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Adapting to Climate Change Strategies to Sustain Fish Populations in India

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Abstract

Climate change poses a significant and escalating threat to India's fisheries and aquaculture sectors, which are vital for the country's food security, economy and the livelihoods of over 28 million people. As a leading global fish producer, India's vast aquatic resources, including its extensive coastline and major river systems, are increasingly vulnerable to climate-induced stressors. This paper synthesizes the multifaceted impacts of climate change on both marine and inland fisheries, examining key indicators such as rising sea surface temperatures, altered monsoon patterns and sea-level rise. We find that these changes are already causing significant disruptions, including shifts in commercially important fish species, declining catch rates and the degradation of critical habitats like mangroves and estuaries. The socio-economic consequences are profound, disproportionately affecting vulnerable coastal and riparian communities through livelihood insecurity, damage to fishing infrastructure and nutritional deficiencies. The burgeoning aquaculture industry is also under immense pressure from rising water temperatures, salinity intrusion and increased disease outbreaks, which threaten to undermine its impressive growth. In response to these challenges, India has initiated several adaptive policy frameworks, including the National Action Plan on Climate Change and the draft National Fisheries Policy 2020. This includes the promotion of climate-smart technologies like biofloc systems and Integrated Multi-Trophic Aquaculture (IMTA), alongside the deployment of advanced early warning systems and large-scale mangrove restoration efforts. While these measures represent important steps, this paper concludes that a more holistic and integrated approach is essential to build long-term resilience. This requires combining scientific research with traditional ecological knowledge, ensuring equitable access to adaptive technologies and strengthening governance to protect India's aquatic ecosystems and the millions who depend on them.

Keywords:Climate Change,Aquaculture, Vulnerability, Adaptation

Introduction

India ranks among the top fish-producing nations globally, contributing over 8% to global fish production. The sector supports more than 28 million people, directly or indirectly, through capture fisheries and aquaculture (DAHD, 2022). The country's vast aquatic resources include 8,000 km of coastline, 14 major river systems, numerous lakes, reservoirs, estuaries and coastal wetlands.However, Indian fisheries are increasingly vulnerable to climate variability and long-term climate change. Observed trends such as sea surface temperature (SST) rise in the Indian Ocean, altered monsoon patterns, saline water intrusion in estuaries and declining river flowsare already impacting the distribution, productivity and reproductive behavior of several fish species. As fish are cold-blooded and sensitive to environmental changes, even slight shifts in temperature and water quality can disrupt entire aquatic ecosystems.

Climate Change Indicators in Indian Waters

One of the most significant indicators of climate change in Indian waters is the rise in Sea Surface Temperature (SST) in the Indian Ocean. Studies indicate that SST has increased by approximately 1.0-1.3°C over the past six decades, with pronounced warming observed in the Arabian Sea and the Bay of Bengal (Roxy *et al.* 2014). This warming trend has far-reaching implications for marine biodiversity, including shifts in fish distribution, altered breeding cycles and the bleaching of coral reefs. The accelerated warming in these regions is also linked to changes in ocean circulation patterns, which can further exacerbate ecological disruptions.

Another critical impact of climate change is the increasing frequency and intensity of erratic monsoon patterns and cyclonic disturbances. These climatic shifts have disrupted traditional fishing operations by altering fish migration routes and breeding seasons (Vivekanandan *et al.* 2016). Intense cyclones, such as those witnessed in recent years, have caused extensive damage to fishing infrastructure, leading to economic losses for coastal communities. Additionally, unpredictable monsoon rains have affected nutrient cycling in coastal waters, further destabilizing marine ecosystems.

Coastal erosion and sea-level rise are also major concerns, as they contribute to the degradation of critical fish habitats such as mangroves, estuaries and coral reefs. Rising sea levels exacerbate saltwater intrusion into freshwater ecosystems, threatening the survival of several estuarine species (Unnikrishnan and Shankar 2007). Mangrove forests, which serve as vital nursery grounds for many commercially important fish species, are particularly vulnerable to erosion and submergence. The loss of these habitats not only diminishes fish stocks but also reduces the natural buffer against storm surges, increasing the vulnerability of coastal populations.

