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Fostering Indian Fisheries and Aquaculture for Attaining Sustainable Development Goals

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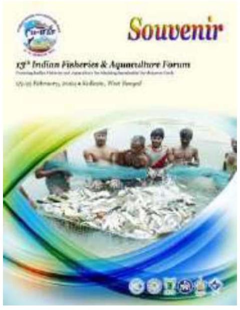

I3th Indian Fisheries and Aquaculture Forum: Fostering Indian Fisheries and Aquaculture for Attaining Sustainable Development Goals

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CMFRI's Pioneering Initiatives: Climate Research in Marine Ecosystems for Sustainable Fisheries and Aquaculture

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Introduction

Climate change has emerged as a paramount global concern, representing threat to food and nutritional security, particularly for the growing global population. While the impacts of climate change are felt worldwide, certain regions, including India, stand out as more vulnerable. India's susceptibility to the implications of climate change is highlighted by its large and dependent population relying significantly on fisheries. The obscure interaction between climate change and fisheries poses a complex challenge, encompassing ecological, economic, and social dimensions. As the climate continues to evolve, the repercussions on marine ecosystems and fisheries could have far-reaching consequences, underscoring the urgent need for comprehensive research and adaptive strategies to ensure the resilience of these critical sectors. CMFRI demonstrates a comprehensive commitment to advancing knowledge and practices in marine ecosystems. From meticulously studying the phenology, distribution, and trophodynamics of climate-vulnerable teleost fishes to employing sophisticated climate change modeling techniques. The integration of field data into a geospatial database enhances the understanding of coastal ecosystems. In a multifaceted approach, CMFRI combines field and laboratory studies, utilizing technologies to monitor habitat usage and species diversity, fostering both scientific understanding and public engagement. The institute's emphasis on vulnerability assessments, hazard atlases, and Climate Change Risk Index calculations reflects understanding of the intricate dimensions of climate-related impacts. CMFRI's commitment extends to sustainable practices, exemplified through climate-resilient farming initiatives such as Integrated Multi-trophic Aquaculture (IMTA), seaweed culture, and the strategic establishment of artificial reefs. CMFRI not only comprehends the challenges posed by climate change but actively contributes to innovative and sustainable solutions in fisheries and aquaculture, emphasizing its dedication to the well-being of marine ecosystems.

Phenology, Distribution and Trophodynamics

The research conducted at the Central Marine Fisheries Research Institute (CMFRI) in India, focusing on the phenology, distribution, and trophodynamics of climate-vulnerable teleost fishes, represents a comprehensive exploration of critical aspects of marine ecology. The study encompasses trophodynamics, phenology, and distribution, exploring the complex ecological interactions, seasonal patterns, and geographical distribution of teleost fishes susceptible to climate variations. A noteworthy dimension of this research involves the identification of locally adapted sardine stocks in the vast expanse of the Indian Ocean, utilizing the ddRAD sequencing techniques. This molecular approach provides a detailed and

