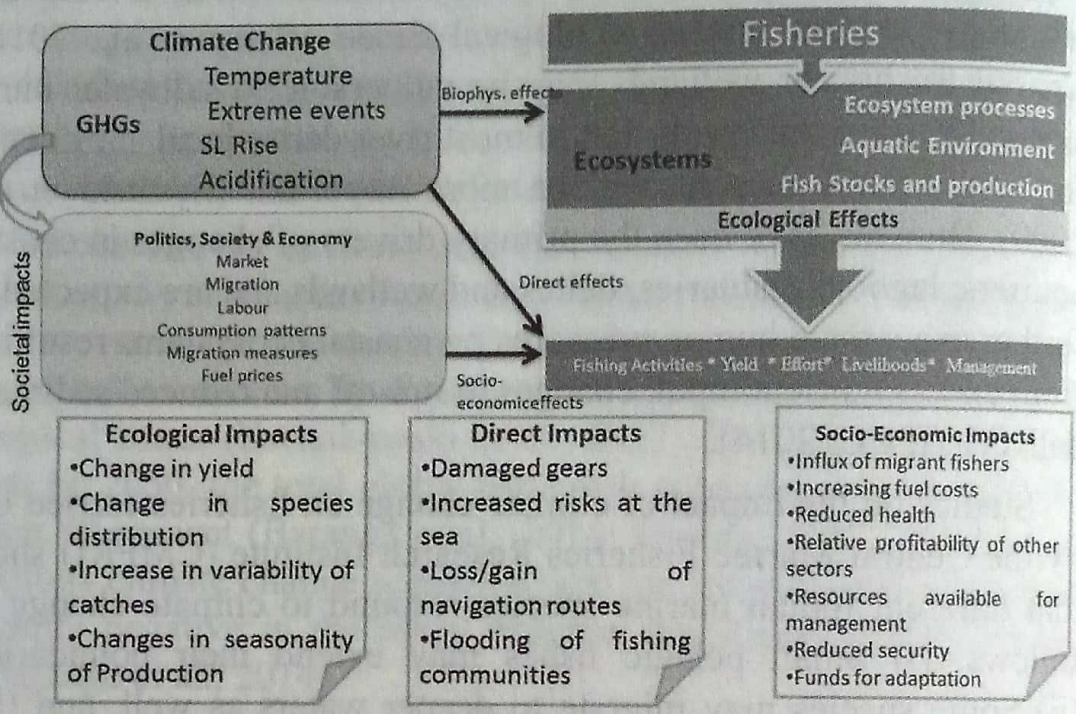

Figure 2. Impacts of climate change on coastal ecosystems and fisheries

Strategies to Combat Climate Change

Climate change includes complex associations between climatic, environmental, economic, political, institutional, social, and technological procedures. It cannot be tended to or comprehended in detachment of more extensive societal objectives, (such as equity or sustainable development), or other existing or probable future sources of stress. Strategies to reduce climate change impacts on fishery resources therefore include a mixture of adaptation and mitigation measures such as containing human population growth, reducing greenhouse gas emissions as per agreed targets, promotion of bioresources to ensure carbon capture, addressing pre-existing stressors on biodiversity, taking adequate steps to adapt to climate

change and to improve conservation efforts by expanding protected areas for conservation of fishery resources.

The IPCC defined adaptation as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploits beneficial opportunities. Adaptation is also defined as an understanding of how individuals, groups and natural systems can prepare for and respond to changes in climate or their environment and is crucial to reducing vulnerability to climate change. Aquatic biodiversity and healthy well-functioning ecosystems provide natural solutions that build resilience and help society adapt to the adverse impacts of climate change. They also support poverty alleviation by giving more secure and more secure livelihoods, particularly for poor people and vulnerable. With climate change already well underway and further change unavoidable, adaptation is gaining significantly more focus, especially in countries like India where the economy is dependent on climate sensitive sectors.

FAO outlines the categories of adaptation in fisheries and aquaculture, which include institutional adaptation, livelihoods adaptation, and risk reduction and management for resilience (Poulain et al., 2018). The possible adaptations tools in capture fisheries is given in Table 1.

Table 1. Few adaptation tools and approaches in capture fisheries (Modified from Poulain et al., 2018)

INSTITUTIONS
● Public investments (e.g. research, capacity building, sharing best practices and trials, communication)
● Climate change adaptation policies and plans address fisheries
● Provide incentives for fish product value addition and market development
● Address poverty and food insecurity, which systemically limit adaptation effectiveness
● Restricting access to resources to fisher community
● Adaptive control of fishing pressure by regulating number of vessels

- Effective arrangements for stake holder's engagement
- Awareness raising and capacity building to integrate climate change into research/management/policy/rules
- Inclusion of climate change in management practices including co-management
- Inclusion of climate change in integrated coastal zone management (ICZM)
- Ensuring water management and minimum environmental flow (Inland systems)
- Enhanced resilience by reducing other non-climate stressors (e.g. habitat destruction, pollution)
- Incorporation of traditional knowledge in management and conservation
- Management/protection of critical habitats for biodiversity and recruitment