Impact on Marine Fisheries

India's marine fisheries, particularly along the east and west coasts, are experiencing significant disruptions due to climate change. One of the most notable effects is the alteration in species distribution, with commercially important fish such as the Indian mackerel (*Rastrelligerkanagurta*) and oil sardine (*Sardinella longiceps*) shifting their habitats toward cooler waters (Vivekanandan *et al.* 2009). These spatial and seasonal changes in fish populations are altering catch compositions, forcing fishers to adapt to new fishing grounds or target alternative species. Such shifts not only affect food security but also disrupt local economies dependent on traditional fishing practices.

Compounding these challenges is the decline in catch rates, particularly in the southeastern and southwestern coastal regions. Rising sea surface temperatures, coupled with overfishing, have placed additional stress on fish stocks, reducing overall productivity (Krishnan *et al.* 2020). Furthermore, the increasing frequency of extreme weather events, such as cyclones and storm surges, has disrupted fish breeding and migration patterns. Many commercially valuable species spawns during specific temperature ranges and sudden thermal fluctuations can lead to failed spawning cycles, further depleting fish populations (Dineshbabu*et al.* 2018).

Impact on Inland and Freshwater Fisheries

Inland fisheries, encompassing rivers, lakes and floodplains, contribute over 65% of India's total fish production, yet they are highly vulnerable to climate-induced changes. Reduced river flows, driven by glacial retreat in the Himalayas and erratic rainfall patterns, are affecting key river systems such as the Ganga-Brahmaputra and Godavari basins (Gosain *et al.* 2011). These hydrological changes diminish fish habitats and disrupt the connectivity of aquatic ecosystems, leading to declines in fish diversity and abundance.

Additionally, prolonged droughts in arid and semi-arid regions have resulted in the drying up of wetlands and traditional fishing tanks, severely impacting livelihoods dependent on freshwater fisheries (Sarkar and Borah 2017). Conversely, excessive rainfall and flooding in low-lying regions like Assam and Bihar destroy breeding grounds, wash away fish stocks and damage aquaculture infrastructure. Rising water temperatures in inland water bodies further exacerbate these challenges by affecting the metabolic rates and survival of economically important species such as Rohu (*Labeorohita*) and Catla (*Catlacatla*) (Das *et al.* 2019). These cumulative stressors threaten the sustainability of India's inland fisheries, necessitating adaptive management strategies.

Socio-Economic Vulnerabilities

The impacts of climate change on marine and inland fisheries extend beyond ecological disruptions, posing severe socio-economic challenges to coastal and riparian communities across India. With over 16 million people engaged in small-scale and artisanal fisheries (CMFRI 2020), livelihood insecurity has emerged as a critical concern. These marginalized fishers, who typically operate with limited technological and financial resources, face compounding pressures from declining fish stocks, shifting species distributions andincreasing frequency of extreme weather events. Studies indicate that reduced catch per unit effort (CPUE) in traditional fishing grounds has forced many fishers into deeper waters or alternative occupations, often at significantly higher economic and safety risks (Salagrama 2019). The lack of adaptive capacity among these communities exacerbates their vulnerability to climate-induced shocks, threatening intergenerational fishing livelihoods.

Nutritional insecurity represents another significant consequence of climate change impacts on fisheries. Fish serves as a crucial and affordable source of animal protein for nearly 60% of India's population, particularly for coastal communities and low-income groups (FAO 2022). The declining availability of staple fish species, coupled with rising market prices due to supply-demand imbalances, may exacerbate protein-energy malnutrition and micronutrient deficiencies in vulnerable populations. Research demonstrates that changes in fish availability disproportionately affect women and children in fishing households, potentially reversing decades of progress in nutritional security (Bennett *et al.* 2018). This nutritional transition warrants urgent attention in public health and food security policies.