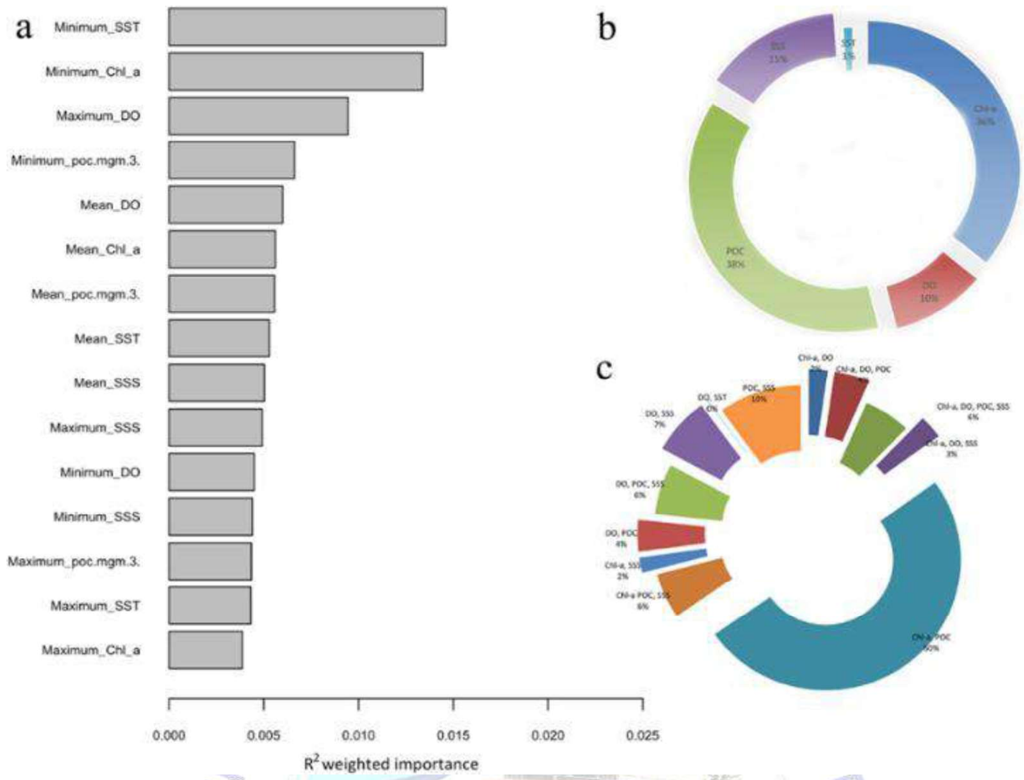

Fig.1. Contribution of each environmental variable in explaining genetic variation across *S. longiceps* populations generated from gradient forest analysis

fine-grained understanding of the genetic variations within sardine populations, contributing to the development of targeted conservation and management strategies. Expanding the scope, the research further encompasses trophodynamics, phenology, and reproductive parameters of 29 climate-vulnerable teleost fishes from diverse regions.

This broad approach facilitates a comprehensive examination of the ecological and biological dynamics of these species, shedding light on their life cycles, reproductive behaviours, and responses to environmental changes. Understanding these aspects is crucial for predicting and mitigating the impacts of climate change on marine biodiversity. The distribution patterns of five marine species in the Arabian Sea and Bay of Bengal have been studied over a specific period, and the resulting geocoded data has been effectively mapped in a GIS platform. This spatial analysis provides valuable insights into the habitats and movement patterns of these species, aiding in the formulation of conservation and management strategies. By employing geospatial technology, CMFRI enhances its capacity to visualize, analyze, and interpret complex ecological data, contributing to a more informed and effective conservation approach. Moreover, the research extends its focus to the climatic resilience and adaptive potential of Clupeid fishes across the world oceans, employing a comparative mitogenomics approach. This molecular investigation into the mitochondrial genomes of Clupeid fishes provides a deeper understanding of the genetic mechanisms underlying their adaptability to changing climatic conditions (Fig.1). CMFRI's research on the phenology, distribution, and trophodynamics of climate-vulnerable teleost fishes represents a holistic and interdisciplinary approach to marine ecology. From advanced molecular techniques like ddRAD sequencing and comparative mitogenomics to the application of geospatial analysis, the institute employs a diverse array of methodologies to unravel the complexities of marine ecosystems.

