Indian Council of Agricultural Research
Central Marine Fisheries Research Institute

National Innovations in
Climate Resilient Agriculture

Impact of Climate Change on India's Marine Fisheries and Ecosystems

One decade of research through NICRA project at ICAR-CMFRI

CMFRI Special Publication No.147

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Edited by
Shoba Joe Kizhakudan, Dineshbabu A. P., Sujitha Thomas, Zacharia P.U., Ratheesh Kumar R., Grinson George, Vivekanandan E. and Gopalakrishnan A.

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Foreword

Climate change is one of the most significant phenomena threatening the world's ecosystems and life forms today. Although much attention is being given to it on a global level, climate change research is yet to evolve strategies to reverse the effects that have already been put into motion. The marine ecosystem is a major receiver of the impacts of climate change, with several critical habitats, particularly coral reefs, being affected on a large scale.

India is the 2nd largest fish-producing country and 2nd largest aquaculture nation in the world. It is one of the leading nations in marine fisheries production, with a coastline of >8000 km and 2.02 million sq. km of Exclusive Economic Zone (EEZ), half a million sq. km of continental shelf, and a potential fish production of 5 .31 million tonnes. India's continental shelves and coastal waters support a number of biodiversity-rich and ecologically sensitive habitats, which are home to several species of fauna and flora, many of which contribute to fish production by coastal fisheries. With the increasing adoption of the Ecosystem Approach to Fisheries Management (EAFM) across the globe and the growing concern over climate change impact on marine ecosystems and fisheries, India too has to develop holistic and integrated frameworks for fisheries management.

National Innovations in Climate Resilient Agriculture (NICRA) is a key network project of the Indian Council of Agricultural Research, designed for extensive and integrated research to support adaptation and mitigation to climate change in different sectors of agriculture, veterinary and fisheries sciences. ICAR-Central Marine Fisheries Research Institute has been spearheading climate change research in the marine fisheries sector, with more than 100 research personnel working on the impact of climate change on different aspects of marine capture and culture fisheries, as well as on coastal livelihoods. More than a decade of dedicated research has supported the understanding of the responses of marine organisms and ecosystems to climate change, which in turn has led to the formulation of strategies for adaptation and mitigation at various levels across coastal communities and stakeholder groups. It is heartening to note that ICAR-CMFRI's research has focused on marine fishery resources, carbon footprint of marine fisheries, climate change impacts on marine ecosystems, carbon sequestration potential of coastal ecosystems, vulnerability of coastal communities, innovations in mariculture practices and widespread demonstration programs to support alternate livelihoods, stakeholder empowerment programs and development of Climate Smart Villages.

This book showcases the research carried out at ICAR-CMFRI during the one decade of the NICRA project, from February 2011, and is testimony to the achievements attained. I congratulate the entire staff of ICAR-CMFRI involved in the NICRA project for utilizing the support provided by ICAR in the best possible manner and wish them all success in furthering the progress made so far and produce fruitful outputs that will empower India's coastal fishing communities to combat climate change impacts.

Dr J K Jena

Preface

Climate change has become a critical concern globally, as it is considered a threat to food and nutritional security for a growing population. The impacts of climate change are global, but countries such as India are more vulnerable because of the high population depending on agriculture. Considering the importance of the issue, the Indian Council of Agricultural Research (ICAR) decided to provide support to the effort of individual institutes, and launched National Innovations in Climate Resilient Agriculture (NICRA), a network project, in February 2011. The research on adaptation and mitigation covers crops, livestock, fisheries, and natural resource management. Impact of climate change on marine fisheries is the focus of attention of research in ICAR-CMFRI. The Institute has been conducting in-depth investigations and evolving mitigation measures to support Indian fisheries production to keep up its increasing trend.

Marine fish production in India has increased by six times in the last six decades. Of late, fishery-related and fishery-independent factors have been surmised to cause distress to sustainable and increasing fish production, of which climate change-related issues are among the major concerns. The support of the NICRA project helped quicken the pace of ICAR-CMFRI's research activities related to climate change in India's marine fisheries. ICAR-CMFRI has focussed on the phenology & distribution of fishes in the Indian EEZ, spatiotemporal mapping of resources, carbon footprint assessment of marine fisheries and marine ecosystems, and fishery projections vis-a-vis climate change. The vulnerability of coastal villages to climate change-related vagaries and technologies developed for increasing climate resilience in climate change-impacted villages were also prime areas of focus that ICAR-CMFRI achieved significantly with NICRA project support. Climate-resilient villages were designed on the east coast and west coast to extend climate-resilient technologies to empower coastal fishermen to combat climate change-related problems.

In mariculture, elevated water temperature and changes in salinity and pH will likely affect the spawning season, spawning strength, and larval growth of candidate species. Seed and feed availability are also likely to be impacted due to climate change. Generally, it is believed that elevated temperature may enhance the spawning success and growth rate of culturable organisms. Hence there is scope for harnessing the benefits of elevated temperature. NICRA provided the right platform for taking up 'state of the art' research using the most modern equipment and the vessel "Silver Pompano," and climate and environmental data collecting and monitoring equipment revolutionized climate research in ICAR-CMFRI. The present document showcases how the support from visionaries can make revolutions in climate research in ICAR Institutes, and this is a token of gratitude from ICAR-CMFRI to the NICRA project and ICAR, New Delhi.

We take this opportunity to place on record our sincere gratitude to ICAR, New Delhi. We hope this document will be only the first of many more to come, and that it will contribute to innovating future research on climate change impacts in the marine fisheries sector.

Shoba Joe Kizhakudan, Dineshbabu A. P., Zacharia P.U., Ratheesh Kumar R., Grinson George, Vivekanandan E. and Gopalakrishnan A.

Executive Summary

With growing global concern over climate change and its possible impacts on food and nutritional security, and the situation likely to be worse in countries such as India where a major part of the fast-growing population depends on agriculture for livelihood and sustenance, the Indian Council of Agricultural Research (ICAR) initiated the National Innovations on Climate Resilient Agriculture (NICRA) project in 2011. NICRA was evolved as a network project linking different research statutes under the ICAR, to promote parallel research in the arenas of crop science, livestock, fisheries and natural resource management, and all their allied fields. The project aims to enhance resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration and provide advisories on adaptation and mitigation.

ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI) has been spearheading climate research in India's marine ecosystems with emphasis on the impacts of climate change on marine fish production and marine habitats, mariculture, and coastal communities and livelihoods.

This book attempts to showcase all the achievements of ICAR-CMFRI made in the NICRA project during 2011-2020, including success stories of adaptation and mitigation measures evolved and empowering coastal communities with climate resilient technologies and products. Post 2020, the focus is on expanding the results obtained to a wider platform and generate smart systems that will enable better flexibility of the stakeholders in adapting to climate change impacts.