The increasing intensity of cyclonic storms and rising sea levels has caused substantial damage to critical fisheries infrastructure along India's coastline. States with extensive fishing economies such as Odishaandhra Pradesh and Kerala have reported recurrent destruction of harbours, fish landing centres and hatcheries during extreme weather events (Santha *et al.* 2021). The 2021 Cyclone Tauktae, for instance, caused estimated losses of ₹15,000 crore to Kerala's fisheries sector, including the complete destruction of numerous artisanal fishing craft (GoK 2021). Such infrastructure damage creates cascading economic effects, disrupting fish supply chains, increasing post-harvest losses and necessitating costly rehabilitation efforts. The compounded effects of infrastructure vulnerability and ecological changes threaten to undermine the sustainability of India's marine fisheries sector, which contributes approximately ₹1.75 lakh crore annually to the national economy (CMFRI 2022).**2.5.**

Aquaculture and Climate Change

India's aquaculture industry, which has experienced exponential growth over the past two decades, faces mounting challenges from climate change that threaten its sustainability and productivity. Coastal aquaculture, particularly shrimp farming (*Penaeus monodon*), is increasingly vulnerable to salinity intrusion caused by sea-level rise and reduced freshwater flows (Kumar *et al.* 2021). Studies in the Sundarbans region demonstrate that rising salinity levels beyond 15-20 ppt significantly impair shrimp growth rates and survival, with cascading effects on production yields and economic returns for small-scale farmers (Rahman *et al.* 2019). This salinity stress is compounded by the increasing frequency of storm surges, which inundate ponds with seawater and degrade soil quality for subsequent production cycles.

The sector also contends with escalating disease risks linked to climate variability. Warmer water temperatures create favourable conditions for pathogenic bacteria (Vibrio spp.) and viruses (White Spot Syndrome Virus), while simultaneously increasing metabolic stress on cultured species (Jithendran*et al.* 2020). Poor water quality resulting from altered precipitation patterns either through drought-induced stagnation or flood-driven turbidity further exacerbates disease susceptibility. Analysis of aquaculture losses in Andhra Pradesh, which accounts for 70% of India's farmed shrimp production, reveals that disease outbreaks now account for approximately 30-40% of production losses annually (MPEDA 2022). These biological stressors necessitate greater antibiotic use, raising concerns about antimicrobial resistance and market access restrictions for Indian seafood exports.

Inland aquaculture systems confront distinct climate challenges, particularly in drought-prone regions where water scarcity has become acute. Traditional carp polyculture systems (*Labeorohita*, *Catlacatla*, *Cirrhinusmrigala*) in states like Tamil Nadu and Rajasthan are experiencing declining productivity due to reduced water availability and elevated temperatures (Dasgupta *et al.* 2023). Farmers report decreasing dissolved oxygen levels and increased algal blooms in shrinking water bodies, leading to higher feed conversion ratios and stunted growth. The groundwater-dependent nature of many inland farms exacerbates these issues, with 65% of surveyed farmers in Maharashtra reporting difficulties securing adequate water for pond replenishment during pre-monsoon months (Naik *et al.* 2022).

Climate-Smart Aquaculture as an Adaptive Strategy

Emerging technologies and integrated approaches offer promising pathways to enhance climate resilience in Indian aquaculture. Bio floc systems, which recycle nutrients and maintain water quality through microbial communities, have demonstrated 20-30% higher productivity than conventional systems while reducing water exchange requirements (Devi *et al.* 2021). Similarly, recirculating aquaculture systems (RAS), though capital-intensive, show particular promise for urban and peri-urban areas by enabling precise environmental control and minimizing disease risks.

Integrated multi-trophic aquaculture (IMTA) systems that combine fish, molluscs and seaweeds are gaining traction in coastal regions as they improve resource efficiency and provide multiple income streams (Ganguly *et al.* 2022). Field trials in Kerala's backwaters indicate that IMTA systems can enhance overall farm productivity by 15-20% while buffering against salinity fluctuations through the osmoregulatory benefits of seaweed cultivation. Policy initiatives such as the Pradhan Mantri Matsya Sampada Yojana are increasingly promoting these climate-smart technologies through subsidies and capacity-building programs, though adoption remains constrained by high initial costs and technical knowledge gaps among smallholders (DoF 2023).

