CLIMATE CHANGE IMPACTS IN FISHERIES AND AQUACULTURE: CASE STUDIES FROM NORTHERN INDIAN OCEAN REGION

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Introduction

The impact of climate change on food production and security is a global concern, particularly in vulnerable regions. The recent report from the Intergovernmental Panel on Climate Change (IPCC) underscores the increasing pressure that climate change will exert on food systems, posing significant challenges to both fisheries and aquaculture. This phenomenon is particularly pronounced in the Afro-Asian perspective, where communities are highly dependent on aquatic resources for sustenance and livelihoods. The IPCC report highlights the risks to food security and nutrition due to the anticipated changes in climate. It points to the intensity, and severity of extreme weather events, such as droughts, floods, and heatwaves, which will increase vulnerabilities in regions (Shafeeque *et al.* 2021) already facing food security challenges. Moreover, the ongoing sea level rise further intensifies these risks, particularly in low-lying coastal areas that are hotspots for fisheries and aquaculture activities. From the Afro-Asian perspective, the implications of climate change on food security are of profound concern. The report underscores those vulnerable regions, including Sub-Saharan Africa and South Asia, are at a high risk of food insecurity, malnutrition, and micro-nutrient deficiencies, especially as global warming exceeds 2 °C (IPCC 2022). This discussion seeks to explore the specific challenges faced by Afro-Asian communities engaged in fisheries and aquaculture in the context of climate change. It aims to explore the unique vulnerabilities of these regions, address the potential consequences on food security and nutrition, and propose mitigation measures that align with the socio-economic and environmental contexts of these communities.

Importance of fisheries and aquaculture

Fisheries and aquaculture hold immense significance in the Afro-Asian context, with distinct contributions and challenges in Africa and Asia. In Africa, fisheries play a vital role in societal and nutritional aspects. The sector contributes significantly to food and nutrition security, providing jobs, particularly for coastal populations, who are often the most economically challenged. Globally, fish and fish products account for 18% of animal protein intake, emphasizing their nutritional importance. However, the growing population and per capita income in Africa are projected to increase fish demand by 30% by 2030. Without effective management, climate change intensifies these challenges, impacting sea temperatures, weather conditions for fishers, and fish migration patterns. Moreover, fisheries contribute significantly to Africa's economy, directly adding $24 billion to the GDP in 2011. The sector employs over 12 million people, with a noteworthy 59% of processing work performed by women (World Bank).

In Asia, fish and seafood have been a crucial part of the region's food culture. While historically dominated by capture fishing, Asia has witnessed a substantial shift towards aquaculture. In 2018, 46% of total fish

production and 52% of human consumption originated from aquaculture, marking a significant transformation. Asia, led by the People's Republic of China, has become a powerhouse in aquaculture, commanding 87.9% of global production in 2018 (Suzuki, 2021). The growth of aquaculture in Asia is attributed to the conversion of agricultural land, technological advancements, and production intensification. This shift not only meets the nutritional needs of the population but also serves as a vital livelihood for numerous communities. However, the rapid expansion raises concerns about sustainability, necessitating careful management to balance economic growth with environmental conservation.

In both Africa and Asia, fisheries and aquaculture play pivotal roles in supporting livelihoods, ensuring food security, and contributing significantly to the economies of the respective regions. Managing these resources sustainably is crucial to addressing the challenges posed by climate change, population growth, and evolving consumption patterns.

Impact of climate change on fisheries and aquaculture

The absence of comprehensive scientific information poses a significant challenge for policymakers in elucidating the potential impacts of climate change on marine ecosystems in the future, as well as formulating effective mitigation measures. Consequently, Gopalakrishnan *et al.,* (2020) endeavour to fill this knowledge gap by quantifying anticipated alterations in key climate variables within the northern Indian Ocean. By incorporating globally recognized climate change model results, the study aims to delineate future challenges faced by marine ecosystems in this region. Long-term forecasts, encompassing major environmental variables such as Sea Surface Temperature (SST), pH, mean sea level, sea surface salinity, rainfall, and chlorophyll, are systematically examined to assess changes and their plausible effects on marine flora and fauna. The discussion extends to the cascading impacts of productivity changes, the vulnerability of sensitive ecosystems like coral reefs, and the broader social and community repercussions of these changes. In addition, the study presents notable changes observed in marine resources over the last two decades, with projections extending to 2030, 2050, and 2080, allowing for a comprehensive temporal assessment. The findings and proposed adaptation strategies outlined in the study are imperative considerations for the existing organizational and institutional frameworks governing the country, offering a scientific guideline for the effective implementation of measures to address the challenges posed by climate change in fisheries and aquaculture within the northern Indian Ocean region.