Salient achievements 2011-2020

Theme	Achievement
Temperature impacts on the fishery along Indian coast	• Spatiotemporal mapping of abundance of various fishery resources such as tunas, Indian mackerel and threadfin breams was done. • Impact of climate parameters on spawning activity of commercially important resources like Indian oil sardine, Indian mackerel, threadfin breams, prawns, crabs and cephalopods was unraveled. • Relative vulnerability of 68 species of finfish and shellfish was assessed vis-à-vis climate, fishery and biological parameters, with a suitable vulnerability assessment method modified to meet Indian conditions and the highly vulnerable species for each maritime zone (northwest, southwest, northeast and southeast) were identified to evolve management options to ensure their sustainability.

Theme	Achievement
Harnessing the beneficial impacts of changes in temperature for mariculture	• Experiments on temperature tolerance and impacts on the growth stages of various cultivable species of finfish and shellfish helped identify climate resilient species such as cobia and silver pompano, to promote their mariculture, particularly through cage farming, as an alternate livelihood option. • Resilience experiments on larval stages of cultivable species and on live feed also helped establish key control points that could be manipulated to achieve best results in terms of hatching efficiency, growth rate and net survival.
Vulnerability of India's coastal villages to climate change	• IDLAM – Integrated District Level Adaptation and Mitigation, a methodological framework for assessing the vulnerability of coastal districts and to evaluate adaptation and mitigation options was developed. • Vulnerability Indices of coastal districts in all the maritime states were assessed, which formed the basis for planning training and awareness programmes in select villages for developing Climate Smart Villages.
Carbon footprint and blue carbon	• Carbon footprint of Indian marine fisheries were assessed in different fishing gear sectors at major landing centres. • Carbon sequestration potential of various mangrove ecosystems in Kerala and Tamil Nadu and cultured seaweeds in Tamil Nadu were assessed.
Empowering coastal communities to adapt to climate change impact	• Technology demonstration and transfer programmes were conducted in the maritime states to improve adoption of climate resilient technologies among coastal fisher populations. • Enriching of fisher's knowledge was done by harnessing their traditional knowledge and adding on to their knowledge bank. • Climate Smart Villages were developed in Karnataka and Tamil Nadu through intensive stakeholder interactions, technology demonstration & transfer and awareness drives.
Mitigation of climate change impacts through wetland preservation	• National Wetland information mobile app and website were developed and transferred by SAC-ISRO to NICRA project of ICAR-CMFRI to enable integration of additional field level datasets of wetlands to the existing wetland database of ISRO-SAC.
Success stories - Climate resilient technologies and products	**Technologies:** • IMTA design and technology for integrating seaweed culture with cage culture of fishes such as cobia and silver pompano. • Co-cultivation of red seaweed with green mussel • Integrated fish-cum-paddy shrimp farming in pokkali fields • Improved monoline seaweed culture **Products:** • Fifth generation low-cost cages, costing less than Rs. 1,00,000/- and lasting at least for 5 years were developed; these were tested and found to be more sustainable and economical in the long run. • "Pearl Plus" – a specialized pellet feed developed for culture of the pearl spot Etroplus suratensis.

Theme	Achievement
	• Biofuel and biochar produced from seaweeds and water hyacinth. • Prototype for carbondioxide flow regulator and recorder was developed for ocean acidification studies. • E-commerce platform setup as a socio-economic resilience strategy against climate change for fishermen communities.
Climate change modelling and projections	• Oceanographic database for 11 parameters for Indian Ocean was collated/ downscaled. • Time series analysis and projections till 2100 under RCP 4.5 scenarios were obtained for SST and Chlorophyll along four coastal zones. • Multi-gear Biomass Dynamic Models were developed for different marine fishery resources of India. • Catch forecast of Indian oil sardine till 2030 was obtained using ARIMA models. • Catch forecasts of Indian oil sardine and Indian mackerel were obtained for 2020–2100 based on oceanographic parameter projections under RCP 4.5 and RCP 6.0.

Way forward (2021-2025)

Work Programme	Objectives
WP 1: Projection on marine fisheries (WP 1.1) & mariculture production (WP 1.2)	WP 1.1: To project marine fish catch in the Indian seas under IPCC climate change scenarios in the 21st century. WP 1.2: To project mariculture production in India under IPCC climate change scenarios in the 21st century..
WP 2: Risk Assessment and adoption of weather forecast	To suggest measures to reduce impact of extreme events on fishing communities and farmers, through risk assessment for clusters of coastal districts in each maritime state following Exposure, Sensitivity, Adaptation capacity and Mitigation criteria.
WP 3: Behaviour of value chains	To identify opportunities and barriers in changing climate and to understand and develop future models of climate resilient value chains with identified critical control points.
WP 4: Mitigation potential of mangroves and coastal wetlands and cost-effectiveness of restoration	To further the research on role of blue carbon in coastal habitats especially mangroves, seagrasses and salt marshes to a larger scale with the purpose of projection for the entire coastal area in the country.
WP 5: Response of capture and mariculture species	To collect data for input of projection models; and to find out the impact of 'deadly trio' water temperature, oxygen and acidification, and quantifying sensitivities.
WP 6: Potential for adaptive management of fisheries (WP 6.1) and mariculture (WP 6.2) to climate change	Preparation of detailed report on potential adaptation and mitigation for consideration of policy makers and managers, as envisaged through (1) Compendium of pan-India and local measures currently followed with case studies; (2) Identifying pan-India and local management measures and practices that have the potential (best practices) to reduce the impact and risks in the next 20–30 years for fish resources, fisheries and fishing communities; (3) Projection on cost of adaptation and mitigation and (4) Suggestions to integrate the measures into management instruments.

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Abbreviations

ADCP	Acoustic Doppler Current Profiler
ADG	Average daily growth
ADMB	Automatic Differentiation Model Builder
AI	Average index
ARIMA	Autoregressive integrated moving average
BRAQCON	World Brackish water aquaculture conference
B_(sp,t)	Biomass of the species at time t
BST	Bottom Sea Temperature
CAA	Cage Aquaculture in Asia
CBA	Capture-based aquaculture
CBS	Carbon budget survey
CH_4	Methane
Chl	chlorophyll
Chl-a	Chlorophyll a
CHN	Carbon Hydrogen Nitrogen
CIBA	Central Institute of Brackish water Aquaculture
CMFRI	Central Marine fisheries Research Institute
CMIP5	Coupled Model Inter Comparison Project
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COMAD	National Conference on Marine Debris
C_(sp,t)	Catch of the species at time t
C-stock	Carbon stock
CSV	Climate Smart villages
CTD	Conductivity, Temperature, and Depth
CULINKBIOCON	Cultural Landscapes, Indigenous Knowledge and Biotechnological tools for Biodiversity conservation
DBH	Diameter at breast height
DNA	Deoxyribonucleic Acid
DO	Dissolved oxygen
DPH	Day post-hatch
EEZ	Exclusive Economic Zone
ENSO	El Nino Southern Oscillation
ETS	Exponential Smoothing
FAO	Food and Agriculture Organization