LIVELIHOODS

- Diversification of markets/fish products based on consumer demands
- Improvement or change post-harvest techniques/practices and storage
- Improvement of product quality: eco-labelling, reduction of post-harvest losses, value addition
- Diversify patterns of fishing activities with respect to the species exploited, location of fishing grounds and gear used to enable greater flexibility
- Livelihood diversification (e.g. switching among rice farming, tree crop farming and fishing in response to seasonal and inter-annual variations in fish availability)
- Risk insurance, improved financial security, social protection and safety nets
- Extreme weather and flow forecasting, early warning systems
- Monitoring climate change trends, threats and opportunities (e.g. monitoring of new and more abundant species)
- Risk assessment to identify risk points

Safety at sea and vessel stability

- Reinforced barriers to provide a natural first line of protection from storm surges and flooding
- Climate resilient infrastructure (e.g. protecting harbours and landing sites)
- Address underlying poverty and food insecurity problems
- Rehabilitate ecosystems
- Compensation (e.g. gear replacement schemes)

Biodiversity, including fishery resources, is linked to climate change adaptation in through three ways. First, it can play a role in societal adaptation and ecosystem-based adaptation can provide cost-effective strategies across the major sectors involved in adaptation (e.g. coastal defense, water sector, agriculture, etc.). Second, societal adaptation strategies can have significant impacts on bioresources and these impacts are negative, but where appropriate natural resource management is used, for example in improved fishery and aquaculture practices, adaptation strategies may prove beneficial for sustaining fishery (CBD, 2009). Third, conservation of fishery resources itself is a sector that requires its own adaptation strategies. Such strategies, which involve improved protected area design, maintaining habitat connectivity in the river flood plains and ensuring minimum environmental flow, and reducing other anthropogenic pressures, are likely to increase the resilience of aquatic biodiversity to climate change (CBD, 2009). Adaptation activities can also threaten the fisheries and fishery-related activities either directly through the destruction of habitats (e.g. building sea walls), thus affecting coastal ecosystems, or indirectly through the introduction of new species or changed management practices such as aquaculture.

Since the frequency of extreme climatic events may increase in future under the climate chance scenario, there should also be efforts to safeguard the lives and livelihoods of fishermen in Kerala. The recent incidences of cyclones such as Ockhi and massive floods are pointers towards this. The disaster risk management and disaster risk reduction framework should be strengthened in fisheries sector to reduce the vulnerabilities of coastal fishing communities. Periodic awareness and training programmes in

disaster preparedness guided by community-based disaster management approach are recommended to circumvent the issues, besides utilizing the traditional knowledge of fishers in identifying likely fishing zones during search and rescue operations by the Coast Guard and Navy (Lakshmi, 2018).

In terms of management of fishery resources and the guidelines in support of implementation of the FAO Code of Conduct for Responsible Fisheries are all relevant to the application of Ecosystem Approach to Fisheries and Aquaculture (EAF/EAA). The major features of the ecosystem approach to fisheries and aquaculture include participatory risk-based management process adapted to the fisheries and aquaculture sectors (FAO, 2018). In Kerala also, this approach would become necessary to ensure wide stakeholder participation at all levels of planning and implementation and comprehensive and explicit consideration of all key components of a fishery or aquaculture system (ecological, social, economic and governance) as well as external drivers such as climate change (FAO, 2018). Moreover, to frame effective adaptation measures, we need primary investigations on the impact of climate change in both inland and marine fishery sectors, and to fill the knowledge gaps. There should be awareness programmes to make the stakeholders aware of the ecological, economical and social implications of climate change on fisheries and aquatic ecosystems.

In short , the advantages of activities can be accomplished through: maintaining and restoring local ecosystem; securing and upgrading ecosystem services; actively preventing and controlling obtrusive alien species; managing habitats for rare, threatened and endangered species; creating agro forestry frameworks at transition zones; paying attention to traditional knowledge; and monitoring results and changing management regimes accordingly. Adaptation activities that can be advantageous to biodiversity include the establishment of a mosaic of interconnected terrestrial, freshwater and marine multiple use reserve protected areas designed to take into account projected changes in climate, and integrated land and water management activities that reduce non-climatic pressure on the aquatic resources and thus make the framework less vulnerable against changes in climate.

The way forward

Fisheries and related activities, including aquaculture in inland and marine sectors offer livelihoods to thousands of people in Kerala, besides contributing significantly to economic and nutritional security of the state. There are unequivocal evidences to establish the possible impacts of climate change in the fisheries sector, and though there are only few case studies in Kerala, the predicted impacts would not only affect fisheries, but also livelihoods of thousands of people depending on the sector directly or indirectly. The ecosystem changes related with climate change would also impact sustainability of fisheries. In Kerala, there should also be efforts to reduce poverty and marginalization of the fisher folk, as these causes may enhance their vulnerability and impact their resilience to climate change. Therefore, the efforts to adapt to and mitigate climate change should be planned and implemented with full consideration of this complexity and how any new interventions will affect not only the immediate targets of the actions but the system as a whole. The failure to envisage the complexity of the issue and knowledge gap prevailing on local situations would not only lead to maladaptation, but also exacerbate the impacts of climate change.