Brief overview of the impacts of climate change on marine ecosystems and fisheries

Impacted variables	Intermediate biophysical process	Biological impacts	Fisheries impacts
Rise in SST	Change in El Niño & La Niña; change in current and water mass movement, density		Commercially important species may be replaced by low-priced species
Changes in Salinity		Changes in distribution and abundance of species, phenology, growing and breeding seasons, feeding habits and deformities.	Reduction in overall catch of marine fishes

Decrease in pH	Ocean acidification		Affects the growth and catch rate of pelagic fishes
Changes in rainfall patterns	Alters the hydrology of estuarine ecosystems	Alters the nutrient composition, diatoms and planktons	Economic drain on fisherman
Frequency of storms / cyclones	Destruction of corals, vessels, fishing equipment and infrastructure on the coasts, breaking of vertical stratification where coastal upwelling is absent.		
Changes in chlorophyll composition	Inundation of coastal habitats such as mangroves, seagrass beds		
Rise in Sea level	Inundation and physical impacts on coastal areas	Alters critical habitats and community structure	Rehabilitation of fishermen into inland areas

Impact on fisheries

A study on Indian mackerel conducted in the south-eastern Arabian Sea off the coast of Kerala, India, revealed substantial negative effects of sea surface temperature (SST) and sea surface salinity (SSS), while highlighting the notable positive influence of precipitation (Pr) on the weighted Catch Per Unit Effort (CPUE) of Indian mackerel. These results provide valuable insights into the intricate interplay between environmental variables and fishery dynamics in the region (Zacharia *et al.,* 2020). To assess the impacts of climate change on fisheries, a study utilized a combination of observational data and a two-dimensional numerical model. The investigation focused on elucidating the outcomes of fish eggs released in the Gulf of Kachchh. Treating fish eggs as passive particles in the model, they were released from identified probable spawning sites, as determined through exploratory surveys (George *et al.,* 2011). Investigations conducted on the Saurashtra coast in Gujarat regarding the distribution and community structure of Zoanthids have revealed a notably higher adaptive capacity to environmental and abiotic changes compared to their counterparts. Despite the ongoing challenges faced by coral reefs, including elevated nutrient inputs, bleaching, and other anthropogenic activities, there is evidence of a shift in reef patterns toward more resilient and rapidly growing benthic communities, exemplified by the prevalence of zoanthids (Kumari *et al.,* 2015).

Impact on aquaculture

The estimated global production of aquatic animals reached 178 million tonnes in 2020, with aquaculture playing a significant role by contributing 88 million tonnes, representing 49 per cent of the total production (SOFIA, 2022). The shift from less than 20% to just below 50% contribution to food fish supply from

aquaculture between 1970 and 2020 underscores its growing importance. Fish being poikilothermic, is highly susceptible to temperature variations. While rising sea temperatures initially boost mariculture production, adverse effects emerge at higher temperatures. Studies on silver pompano growth reveal defects at temperatures exceeding 31°C. Increased temperatures alter hydrology, leading to algal blooms and red tides, limiting species suitable for cultivation. Changes in water temperatures and associated physical changes elevate disease risks. Future modifications to ocean upwelling systems may have profound effects on biogas emissions and production losses in aquaculture farms. Extreme climatic events, such as floods, droughts, and cyclones, pose threats to brackish water aquaculture. Damage to infrastructure, changes in salinity, and introduction of diseases result in yield reduction and crop losses. Risk assessments in coastal states reveal seasonal variations causing 20-40% production loss, while extreme weather events can lead to 50-100% loss (Zacharia *et al.,* 2016).