FCR	Feed conversion ratio
f_(l,t)	Fishing effort by gear l in year t
FFDA	Fish Farmers Development Agency
GAM	Generalized additive model
GDP	Gross Domestic Product
GHG	Greenhouse gases
GIS	Geographic Information System
GLM	Generalized linear model
GWP	Global warming potential
HDPE	High density polyethylene
HRD	Human Resource Development
HSS	Household survey schedule
ICAR	Indian Council of Agricultural Research
ICOADS	International Comprehensive Ocean Atmosphere Data Sets
IDLAM	Integrated District Level Adaptation and Mitigation
IFAF	Indian Fisheries and Aquaculture Forum
IMTA	Integrated Multi-Trophic Aquaculture
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IRI	Index of relative importance
ISRO	Indian Space Research Organization
ITK	Indigenous Technical Knowledge
KRC	Karwar Research Centre
$kgCO_2e$	Kilograms carbon dioxide equivalent
K_sp	Carrying capacity for the species
KUFOS	Kerala University of fisheries and ocean studies
KVK	Krishi Vigyan Kendra
kWh	Kilowatt hour
L_∞	Asymptote length or L infinity
Lc/Lm	Length at capture/length at maturity(50%)
Lm	Mean length at first maturity
Lm_{50}/L_∞	Length at maturity (50%)/Length at infinity.
MECOS	Marine Ecosystem Challenges & Opportunities
MEI	Multivariate ENSO index
MLD	Mixed Layer Depth
MLT	Mixed layer temperature
MPIESM	Max Planck Institute Earth System Model
MSP	Marine Spatial Planning
NABARD	National Bank for Agriculture and Rural Development
NAS	National Achievement Survey
NATP	National Agricultural Technology Project
NE	Northeast
NICRA	National Innovations in Climate Resilient Agriculture
N_2O	Nitrous oxide
NOAA	National Oceanic and Atmospheric Administration
NW	Northwest
PAR	Photo synthetically Active Radiation
PARS	Parameter, Attribute, Resilient indicator and Score

PE	Polyethylene
pH	Potential of Hydrogen
PPP	Public Private Partnership
PPT	Parts per thousand
Pr	Precipitation
PRA	Participatory Rural Appraisal methods
P_(sp,l,t)	Catch proportion of the species in gear type l in year t
PVC	Polyvinyl Chloride
q_l	Catchability coefficient for gear l
RBQ	Rank Based Quotient
RCP	Representative Concentration Pathway
RF	Relative Fecundity
RNA	Ribonucleic acid
RRA	Rapid Rural Appraisal
r_s	pIntrinsic growth rate for the species biomass
SAC	Space Applications Centre
SAFARI	Remote Sensing for Ecosystem Analysis and Fisheries
SCAFi	Society of Coastal Aquaculture and Fisheries
SCPUE	Standardized Catch per unit effort
SE	Southeast
SGR	Specific growth rate
SHGs	Self-help groups
SIED	Single Image edge detector
SLR	Sea Level Rise
SSH	Sea Surface Height
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SW	Southwest
TAT	Thematic Apperception Test
TEI	Training Effectiveness Index
TF	Total Fecundity
TL	Total length
UI	Upwelling intensity
UPI	Upwelling index
VI	Vulnerability index
VSS	Village survey schedule
WG%	Weight gain percentage
WR	Below-ground biomass
Wtop	Above-ground biomass
x_t	Value of the environmental variable at time t
β_k	Parameter for environment variable for lag kc
λ_l	Gear standardization parameter for gear l
ρ	density
μ	biomass ratio exponent parameter

Introduction

NICRA

National Innovations in Climate Resilient Agriculture (NICRA) is a network project of the Indian Council of Agricultural Research (ICAR) initiated in February, 2011. The project aims to enhance resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstration. The research on adaptation and mitigation covers crops, livestock, fisheries and natural resource management. The project consists of four components –

- Strategic Research
- Technology Demonstration
- Capacity Building
- Sponsored/Competitive Grants

Why NICRA?

Climate change has become an important area of concern for India to ensure food and nutritional security for growing population. The impacts of climate change are global, but countries such as India are more vulnerable in view of the high population depending on agriculture. In India, significant negative impacts have been implied with medium-term (2010-2039) climate change, predicted to reduce yields by 4.5 to 9 percent, depending on the magnitude and distribution of warming. Since agriculture contributes 16% of India's GDP, a 4.5 to 9% negative impact on production implies a cost of climate change to be roughly up to 1.5% of GDP per year. The Government of India has accorded high priority on research and development to cope with climate change in agriculture sector. The Prime Minister's National Action Plan on Climate Change has identified Agriculture as one of the eight national missions.

Climate Change and Indian Marine Fisheries Sector

Marine fish production in India has increased by six times in the last six decades. However, there are sustainability concerns such as production approaching the maximum sustainable yield, overcapacity in the fishing sector, open access to the fishery, degradation of habitats and trade-related issues. Climate change exacerbates the situation.

Sea surface temperature has increased by 0.2 to 0.3^{0}C along the Indian coast in the last 45 years, and is projected to increase by 2 to 3.5^{0}C by 2099. The projected sea level rise is 30 cm in 50 years. During the southwest monsoon, the wind speed, coastal upwelling strength and chlorophyll concentration also undergo changes in the Indian Ocean region. These changes are likely to influence the structure and function of marine ecosystems, on which evidences are accumulating. Species response to elevated temperature is different, showing changes in composition and abundance at the base of the food web.

Among marine fish, the more mobile species should be able to adjust their ranges over time, but less mobile and sedentary species may not. Depending on the species, the area it occupies may expand, shrink or be relocated. This will induce increases, decreases and shifts in the distribution of marine fish, with some areas benefiting while others lose. In the recent past small pelagics such as the Indian oil sardine and the Indian mackerel have extended their distributional boundary to northern and eastern latitudes. They have extended their distribution to midwaters as well. The threadfin breams are found to shift their spawning towards cooler months off Chennai. These distributional and phenological changes may have impact on nature and value of fisheries. If small-sized, low value fish species with rapid turnover of generations are able to cope up with changing climate, they may replace large-sized high value species, which are already showing declining trends due to fishing and other non-climatic factors.

In mariculture, elevated water temperature and changes in salinity and pH are likely to affect the spawning season, spawning strength and larval growth of candidate species. Seed and feed availability are also likely to be impacted due to climate change. Phytoplankton, which form food of larvae of culturable organisms, grow faster at elevated temperature, but the decay sets-in earlier. Generally, it is assessed that elevated temperature may enhance spawning success and growth rate of culturable organisms. Hence, there is a scope for harnessing the benefits of elevated temperature.