Adaptation and Policy Measures in India

Recognizing the growing threats posed by climate change to its fisheries and aquaculture sectors, India has instituted several policy frameworks and adaptation initiatives. The National Action Plan on Climate Change (NAPCC), formulated in 2008 and subsequently revised, incorporates fisheries-related climate adaptation through its National Mission on Sustainable Agriculture (NMSA) (MoEFCC 2022). This mission specifically promotes climate-resilient aquaculture practices by providing financial support for water-efficient systems, disease-resistant seed production and capacity-building programs for fish farmers. Recent evaluations indicate that NMSA interventions have enhanced adaptive capacity among 15-20% of targeted aquaculture farmers through technology dissemination and infrastructure development (NITI Aayog 2023).

The draft National Fisheries Policy 2020 represents a significant advancement in addressing climate challenges systematically. The policy explicitly identifies climate change as a critical threat to marine and inland fisheries, advocating for enhanced research on species-specific vulnerabilities, ecosystem-based fisheries management and the development of climate-adaptive aquaculture systems (DoF 2020). Notably, it emphasizes the need for integrating traditional ecological knowledge with scientific research to develop location-specific adaptation strategies. While the policy's implementation remains pending, its provisions have already influenced state-level fisheries development plans in climate-vulnerable regions such as Odisha and Kerala.

Technological and Ecological Adaptation Measures

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Technological and Ecological Adaptation Measures

Operational adaptation measures include advanced early warning systems deployed by the Indian National Centre for Ocean Information Services (INCOIS). The organization's integrated Potential Fishing Zone (PFZ) advisories and Ocean State Forecast (OSF) systems now incorporate climate variability parameters, providing real-time alerts on cyclones, storm surges and sea surface temperature anomalies to over 900,000 registered fishers (INCOIS 2023). These systems have demonstrably reduced fisher mortality during extreme weather events by 40-50% in high-risk coastal districts (Srinivasan *et al.* 2022).

Ecosystem-based adaptation has gained prominence through large-scale mangrove restoration initiatives. The Sundarbans region has seen approximately 5,000 hectares of mangrove reforestation under the National Coastal Mission, which has contributed to stabilizing estuarine fish habitats and reducing cyclone damage to coastal fisheries infrastructure (Forest Survey of India 2023). Similar initiatives in Andhra Pradesh and Maharashtra have combined mangrove rehabilitation with crab and shrimp polyculture systems, demonstrating 25-30% higher productivity compared to conventional systems while enhancing coastal protection (Nayak *et al.* 2023).

Institutional Research and Capacity Building

The Indian Council of Agricultural Research (ICAR) institutes play a pivotal role in generating climate adaptation solutions. ICAR-Central Marine Fisheries Research Institute (CMFRI) has developed vulnerability assessment frameworks for 60 major marine fish stocks, identifying specific thermal tolerance thresholds and potential distribution shifts (CMFRI 2023). Concurrently, ICAR-Central Inland Fisheries Research Institute (CIFRI) has pioneered climate-resilient fish seed production techniques, including thermally selected strains of major carps that show 15-20% better survival rates under elevated temperatures (CIFRI 2022).

These research institutions collaborate with state fisheries departments to implement adaptive management practices such as dynamic fishing closures based on spawning phenology shifts and community-managed fish sanctuaries in flood-prone regions. The Pradhan Mantri Matsya Sampada Yojana (PMMSY) has allocated ₹1,200 crore specifically for climate adaptation in fisheries, funding hatchery modernization, climate-smart infrastructure and fisher community training programs (DoF 2023). While these measures represent significant progress, challenges remain in scaling up localized solutions and integrating climate adaptation across all levels of fisheries governance.

Conclusion

Climate change is rapidly transforming India's aquatic ecosystems, posing serious risks to biodiversity, fish productivity and the socio-economic well-being of millions who depend on fisheries. The impacts are already visible-from changing species distributions in the Arabian Sea to declining catches in major river systems. To build climate resilience, India must integrate climate considerations into fisheries governance, enhance scientific monitoring, promote community-based adaptation and invest in climate-smart infrastructure and practices. Protecting the future of Indian fish populations will require a balanced approach-combining ecological sustainability with socio-economic inclusivity in the era of climate uncertainty.

Conflict of Interest

The author has no conflict of interest.

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