Impact on fishing communities

Sea level rise and abnormal weather events present significant risks for vulnerable coastal communities. A rise of 30 cm in sea level can cause 45 m of landward erosion in some coastal areas of Asia (IPCC, 2007). Small-scale fisheries, comprising artisanal and subsistence fishers, are most susceptible to climate change effects due to their low and irregular income. Economic effects on this sector may hinder its ability to contribute to overall fisheries output, necessitating aid and assistance programs. The multifaceted impact of climate change on fisheries and aquaculture in India emphasizes the urgency for adaptive strategies, sustainable practices, and effective policies. As climate change continues to unfold, the resilience of these sectors will depend on collaborative efforts from government institutions, stakeholders, and the global community.

Strategies for climate change adaptation in fisheries and aquaculture

Climate change has far-reaching implications, necessitating the development and implementation of management plans to enhance the resilience of various aquatic systems, including fresh, cold-water, brackish, inland, and marine environments. Additionally, the infrastructure supporting these systems requires resilience to ensure sustainable utilization by stakeholders. A comprehensive action plan is essential, incorporating targeted scientific approaches, robust coastal ecosystems, community and industry collaboration, and the integration of climate-sensitive technologies with reduced carbon footprints.

Adaptation strategies for fisheries habitat

To improve conservation, management, and sustainable utilization of aquatic resources, habitat mapping should be extended, focusing on both commercial and vulnerable species. The development of regional and species-level models, considering oceanic and climatic parameters, enables the prediction of quantitative changes in climatic stressors. A study conducted by Akhiljith *et al.,* 2019 projects climatic variations in the Indian Ocean for 2030, 2050, and 2080, focusing on key variables such as Sea Surface Temperature (SST), Sea Surface Salinity (SSS), Sea Level Rise (SLR), Precipitation (Pr), and pH. The findings indicate an increasing trend in SLR and SST, with potentially negative implications on marine fisheries due to elevated temperatures, while changes in SSS, SLR, and precipitation pose challenges for aquaculture systems, affecting water quality, spawning, and seed availability. Continuous monitoring of habitat changes enhances adaptation and management of fisheries habitat, with a focus on improving resilience. Mangrove ecosystems, acting as significant habitats for aquatic species, play a crucial role in coastal resilience. Mapping, conserving, and restoring mangrove ecosystems can enhance productivity, providing breeding and nursery grounds for valuable biota. Mangrove planting in aquaculture ponds contributes to stress reduction from high temperatures and supports artisanal aquaculture activities.

Adaptation strategies for fishery stocks

Enhancing the resilience of fish stocks to recover from population collapses involves stock modelling. Collaboration with research institutions is essential for effective implementation, contributing to the sustainable management of fishery stocks. The harvesting sector faces challenges attributed to climate change and stock distribution. To ensure sustainable fishing practices, the implementation of MLS (Minimum Legal Size), setting the minimum size for legally retained species, is advocated (see Mohamed *et al.,* 2014, MLS advisory for Kerala). This approach aims to balance fishing pressure on vulnerable populations. Considering alternative energy usage in fishing operations is essential, but cautious implementation is emphasized due to the fisheries sector's direct contribution to food security. Green fishing protocols should be explored to reduce the sector's carbon footprint while maintaining its vital role in providing nutrition.

Adaptation in aquaculture

To cope with rapid and unpredictable climate change, resilient aquaculture systems are crucial. These systems, maintaining economic, ecological, and social benefits, require genetic diversity, low stress, and efficient resource use. Improved feeding technology, diet formulation, and integration on a global scale contribute to enhancing resource use efficiency. Experiments on climatic parameters help identify stress-tolerant species suitable for mariculture. Selective breeding can enhance tolerance to higher temperatures, salinity, and diseases, addressing the impacts of climate change on wild species distribution and catch. The integration of aquaculture with fisheries, agriculture, and ecosystem management activities, such as Integrated Multi-Trophic Aquaculture (IMTA), is explored. Successful techniques like IMTA demonstrate