Despite the uncertainties and potential negative impacts of climate change on fisheries and aquaculture, there are opportunities to reduce the vulnerability to climate-related impacts. As the first step, projections on fish distribution, abundance and catches need to be developed; and for mariculture, suitable candidate species, which would be benefited by elevated temperature, need to be identified for planning better management adaptations. NICRA component of marine fisheries worked on following objectives

- Unraveling the effect of changing climate on the phenology, abundance and trophodynamics of identified species;
- Spatiotemporal mapping of marine resources;
- Identify the effect of environmental variables on larval distribution and plankton concentration;
- Vulnerability assessment of Indian marine fisheries sector;
- Carbon footprint and blue carbon assessment in marine fisheries sector;

- Climate modeling;
- Developing climate resilient technologies and products;
- Developing climate resilient villages.

The project was implemented in in 2011 and is currently in the second phase which commenced in 2017. The works carried out by ICAR-CMFRI were under four major thematic areas - Capture Fisheries, Mariculture, Coastal Ecosystems and Empowering Coastal Communities to Adapt to Climate Change.

Capture Fisheries

Temperature impacts on the fishery along Indian coast

Under this theme, changes in environmental parameters, especially temperature fluctuations occurring over a period of more than 40 years, were analyzed for their impact on the distribution, phenology, and survival of fishery resources along the Indian coast. In addition to individual case studies from various coastal regions, a comprehensive national analysis of vulnerability indices was conducted. This analysis provided a new perspective on the classical stock assessment of marine fisheries resources and aimed to offer a broad assessment of the vulnerability of fish and shellfish to climate change along the Indian coast. The findings of these studies will aid in prioritizing strategies for adaptation and mitigation measures to address climate change. Given the high reliability of projections regarding climate change, such as increasing temperatures and variations in current speed and direction according to various IPCC scenarios, fishery managers are left with no option but to make necessary adjustments in fishing pressure and methods to maintain fisheries sustainability. The current vulnerability ranking of species in different zones will serve as a useful tool for conserving species deemed highly vulnerable.

Climate change modelling and projections

Climate change models are computer programs designed to calculate the interactions between the ocean, atmosphere, and land. These models play a crucial role in helping us understand how our actions can impact future climate conditions. They are mathematical representations of the various components of the climate system and their interactions. Climate models aid in improving our understanding and prediction of climate behaviour across different time scales, from seasonal to centennial. Under the NICRA project at CMFRI, relevant methodologies, tools, and routines were developed to achieve tangible and interpretable outputs. These outputs aim to provide predictive qualifications and plausible outcomes based on Representative Concentration Pathway (RCP) scenarios, particularly concerning fisheries within the Indian Exclusive Economic Zone (EEZ). Modelling of Fish Biomass Dynamics using a multi-species multi-gear biomass dynamics model was employed to study species such as Indian oil sardine and seerfish. The results of these modelling studies will support the development of sustainable fishery management plans, with a specific focus on early catch of key species. Additionally, species-wise catch forecasts will assist in the formulation of state-wise fishery resources management plans.

Vulnerability of India's coastal villages to climate change

A vulnerability assessment of villages was conducted to determine the consistency of knowledge levels with the potential severity of climate change problems in coastal zones. Awareness among fisherfolk about climate change can be enhanced through village knowledge centres, providing daily information on climate-related changes, disaster warnings, preparedness, and rehabilitation measures in the event of climate-related incidents. A methodological framework was developed to assess the vulnerability of coastal districts and evaluate adaptation and mitigation options. This framework aimed to subsequently implement adaptation and mitigation strategies in vulnerable districts. The study facilitated preparation to provide timely information on the baselines of actual coastal changes, including local factors, sea-level rise, and climate and non-climate drivers. Additional observations and expanded monitoring through such centres could establish causal links between climate and coastal changes, supporting model development. The results of these vulnerability studies have been effectively utilized to establish networks between researchers and stakeholders, particularly in the states of Karnataka and Tamil Nadu. Extensive demonstration and capacity-building programs were conducted in selected villages to promote climate change awareness and foster climate-resilient communities. One significant outcome has been the development of Climate Smart villages in these two states.

Carbon footprint

Research focusing on understanding the role of marine fishing in greenhouse gas (GHG) emissions and how these emissions can be reduced to achieve greener production from marine fisheries was conducted. This assessment also helps us understand our position in terms of emission intensity per kilogram of fish production compared to global standards. Such projections are crucial in the global fish trade, where fish produced with lower emissions can command premium value. The study revealed that the emissions of CO_2 equivalent gases for producing one tonne of fish from Indian marine fisheries are lower than the emissions reported in global standards. Sector-wise and zone-wise studies were undertaken to comprehend emission intensity across different sectors and zones, enabling appropriate measures to mitigate emissions through the introduction of action plans. However, it is imperative to implement management measures to further reduce CO_2 emissions, thereby making India's marine fisheries greener.

Mariculture

Harnessing the beneficial impacts of changes in temperature for mariculture

The resilience of cultivable resources used in Indian mariculture to climate change, as demonstrated by temperature rise, salinity changes, and acidification of the culture medium, was investigated to identify the most suitable species for future mariculture programs. Individual studies on different species from various geographical zones of the country were conducted to understand their growth, reproduction, spawning, larval growth, and larval survival in response to these changes. The study also focused on how we can effectively utilize the increased growth of species, which is a positive impact of temperature rise, to enhance fish production in the country. Additionally, the impact of temperature on phytoplankton was examined, as molluscan resources and herbivorous fishes depend entirely on phytoplankton for their survival. Apart from temperature, the effects of salinity, light intensity, and pH changes were also studied. These studies aided in identifying appropriate species for mariculture activities and in implementing precautions to mitigate the negative impacts of climate change

Success stories - Climate resilient technologies and products:

ICAR-CMFRI has successfully implemented Integrated Multi-Trophic Aquaculture (IMTA) in collaboration with a fishermen group at Munaikadu (Palk Bay), Ramanathapuram district, Tamil Nadu. This initiative involves integrating seaweed cultivation with cage farming of cobia. Approximately 100 fishers in the district have benefited from this technology, and they continue to adopt it with their own investments. This project stands out as one of the success stories of the NICRA project. Similarly, the integration of fin fish culture with paddy-shrimp farming in Pokkali, Ernakulam district, Kerala, is another successful output of the NICRA project. Demonstrations showcasing the role of e-commerce as a socio-economic resilience strategy against climate change for fishing communities have also proven successful, benefiting the fishermen community. Additionally, demonstrations of improved monoline seaweed culture and low-cost cages have been adopted by fishermen with considerable success. Feed for the culture of pearl spot (*Etroplus suratensis*), as well as biofuel and biochar production from seaweeds and water hyacinth, are among the products developed through the NICRA project's research efforts.