Carbon footprint and blue Carbon assessment

The comprehensive assessment of the carbon footprint of Indian marine fisheries conducted by ICAR-CMFRI involved an in-depth analysis of greenhouse gas equivalent (GHG) emissions from diverse fishing activities, encompassing construction and fabrication. The developed methodology, standardized by ICAR-CMFRI and implemented from 2013 to 2018, offers a unique approach to evaluating multi-sector, multi-gear marine fishing activities in India, with a focus on pre-harvest, harvest, and post-harvest scenarios for various fishing methods. This methodology integrates standard processes with indigenous modifications, serving as a model adaptable for countries with diverse small-scale mechanized/motorized fishing sectors (Fig.2). A global study reported an average release of 2.2 kg of CO_2 equivalent emissions (CO_2e) to catch 1 kg of fish. However, in India's mechanized fishery sector, the average emission was notably lower at 1.47 kg CO_2e per kg of fish, representing a 33% reduction compared to the global estimate. Similarly, for fishing operations in India encompassing mechanized, motorized, and indigenous sectors, the average emission stood at 1.52 kg CO_2e per kg of fish, indicating a 30% reduction compared to the global estimate. Over the past decade, GHG emissions from Indian trawlers have consistently remained below the global average, initially at 16.3% less and now at 17.7% less than the global average, despite increased emissions globally. The pivotal role of mangroves in climate change mitigation arises from their substantial contribution to capturing and storing carbon, emphasizing their significance as vital blue carbon ecosystems. This study delves into assessing the monetary value of services provided by India's mangrove ecosystems, specifically focusing on their contribution to reducing CO_2 emissions through carbon sequestration. Utilizing a comprehensive methodology and field-level data from Kerala and Andhra Pradesh, combined with secondary data from coastal states and Union Territories across India, the study evaluated carbon stocks in above-ground, below-ground (root), and sediment components. Converting estimated total carbon stocks into CO_2equivalence and applying standard estimates, the study determined their corresponding monetary value. Findings revealed a combined extrapolated total carbon stock of 59,463,228 tonnes across India's coastal regions, translating to a total CO_2 equivalence of 217 million tonnes. Notably, the cumulative monetary value of carbon sequestration efforts within Indian mangrove ecosystems amounted to an impressive 18,716 million US dollars. Furthermore, a model mangrove farm in Tuticorin, employing an allometric approach, estimated carbon stocks in above-ground and below-ground biomass, unveiling variations in carbon stock over time. Additionally, seaweed farming in Tuticorin explored carbon sequestration potential, with GIS data and satellite imagery estimating seaweed farming areas and biomass production. The assessment of net carbon sequestration potential revealed fluctuations over different years, providing insights into factors influencing seaweed production and its role in carbon sequestration. Collectively, these studies significantly contribute to the understanding of carbon dynamics in coastal ecosystems and the potential for mitigating climate change through blue carbon initiatives.

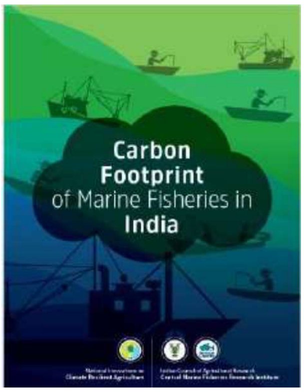

Fig. 2. Carbon footprint study of marine fisheries in India

Geospatial Assessment for Coastal Ecosystems

In a determined effort to integrate field data into a comprehensive geospatial database, CMFRI collaborated with the Indian Space Research Organisation (ISRO) and the National Innovations in Climate Resilient Agriculture (NICRA) program, employing the ISRO-CMFRI-NICRA wetland mobile application. This initiative involved systematic and continuous samplings across 96 wetlands situated around coastal villages in the states of Kerala, Karnataka, and Tamil Nadu. The data collected through this extensive fieldwork became a vital component of the geospatial database, providing valuable insights into the dynamic nature of coastal ecosystems. A significant aspect of the geospatial assessment focused on evaluating temporal changes in seagrass coverage within Kalpeni lagoon. This analysis spanned the years from 2003 to 2020 and was conducted using Landsat data on the Google Earth Engine platform (Fig 3). The objective was to recognise alterations in seagrass coverage over time and to understand the influence of selected climate factors on this vital coastal ecosystem. The findings of this study revealed a decline of over 99% in seagrass coverage, deteriorating health of the seagrass ecosystem in the region. The continuous samplings in the wetlands allowed for the creation of a detailed geospatial map, enriching the understanding of the spatial distribution of various ecological features.