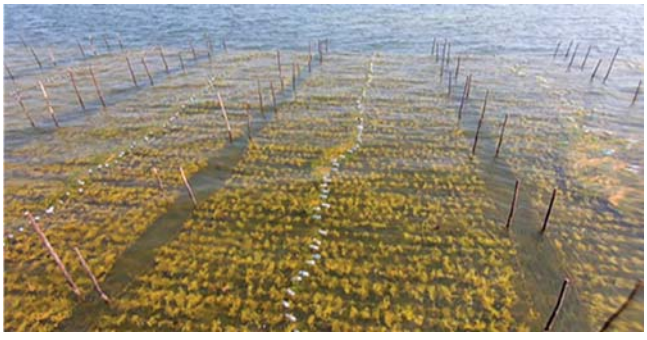
The demonstration of Integrated Multi Trophic Aquaculture (IMTA) under NICRA by integrating the seaweed *Kappaphycus alvarezii* with cage farming of cobia. (a) Cage farming of cobia, (b) Seaweed rafts integrated with cobia cage and (c) Comparison of IMTA (Left) and non IMTA seaweed (Right)

the potential of integrated farming technologies to improve overall sustainability (Johnson,2018). George *et al.,* 2015 highlight the significance of adopting an effective Ecosystem Approach to Aquaculture (EAA) for sustainable mariculture, underscoring the need for optimal production within a 'green environment.' Drawing lessons from past intensive shrimp farming, which led to environmental degradation and disease issues, the study advocates for Better Management Practices and species diversification. Carrying-capacity assessments are deemed essential, particularly for sea cage farming, considering factors such as tidal ranges, residence times, and tidal currents for suitable site selection. Additionally, the integration of satellite remote sensing (SRS) and Marine Spatial Planning (MSP) is proposed as a powerful tool for effective marine fisheries management in India. Leveraging India's leadership in satellite technology, dedicated satellites for mariculture and marine fisheries are suggested, along with the establishment of an "e-infrastructure" for enhanced data sharing and connectivity. The applications of SRS encompass real-time mapping of marine ecosystems, identifying suitable mariculture sites, and monitoring environmental impacts, thereby transforming challenges in the operating environment into opportunities for holistic development in the marine fishing sector. Integration of fisheries into national adaptation strategies and the promotion of context-specific and community-based adaptation are emphasized. Wetland restoration and scientific fish farming at the village level are identified as climate-resilient strategies. Qualitative and quantitative assessments using geospatial techniques contribute to sustainable wetland health, supporting adaptation efforts.

GHGs and carbon footprint in aquaculture

Developing a methodology for quantifying greenhouse gas emissions from aquaculture ponds contributes to understanding the climate-friendliness of aquaculture production systems. Conducting life cycle analysis highlights the impact of aquaculture production on greenhouse gas emissions. Management and microbial interventions are discussed to mitigate GHGs emissions (Zacharia *et al.,* 2016). Exploring the concept of water footprints in aquaculture emphasizes the climate-friendly nature of brackish water aquaculture. Seaweed farming is identified as a climate-resilient strategy with multiple benefits, including carbon sequestration and coastal pollution abatement.

Seaweed farming



Seaweed farming

Adaptation in fishing communities

Implementing climate preparedness activities for vulnerable coastal populations involves raising awareness, providing training, and offering supplementary vocations to strengthen fishing communities. Strengthening basic amenities in coastal villages, including infrastructure development and protection aids for traditional fishers, is emphasized. Improved infrastructure mitigates the impacts of extreme climate events. Implementing successful disaster management plans at each coastal village, including weather forecasting and climate change adaptations at the village level, is crucial for minimizing risks. Exploring e-commerce solutions for fish products, especially through multivendor platforms directly engaging fisher self-help

groups, is advocated (Zacharia *et al.* 2019). This approach aims to improve the livelihoods of fishing communities.