Coastal Ecosystems

Mapping of coastal wetlands

Wetlands are areas where water covers the soil for varying periods, including during the growing season. They serve as transition zones between land and water, where the flow of water, nutrients, and the sun's energy converge to create unique ecosystems. In coastal areas, wetlands play crucial roles as water storage and purification points, as well as in maintaining the water table. Coastal wetlands such as mangroves, estuaries, lagoons, creeks, tidal/mud flats, and salt marshes were studied, and efforts to inventory wetlands along the Indian coast were initiated by NICRA and CMFRI as part of their conservation programs. Climate change events, including runoff influxes, stormwater discharges, and flooding, alter the physico-chemical profiles of several wetlands. This, in turn, leads to economic losses for fish farmers due to changes in wetland composition, loss of cages, and stock loss. A national resilience framework, envisioning an e-platform to link field-level datasets with spatial data, was developed through the NICRA project to facilitate monitoring and forecasting of regional wetland impacts. The Indian Space Research Organization (ISRO) – Space Applications Centre (SAC), Ahmedabad, already possesses datasets of smaller wetlands (<2.2ha) in the country, which are being updated with the assistance of ICAR-CMFRI using an android mobile application. A wetland of approximately 5 acres was restored and made suitable for aquaculture practice in Edakochi, Kerala. The restored wetland was used for multi-species farming of milkfish, pearl spot, and prawns.

Blue carbon potential of coastal ecosystems

The coastal ecosystems comprising mangroves, tidal marshes, and seagrass meadows serve as reservoirs for carbon stored over centuries. These ecosystems possess the potential to sequester and store large quantities of carbon, often referred to as 'blue carbon', per unit area compared to terrestrial forests. A study was conducted in selected mangroves and seagrass ecosystems to understand the carbon sequestration potential of these wetlands. Initially, mangroves in North Kerala and seagrass ecosystems in Tamil Nadu were analyzed as models for conducting similar studies along the entire coast in the future. Additionally, the carbon sequestration potential of farmed seaweeds was also included in the study. The significant potential of mangroves, tidal marshes, and seagrass meadows to sequester and store carbon in their biomass and sediments was well established in these studies, as well as in studies conducted elsewhere. This underscores the importance of mangrove ecosystems in mitigating climate change. Mangroves, apart from serving as large carbon storehouses, provide numerous ecological services; however, they are fragile and vulnerable to natural and man-made disturbances. Therefore, the conservation of existing mangroves and the restoration of mangroves in degraded habitats are urgent needs to capitalize on the benefits of these blue carbon ecosystems.

Empowering coastal communities to adapt to climate change impact

Technology demonstration & training

Technology demonstrations and training sessions were conducted to showcase the technologies developed by ICAR organizations for marine and brackish water cage farming. Coastal communities vulnerable to resource loss due to climate change were equipped with knowledge in cage farming. Collection, collation, and scientific analysis of locally available "Indigenous Technical Knowledge" from various parts of the country benefited fishermen and the entire coastal population. Illustrated documentation of this knowledge could assist fishermen at the field level.

Developing "Climate-Smart Villages"

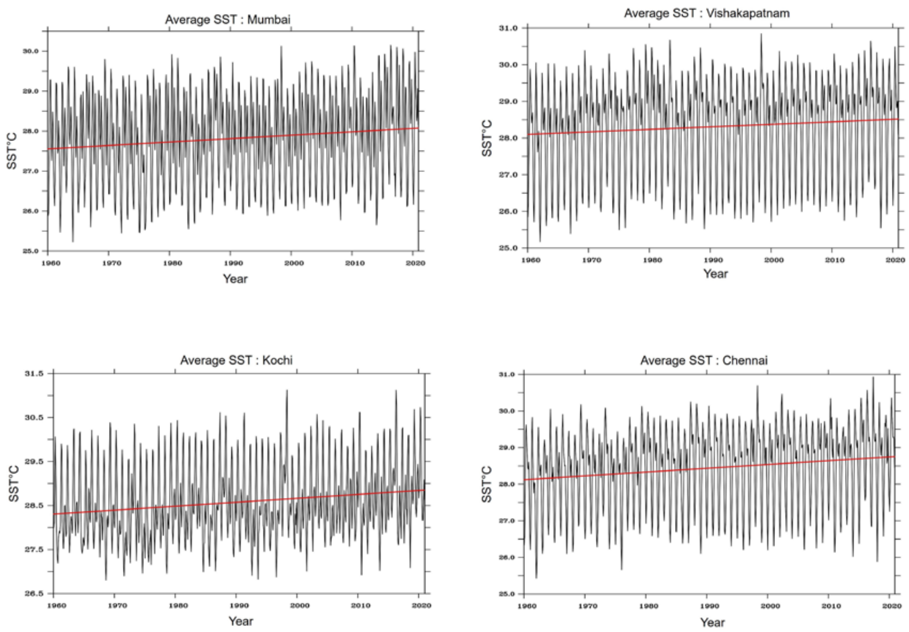
Adaptation and Mitigation (IDLAM) studies in Karnataka and Tamil Nadu led to the establishment of Climate Smart villages. Low returns from fisheries were projected as a major consequence of climate change, highlighting the immediate need for awareness regarding alternative vocations. Fisherwomen, involved in daily fish collection, transportation, and sales, found themselves jobless as income from fishing-related activities ceased entirely. An awareness workshop was conducted, wherein officials from agriculture, horticulture, livestock, and fisheries departments, along with KVK resource persons, explained potential activities to increase income from alternative sources. This aimed to prevent fishermen from resorting to unskilled sectors in urban areas by empowering them with knowledge of alternative income generation possibilities.

Capture fisheries

Temperature impacts on the fishery along Indian coast

Sea surface temperature (SST)

Increase in world temperature is projected to range from 0.3 to 6.4°C by 2090-2099 relative to 1980-1999[1]. The temperate and polar latitudes are predicted to experience a higher temperature change than tropical and subtropical latitudes. The variation of SST in Indian seas during the 40 years from 1976 to2015 revealed that it has increased by 0.602°C along northeast India, by 0.597°C along northwest India, by 0.690°C along southeast India and by 0.819°C along southwest India. However, the rate of change in SST was highest in northwest India (0.0156°C/annum) followed by southwest India (0.0132°C/annum), southeast India (0.005°C/annum) and northeast India (0.001°C/annum), indicating greater climate change impact along the west coast than the east coast. Unlike the Pacific and the Atlantic, the northern Indian Ocean region is facing unusual warming during El-Nino southern oscillation events during summer months due to the altered Walker Oscillation during such episodic events.