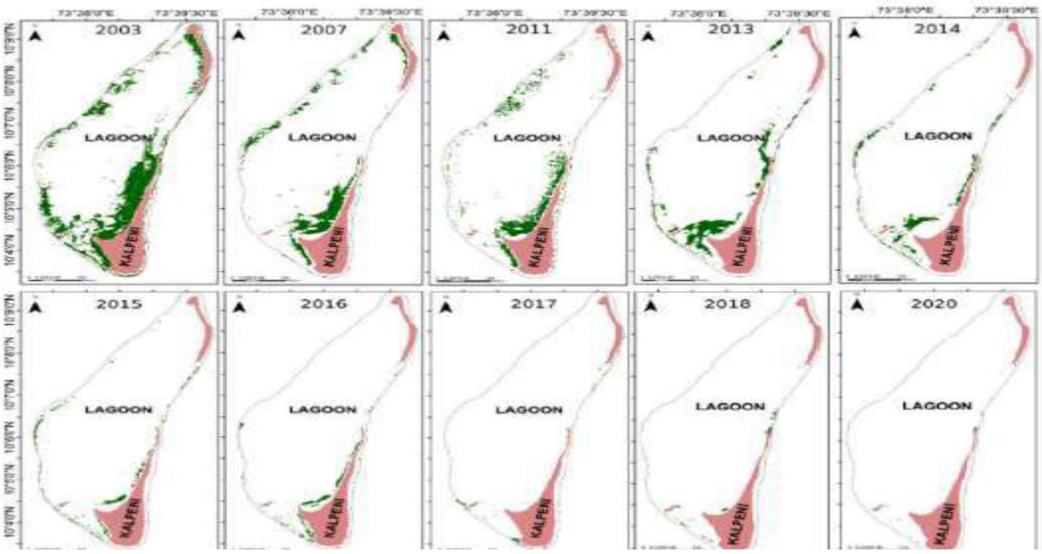

Fig.3. The change in the seagrass coverage along the years from 2003 to 2020

The effective management of fisheries can greatly benefit from the utilization of geographic information system (GIS) tools. These tools facilitate habitat mapping, georeferencing fish catch and fishing effort data, and linking catch information to oceanographic and biochemical parameters. Historically, the range of Indian fishermen was limited due to the constraints in the mechanization of fishing vessels. Catch reports were typically associated with the nearby coastal area of a designated landing center. However, with the widespread adoption of powerful engines, fishing evolved into a more professional pursuit, with mechanized boats undertaking extended journeys lasting weeks. The shift towards extensive fishing activities resulted in an immediate challenge, the lack of accurate information about the specific locations where catches were obtained. Precise identification of fishing grounds became possible with the use of GPS devices, but retroactively assigning geographical coordinates to historical data lacking latitude and longitude details remained a challenge. Typically, landing records include information about bearing and the distance covered by the surveyed craft. Using the Haversine formula to determine destination coordinates based on distance and bearing from the starting point coordinates, probable latitude and longitude of fishing grounds can be estimated. Passive geo-referenced species distribution data was plotted in a GIS platform and overlaid with India's coastal line spatial dataset. Spatial analysis tools refined the datasets and eliminated false information. Once the datasets were prepared, they were superimposed with various environmental variables derived through remote sensing, such as ocean temperature, salinity, dissolved oxygen, and chlorophyll. A well-designed, easily modifiable database was created. A modeling attempt was made to establish a relationship between the dichotomous dependent variable (presence/absence) of the species and environmental drivers. The Ensemble model with a logistic link function was employed for this purpose. The results indicated a good fit with a significant influence of climatic factors on species presence/absence. The fitted models were then used to project the probable distribution of the species along the west coast.

Field and Laboratory Studies on Species Adaptation to Climate Change Resilience

Broad and innovative study was conducted, integrating both field and laboratory investigations to assess the mitigation potential of mangroves and coastal wetlands within India's diverse coastal ecosystems. The research employed non-invasive Remote Underwater Video (RUV) technology, which played a pivotal role in monitoring habitat usage, species abundance, and diversity. This approach not only contributed to the scientific understanding of coastal ecosystems but also engaged the public in the conservation discourse. By laying the groundwork for evaluating conservation measures, the study aimed to enhance the resilience of these crucial habitats. Laboratory experiments were undertaken to assess the thermal tolerance of the silver pompano fish species. The findings revealed that acclimation to higher temperatures significantly increased their thermal tolerance, positioning these resilient fish as potential candidates for integration into climate-smart aquaculture systems. The combined insights from field and lab data provided a holistic perspective on coastal ecosystem conservation and speciesadaptation to climate change, offering valuable information for sustainable management practices. Multifaceted study investigated the complexities of climate-drivenchanges in small pelagic fish populations, employing a meticulous approach to understand and adapt to environmental shifts.