Implements distribution for traditional fishers at CMFRI, Kochi, India

Policy and planning

Cooperation between governmental and non-governmental sectors for climate change risks assessment and preparedness planning is recommended. Integration of climate change policies with sustainable development and poverty alleviation measures ensures a holistic approach. Similar to agriculture, aquaculture vulnerability assessments are necessary. Guidelines and support from fisheries research institutes during extreme weather events contribute to resilient aquaculture practices.

Formulated pellet feed for Pearl Spot, *Etroplus Suratensis* developed under CADALMINTM brand in the trade name "Pearl Plus"

Conclusion

A comprehensive and sustainable approach to climate change adaptation in fisheries and aquaculture involves multifaceted strategies across various sectors. The integration of scientific, ecosystem-based, community-oriented, and technologically advanced approaches is essential to enhance resilience and ensure the continued benefits of aquatic systems. Collaboration between stakeholders, research institutions, and policymakers is crucial for effective implementation and long-term success in adapting to the impacts of climate change.

References

Akhiljith, P.J., Liya, V.B., Rojith, G., Zacharia, P.U., Grinson, G., Ajith, S., Lakshmi, P.M., Sajna, V.H. and Sathianandan, T.V., 2019. Climatic projections of Indian Ocean during 2030, 2050, 2080 with implications on fisheries sector. Journal of Coastal Research, 86(SI), pp.198-208.

George, G., Jayasankar, J., Mini, K.G., Shah, P., Platt, T. and Sathyendranath, S., 2015. Satellite Remote Sensing Applications in Mariculture Activities.

George, Grinson., Vethamony, P., Sudheesh, K. and Babu, M. T., 2011. Fish larval transport in a macro-tidal regime: Gulf of Kachchh, west coast of India. Fisheries Research, 110 (1): 160-169.

Gopalakrishnan, A., Zacharia, P.U. and George, G., 2020. Impact, vulnerability and adaptation strategies for marine fisheries of India. CMFRI Special Publication (135). ICAR - Central Marine Fisheries Research Institute, Kochi.

IPCC 2007: Climate change 2007: working group II: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change.

IPCC 2022: Climate Change 2022: Mitigation of Climate Change. Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK and New York, NY, USA: Cambridge University Press.

Johnson, B., 2018. Techniques of Integrated Multi-Trophic Aquaculture (IMTA). Winter School on Climate Change Impacts and Resilience Options for Indian Marine Fisheries pp. 177-183.

Mohamed, K.S., Zacharia, P.U., Maheswarudu, G., Sathianandan, T.V., Abdussamad, E.M., Ganga, U., Pillai, S.L., Sobhana, K.S., Nair, R.J., Josileen, J. and Chakraborty, R.D., 2014. Minimum Legal Size (MLS) of capture to avoid growth overfishing of commercially exploited fish and shellfish species of Kerala. Marine Fisheries Information Service; Technical and Extension Series, (220), pp.3-7.

Shafeeque, M., George, G., Akash, S., Smitha, B.R., Shah, P. and Balchand, A.N., 2021. Interannual variability of chlorophyll-a and impact of extreme climatic events in the South Eastern Arabian Sea. Regional Studies in Marine Science, 48, p.101986.pp1-31.

Suzuki, A., 2021. Rising importance of aquaculture in Asia: current status, issues, and recommendations. Asian Development Outlook Update Background Paper. Asian Development Bank, Manila.

World Bank. "Africa Program for Fisheries." Retrieved from https://www.worldbank.org/en/programs/africa-program-for-fisheries on November 22, 2023.

Zacharia, P.U., Sajna, V.H., Rojith, G., Roshen, G.N., Joseph, D., Kuriakose, S. and George, G., 2020. Climate change drivers influencing Indian mackerel fishery in south-eastern Arabian Sea off Kerala, India. Indian Journal of Fisheries, 67(3), pp.1-9.

Zacharia, P.U., Gopalakrishnan, A., George, G., Muralidhar, M. and Vijayan, K.K., 2016. Climate change impact on coastal fisheries and aquaculture in the SAARC region: Country paper–India.

Zacharia, P.U., Rojith, G. and Najmudeen, T.M., 2019. ClimFish NICRA Newsletter Vol. 3.