Sea Surface Temperature changes in temporal scale along Indian coast.

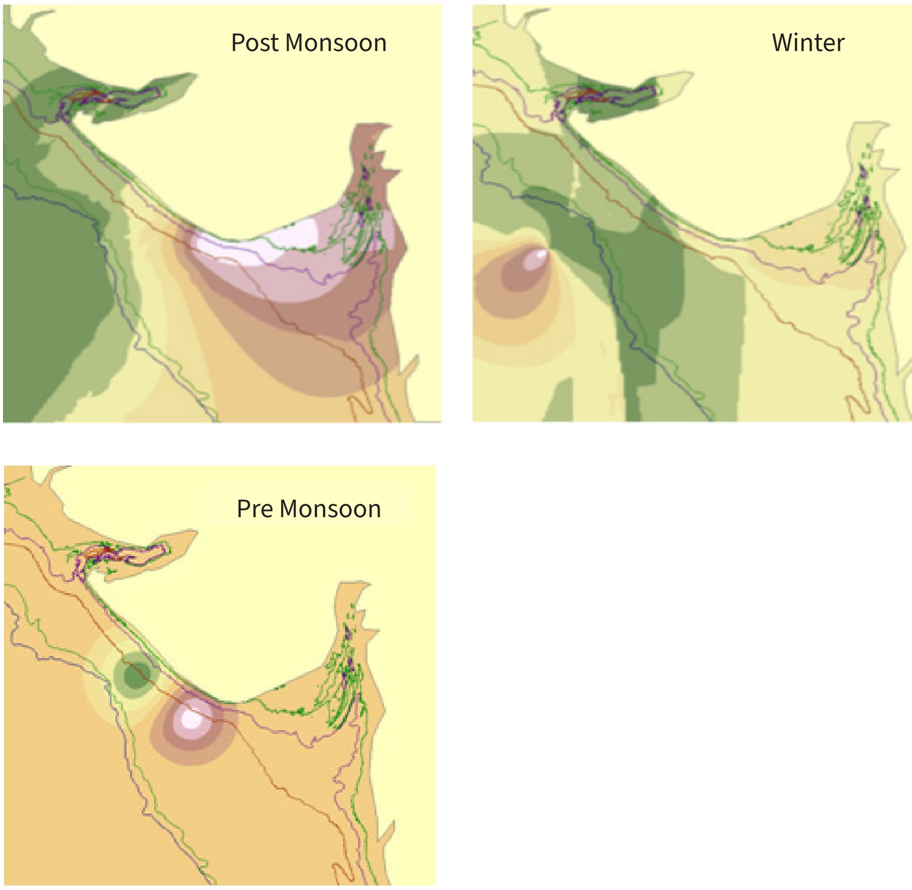
1 IPCC, 2007

Impacts on catch & distribution

Changes in seasonal distribution pattern of tunas in north-eastern Arabian Sea

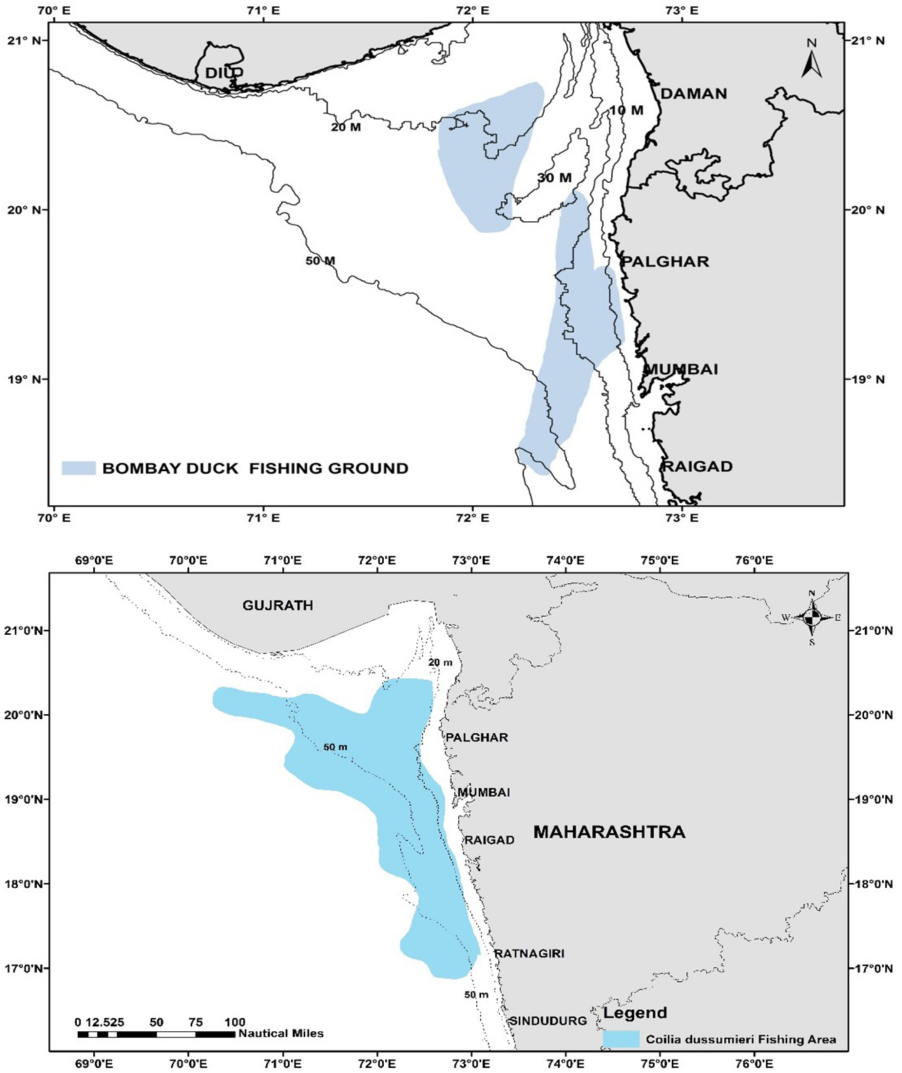
Tunas being active swimmers are highly migratory fishes and the shoals of species tend to aggregate at the places, where specific ecological and environmental conditions prevail[2]. Studies on larval distribution pattern of tunas across Gulf of Guinea and off Sierra Leone reveal the preference for higher water temperature[3].

Seasonal distribution pattern of skipjack tuna was studied using ordinary krigging interpolation method. Size of the fishes, as an indicator of their age, was taken into consideration for analysis. The results indicate abundance of skipjack tuna in the off shores areas (100 m zone) during winter months of November, December and January, when the surface SST is lower, whereas the migration is towards the inshore areas (30-50 m) zone during the pre-monsoon (March, April and May) and post-monsoon (September and October) seasons. The analysis revealed that both small size and large sized tuna showed migration to the deeper waters during winter season.