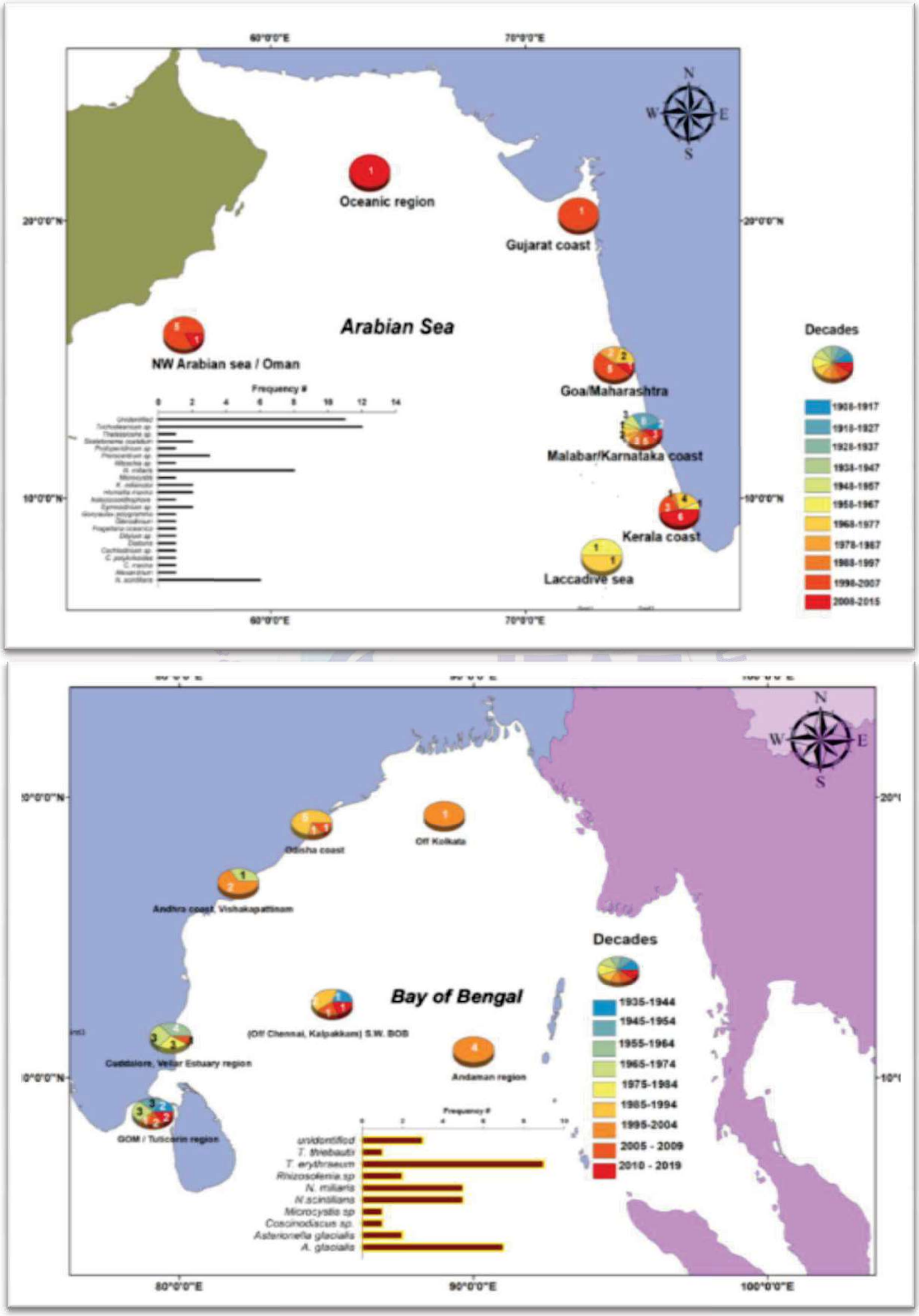

Fig. 4. Secondary data of bloom events across Arabian Sea (AS) (1908 to 2015) and Bay of Bengal (BoB) (1935-2019) was catalogued to identify spatio-temporal variability

Notably, the research identified the optimal acclimatization temperature (Topt) for the *Trachinotus mookalee* as 26°C, showcasing a thermal tolerance range between 12.66°C and 43.22°C. Additionally, the study observed a remarkable 100% survival rate for spiny lobsters (*Panulirus homarus)* exposed to gradual salinity changes between 17‰ and 44‰, as well as abrupt salinity exposures ranging from 26‰ to 41‰. The impact of environmental variables on resource abundance, potential yields, and spawning of selected marine fishes and crustaceans was systematically assessed. This comprehensive analysis contributed to the understanding of how these species respond to climate-related changes, providing crucial insights for fisheries management and conservation efforts. Harmful Algal Blooms (HABs) pose a significant risk to India's coastal resources, with repeated emergence of toxin producing HABs causing substantial losses in aquaculture as algal toxins accumulate in fishes beyond permissible levels. Non-toxic algae blooms can also cause harm through various means, including the substantial biomass achieved by certain blooms. As these blooms decompose, oxygen depletion occurs, resulting in widespread mortality of plants and animals in the affected area. Prolonged blooms of non-toxic algal species, even in the absence of toxins, can have detrimental effects by reducing light penetration to the bottom, adversely affecting submerged aquatic vegetation, and impacting coastal ecosystems. These vegetation areas, serving as critical nurseries for the offspring of commercially important fish and shellfish,further contribute to the impact on fisheries.