References

1. Anyanwu, C. N., D. I. Osuigwe, and G. S. Adaka. "Climate change: impacts and threats on freshwater aquaculture." (2013): 72-75.
2. Bahri, T., Barange, M. and Moustahfid, H. 2018. Climate change and aquatic systems. In: Barange et al., Eds). Impacts of climate change on fisheries and aquaculture: synthesis of current knowledge, adaptation and mitigation options. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO.
3. Barange, M., et al. "Impacts of climate change on fisheries and aquaculture: synthesis of currrent knowledge, adaptation and mitigation options." FAO Fisheries and Aquaculture Technical Paper (FAO) eng no. 627 (2018).
4. Barange, M., et al. "Impacts of climate change on marine ecosystem production in societies dependent on fisheries." Nature Climate Change 4.3 (2014): 211.

5. Biju Kumar, A. and Suvarna Devi, S. 2019. Climate change, freshwater ecosystems and inland fisheries: implications for Kerala. Institute for Climate Change Studies, Kottayam, Kerala.

6. Bindoff, Nathaniel L., et al. "Detection and attribution of climate change: from global to regional." (2013).

7. Cheung, William WL, et al. "Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change." Global Change Biology 16.1 (2010): 24-35.

8. Economic Review (2017). State Planning Board, Government of Kerala, Thiruvananthapuram (http://spb.kerala.gov.in/ER2017/)

9. Eikeset, Anne Maria, et al. "What is blue growth? The semantics of "Sustainable Development" of marine environments." Marine Policy 87 (2018): 177-179.

10. FAO. 2018. The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals. Food and Agricutlure Organisation, Rome,.

11. Field, Christopher B., et al. "Cambio climático 2014 Impactos, adaptación y vulnerabilidad." (2014).

12. Gosain, A. K., Sandhya Rao, and Anamika Arora. "Climate change impact assessment of water resources of India." Current Science (2011): 356-371.

13. Indian Network for Climate Change Assessment, and India. Ministry of Environment. Climate Change and India: A 4 X 4 Assessment, a Sectoral and Regional Analysis for 2030's. Vol. 2. Ministry of Environment & Forests, Government of India, 2010.

14. Intergovernmental, P. "Climate Change and Biodiversity (IPCC Technical Paper V)." (2002).

15. Kripa, V., Jeyabasker, R., Padua, S., Prema, D. and Mohamed, K.S. 2019. Climate related "Ocean drought' and impacts on Indian sardine fishery of Kerala. Institute for Climate Change Studies, Kottayam, Kerala.

16. Kwiatkowski, Lester, et al. "Emergent constraints on projections of declining primary production in the tropical oceans." Nature Climate Change 7.5 (2017): 355.

17. Lakshmi, Ahana. "Report of the national workshop on small-scale fisheries, Cyclone Ockhi and disaster risk management 29 to 30 May, 2018, Thiruvananthapuram, Kerala, India." (2018).

18. Pachauri, Rajendra K., et al. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. IPCC, 2014.

19. Padmakumar, K. B., N. R. Menon, and V. N. Sanjeevan. "Is occurrence of harmful algal blooms in the exclusive economic zone of India on the rise?." International Journal of Oceanography 2012 (2012).

20. Poulain, Florence, Amber Himes-Cornell, and Clare Shelton. "Methods and tools for climate change adaptation in fisheries and aquaculture." Impacts of climate change on fisheries and aquaculture: 535.

21. Rajendran, K., et al. "How dependent is climate change projection of Indian summer monsoon rainfall and extreme events on model resolution?." Current science (2013): 1409-1418.

22. Roxy, Mathew Koll, et al. "A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean." Geophysical Research Letters 43.2 (2016): 826-833..

23. Secretariat, C. B. D. "Connecting biodiversity and climate change mitigation and adaptation: Report of the Second Ad Hoc Technical Expert Group on biodiversity and climate change, Montreal." Convention on Biological Diversity Technical Series. Vol. 41. 2009.

24. Solomon, Susan, et al. "Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change." (2007).

25. Vivekanandan, E. "Climate change: Challenging the sustainability of marine fisheries and ecosystems." Journal of Aquatic Biology and Fisheries 1.1 & 2 (2013): 54-67.

26. Vivekanandan, E. 2019. Potential adaptation and mitigation options in marine fisheries sector in Kerala to cope up with the impact of climate change. Institute for Climate Change Studies, Kottayam, Kerala.

27. Vivekanandan, E., M. Rajagopalan, and N. G. K. Pillai. "Recent trends in sea surface temperature and its impact on oil sardine." (2009): 89-92.

28. Zacharia, P.U, Rojith, G. and Sajna, V.H. 2019. Implications of monsoon variability on Indian marine fisheries in the context of climate change. Institute for Climate Change Studies, Kottayam, Kerala.