Seasonal differential distribution of different size of Katsuwonus pelamis in multiday gillnetters off Gujarat

2 *James and Jayaprakash, 1988*
3 *Richards and Simmons 1971*



Distribution maps for a. Bombay duck, Harpadon nehereus and golden anchovy Coilia dussumieri in north-eastern Arabian Sea along northwest coast of India

Mapping and catch composition studies of different species in north-eastern Arabian Sea

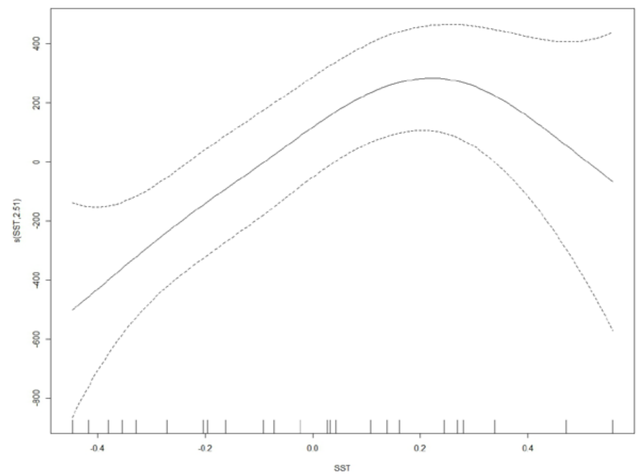
Geo-coordinated trawl and dol net catch data were used to map the distribution of Bombay duck, *Harpadon nehereus* and *Coilia dussumieri* using Arc10.1 software. These iconic resources of the northwest coast of India were found to be distributed mainly along the northern coast of Maharashtra and southern coast of Gujarat with maximum extension of depth up to 65m.

Influence of climatological parameters on the fishery of Indian oil sardine and Indian mackerel along southwest coast of India

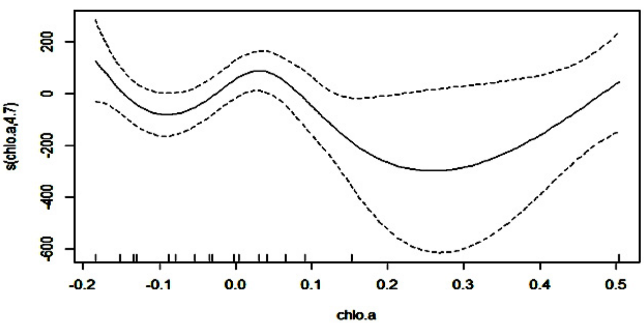
The anomalies of sea surface temperature (SST), coastal upwelling index (UPI), rainfall, multivariate ENSO index (MEI) and chlorophyll a (Chl *a* were analysed and correlated with catch rate anomalies of oil sardine and India mackerel exploited by purse seine in the coastal waters off Karnataka along southwest coast during the period1990-2014.

The catch rate anomalies of oil sardine showed a significant positive correlation with SST and negative statistical correlation with MEI. Such significant relationship was not observed in Indian mackerel. The correlation within the climatological parameters even though insignificant showed anomalies of sea surface temperature (SST) to be positive with rainfall; upwelling index positive with MEI and chlorophyll; MEI negative with chlorophyll-*a* and rainfall; and chlorophyll *a* negative withrainfall.

Generalized additive model (GAM) was used to relate the climatological parameters to variations in distribution of oil sardine and Indian mackerel. GAMs were constructed in R studio (vers. 3.2.2; R Development Core Team, 2015) using the gam function of the Mixed GAM Computation Vehicle (mgcv) package (Wood, 2006) with standardized CPUE as the response variable (dependent) and SST, UPI, Chl *a*, MEI and rainfall as predictor variables (independent) GAM results indicated good fit with mackerel catch rate anomaly and chlorophyll anomaly while for sardine good fit was observed with SST anomaly. R plot showed SST and Chl *a* to be a predicting factor for good distribution of oil sardine and Indian mackerel respectively. A temperature anomaly range of 0.1 to 0.3 indicating temperature of 28.10°C to 28.38°C seems to be favorable for sardine distribution and chlorophyll concentration of 0.50 to 0.59mg/m^3 for mackerel catch distribution.



Modeled (GAM) effect of SST anomaly on oil sardine catch rate anomaly. The x-axis shows the values of the explanatory variables, and the y-axis shows the results of smoothing the fitted values. The tick marks on the horizontal axis represent the values of the observed data points. The solid line shows the fitted GAM function and the black-dotted line indicates 95 % confidence intervals.



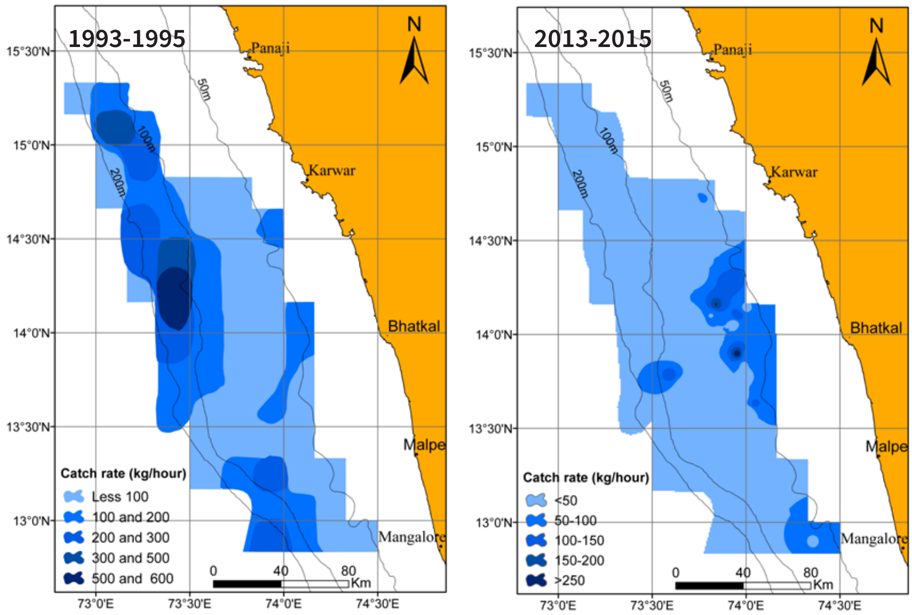
Modeled (GAM) effect of chlorophyll a anomaly on Indian mackerel catch rate anomaly. The x- axis shows the values of the explanatory variables, and the y-axis shows the results of smoothing the fitted values. The tick marks on the horizontal axis represent the values of the observed data points. The solid line shows the fitted GAM function and the black-dotted line indicates 95 % confidence intervals.