As part of a comprehensive study, secondary data of bloom events across the Arabian Sea (AS) from 1908 to 2015 and the Bay of Bengal (BoB) from 1935 to 2019 was catalogued to identify spatio-temporal variability (Fig.4.) In the AS, approximately a three-fold increase in HAB events is reported during the last two decades (31 HAB events) compared with the first two decades (10 HAB events). Similarly, in the BoB, there is an approximately two-fold increase in HAB events during the last two decades (14 HAB events) compared to the first two decades (6 HAB events).

This comprehensive analysis contributes valuable insights into the dynamics of HABs in the Arabian Sea and the Bay of Bengal, aiding in the development of effective strategies for coastal resource management. Furthermore, investigated the patterns and impacts of harmful algal blooms, specifically the green tide caused by *Noctiluca scintillans*, along the Gulf of Mannar. By separating the dynamics of these algal blooms, the research addressed the ecological consequences and potential mitigation strategies for this phenomenon, fostering a more resilient marine ecosystem.

Vulnerability Assessment for Climate Change Risk

Widespread vulnerability assessment was undertaken, aiming to identify and finalize various variables within Hazards, Exposure, and Socio-Ecosystem vulnerability dimensions for the calculation of the Climate Change Risk Index. This meticulous process involved a multifaceted examination of factors contributing to the vulnerability of coastal regions, providing understanding of the complex interplay between hazards, exposure, and socio-ecosystem dynamics. The outcome of this assessment would form the basis for informed decision-making and adaptive strategies in the face of climate change.

To visualize and communicate the vulnerability of coastal districts, Hazard Atlas was developed based on the hazard vulnerability index calculated for each identified risk. Five significant hazards with profound physical vulnerability implications were carefully chosen, including Cyclone Proneness, Flood Proneness, Shoreline Change, Sea Level Rise, and Heat wave. Each hazard underwent a detailed vulnerability index calculation, allowing for the creation of district and state-level atlases that vividly illustrated the degree of vulnerability to each specific hazard. This approach not only facilitated a targeted response to individual threats but also provided a complete view of the overall vulnerability landscape. The development of a Multi-hazards Index (MHI) emerged as a key component of the vulnerability assessment, offering a composite index showcasing the relative proneness of coastal districts to a multiplicity of physical hazards.

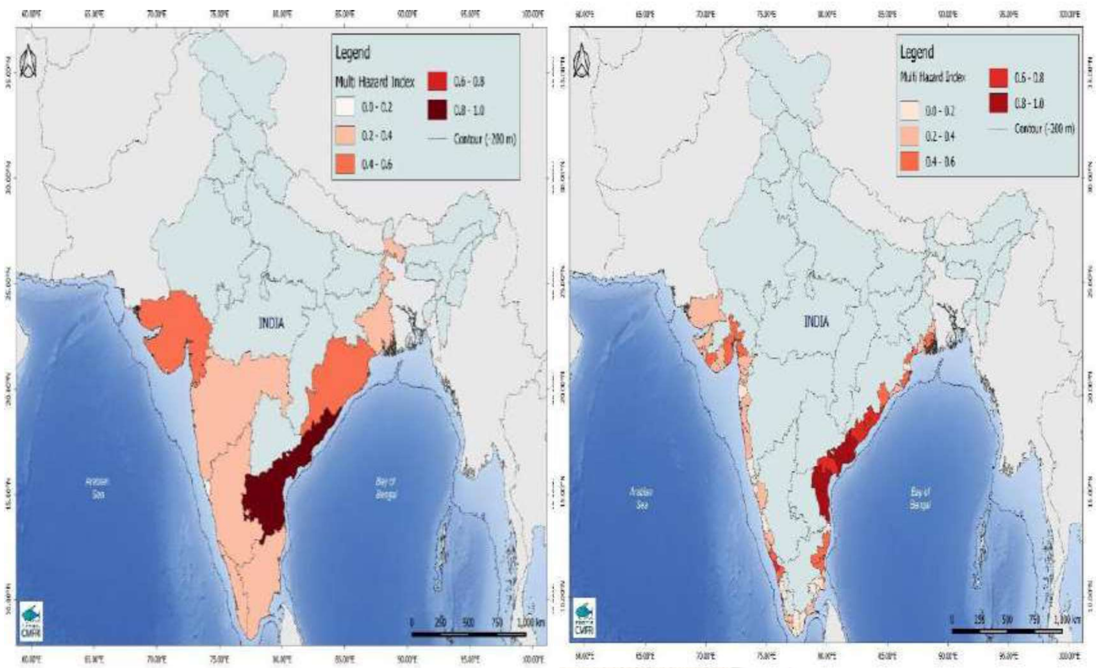

Fig.5. Maritime state-wise and coastal district-wise multi hazards index map

The coastal state of Andhra Pradesh emerged with the highest score for the Multi-hazards Index (MHI), signifying the state's elevated susceptibility to physical hazards induced by climate change (Fig.5) Conversely, Goa exhibited the least proneness to these climate change-induced physical hazards, as evidenced by its lower index value. This comparative analysis provides valuable insights into the varying degrees of vulnerability across different regions. Further refining the assessment, the relative positions of coastal districts within the hazard atlas, based on the Multi-hazard Index, revealed vulnerability patterns. Sindhudurg district in Maharashtra state obtained the lowest score, indicating a relatively lower susceptibility to the identified hazards. Conversely, the Krishna district in Andhra Pradesh exhibited the highest score, signaling heightened vulnerability in this region. These localized vulnerability assessments contribute significantly to the development of targeted adaptation and resilience strategies, allowing for more effective risk management and climate change mitigation at the regional level.

Climate Resilient Farming Practices

CMFRI has been at the forefront of pioneering climate-resilient farming practices, introducing transformative technologies and methodologies that not only enhance productivity but also promote sustainability in the aquaculture sector. One of the landmark achievements has been the development and popularization of cage farming technology in India. With technical support from CMFRI, more than 3900 cages have been established, resulting in an impressive production of over 12,000 tonnes of harvested fishes. This initiative has not only significantly increased production efficiency but has also made aquaculture economically viable, with the cost of production reduced from Rs 350/kg to a more affordable Rs 210/kg. At the Kanyakumari coast, CMFRI initiated climate-smart farming practices, collaborating with Self-Help Groups (SHGs) in the region. Utilizing Geographical Indication (GI) square floating cages measuring 6 m x 6 m with four partitions, the initiative demonstrated remarkable success. Within 40 days, a fourfold growth was observed in seaweeds, showcasing the adaptability and efficiency of this innovative farming approach. The positive outcomes underline the potential for sustainable and lucrative seaweed cultivation in the context of climate resilience. CMFRI further advanced climate-resilient farming through the integration of sea cage culture of seabass with seaweed *Kappaphycus alvarezii* using the net tube method. After 10 months, this integrated approach yielded a seabass harvest of approximately 1144 kg, generating a total revenue of Rs. 4,91,420. This successful integration not only maximizes yield but also promotes ecological sustainability by harnessing the complementary relationships between different species within the aquatic ecosystem. The adoption of Integrated Multi-trophic Aquaculture (IMTA) represents another milestone in climate-resilient farming. CMFRI standardized and developed a package of practices for IMTA, combining 16 seaweed bamboo rafts with one cage.

Fig.6. IMTA

The results demonstrated a remarkable 56% additional yield and an 18% increase in income for farmers. IMTA not only significantly improved water quality in cage culture sites when integrated with seaweeds but also reduced the chances of eutrophication. Furthermore, the carbon sequestration potential of cultivated seaweed in IMTA systems surpassed that of non-integrated rafts, underlining the environmental benefits of this innovative approach. In the field of seaweed culture, CMFRI has developed sea farming techniques for five species of seaweeds. Through GIS-based models, 317 potential seaweed farming sites, covering 23,950 hectares, have been identified. Monoline/longline farming of *K. alvarezii* has proven to be successful, with wet seaweed production ranging from 6 to 10 tonnes per plot per crop (35 days). The dry seaweed yield, coupled with a market price of Rs. 40 per kg, translates to a substantial net income ranging from Rs. 12,000 to 16,000 per plot.

Artificial Reefs in India

The inception of organized efforts on Artificial Reefs (AR) in India dates to 1980s, marking a pivotal moment in marine conservation and ecosystem management. Since then, the initiative has evolved into a remarkable conservation strategy, contributing significantly to the enhancement of marine biodiversity and the promotion of sustainable fisheries. As of the present day, India boasts over 280 functional AR sites, strategically positioned along its vast coastal stretches. These sites collectively encompass an impressive 0.37 million square meters of AR area in Indian coastal waters. This expansive network of artificial reefs serves as a testament to the enduring commitment of marine scientists and conservationists to augmenting the natural habitat for marine life.

Fig.7. The latest AR modules deployed by CMFRI

The success of India's AR program can be attributed not only to its scale but also to the meticulous protocols established for every stage of the AR lifecycle. Evolving from decades of research and hands-on experience, these protocols encompass crucial aspects such as site selection, design, fabrication, deployment, and impact assessment. Site selection is a meticulous process, involving the identification of locations that align with specific conservation objectives. These objectives include boosting fish populations, restoring degraded habitats, protecting sensitive marine ecosystems. The careful consideration of ecological factors ensures that AR sites become thriving havens for marine life. Designing artificial reefs demands a deep understanding of local marine ecology and the specific needs of targeted species. The structures are crafted to mimic natural substrates, providing attachment points for marine organisms to colonize. The fabrication of AR structures involves the use of durable, environmentally friendly materials that withstand the harsh marine environment. The deployment phase is a critical aspect of the AR program, requiring precision in placing structures to optimize their impact on marine life. Once deployed, these artificial reefs become a focal point for colonization by various species, fostering biodiversity and creating new opportunities for fisheries. Impact assessment is an ongoing process that evaluates the effectiveness of ARs in achieving their intended goals. This involves monitoring changes in marine biodiversity, fish populations, and the overall health of the ecosystem. By continually refining protocols based on these assessments, India's AR initiative remains dynamic and adaptive, ensuring sustained positive outcomes.

Conclusion

The research and initiatives conducted by the ICAR-Central Marine Fisheries Research Institute (CMFRI) in India collectively represent all-inclusive and interdisciplinary approach to address the critical challenges in marine ecology, climate change resilience, and sustainable aquaculture practices. The extensive studies on phenology, distribution, and trophodynamics of climate-vulnerable fishes showcase a comprehensive exploration of marine ecosystems, employing advanced molecular techniques and geospatial analysis for understanding of genetic variations, spatial distribution, and ecological interactions. In assessment of the carbon footprint in Indian marine fisheries demonstrates a commitment to sustainable practices, utilizing standardized methodologies to analyse greenhouse gas emissions throughout the fishing process. The significantly lower emissions in India's mechanized fishery sector, compared to the global average, underscore the success of the implemented methodologies and the potential for global adaptation. The pivotal role of mangroves in climate change mitigation is highlighted through the assessment of carbon sequestration efforts, revealing substantial ecological and economic significance. Geospatial assessments of coastal ecosystems offer valuable insights into the dynamic characteristics of wetlands and seagrass coverage. These assessments, coupled with studies on climate change vulnerability, play a pivotal role in informed decision-making and the development of adaptive strategies at regional levels, thereby enhancing resilience to climate change-induced hazards. These comprehensive tools not only facilitate the mapping of habitats but also enable the georeferencing of fish catch and fishing effort data, while simultaneously linking catch information with oceanographic and biochemical parameters. The integration of these approaches contributes to a holistic understanding of coastal environments and supports proactive measures for sustainable resource management. The innovative climate-resilient farming practices introduced by CMFRI, including cage farming, integrated multi-trophic aquaculture, and seaweed culture, demonstrate a commitment to enhancing productivity while promoting sustainability. These practices significantly reduce the carbon footprint, improve water quality, and offer additional income opportunities for farmers. The successful implementation of Artificial Reefs (AR) stands as a testament to sustained efforts in marine conservation. The evolution of AR protocols, from site selection to impact assessment, ensures that these artificial habitats contribute positively to marine biodiversity and sustainable fisheries. The endeavors of ICAR-CMFRI represent a dynamic and adaptable approach to addressing the complexities of marine ecosystems, climate change impacts, and sustainable aquaculture. By integrating cutting-edge technologies, comprehensive methodologies, and community engagement, these research initiatives contribute significantly to global knowledge and best practices in marine science and conservation.

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