The GAM results indicated that for oil sardine SST of R-sq = 0.339 with 40.8% deviance and for Indian mackerel Chl *a* of R-sq =0.419 with 58.9% deviance were better than the other climatological factors (UPI, MEI, rainfall) and can be considered as a climatological predictor of catches in the region. The study also indicated a combination of SST and MEI anomalies had better deviance of 56% for oilsardine.

Distribution of threadfin breams off southwest coast of India

Experimental fishing done off Mangalore during 1993-95 covering depth range from 50-200 m indicated maximum abundance of threadfin breamsat 500-600 kg/h, while in 2013-15 it was about 250 kg/h. The temperature maximum during 1993-95 was 28.65^{0}C and minimum was 28.41^{0}C while during 2013-15 it was 29.85^{0}C and minimum was 29.54^{0}C. A relation between threadfin bream distribution and SST was observed.

SST had a positive and MEI showed a negative relation with the catch rate of oil sardine, whereas mackerel was influenced by *Chl a* concentrations. Temperature of 28.1°C to 28.38°C seems to be favourable for sardine distribution and chlorophyll concentration of 0.50 to 0.59 mg/m^3 for mackerel distribution. Hence distribution of oil sardine and Indian mackerel could also be predicted using SST and Chl *a*.

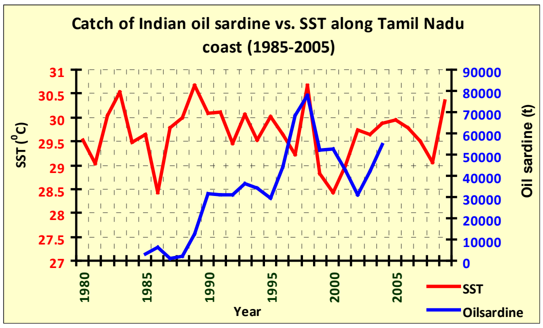


Spatio-temporal distribution of threadfin breams along southwest coast of India – comparison between 1993-1995 and 2013-2015

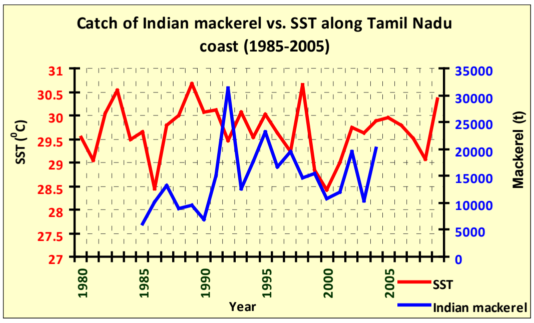
Relation between fish catch and SST along southeast coast of India

Catches of Indian oil sardine and Indian mackerel along north Tamil Nadu coast showed increasing trend over 20 years, corresponding with the increasing trend in SST.

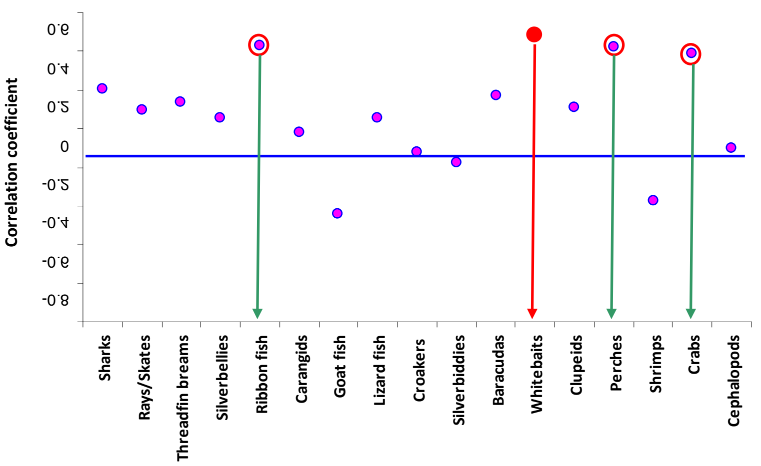
Analysis of the trawl landingsin north Tamil Nadu coast by trawl boats operating from Chennai in relation to the average annual sea surface temperature over a period of 10 years indicated that among the top 17 dominant resource groups, the catch of whitebaits showed significant positive correlation with increasing SST. Ribbonfish, perches and crabs also returned high 'r' values but fell short of being significant.



Catch of Indian oil sardine vs. SST along Tamil Nadu coast (1985-2005)



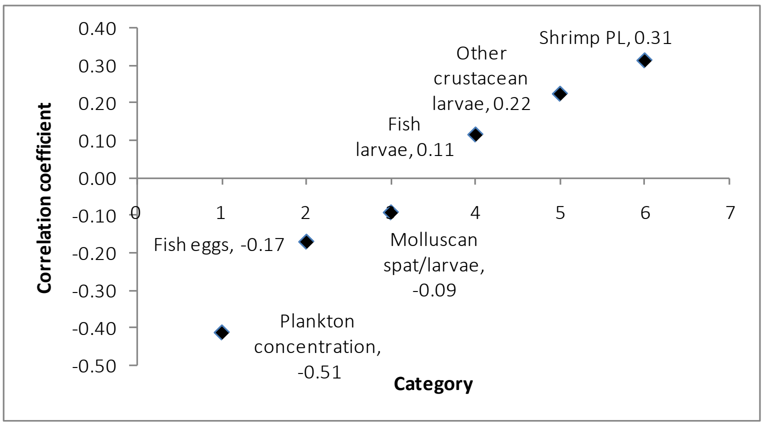
Catch of Indian mackerel vs. SST along Tamil Nadu coast (1985-2005)



Dispersion of Pearson correlation coefficient values for trawl landings of major fishery resources at Chennai vs. SST along north Tamil Nadu coast (1998-2007)

Impact of increasing SST on plankton and larval concentration along southeast coast of India

Marine plankton concentration along southeast coast showed a negative correlation with SST indicating that as SST increases plankton concentration decreases. With future scenarios of the IPCC predicting increase in SST, there is high probability of reduction in plankton concentration in coastal waters, which in turn could potentially have large-scale impacts on fish larval survival, growth and adult fish populations. A shift in the diet composition with dominance of phytoplankton instead of zooplankton and copepods was observed for Indian mackerel. These changes have occurred over a period of 40 years. Increase in SST would have resulted in the changes in dominance of plankton community in eastern Arabian Sea. This is an indication of the resilient strategy of the fish being able to adapt to climate change. Correlation analysis indicated that fish eggs and molluscan spat/larvae were negatively correlated with SST and conversely, fish larvae, shrimp post-larvae and other crustacean (crab and Squilla) larvae were positively correlated with sea surface temperature. Seasonal variations were seen in the concentration of fish eggs and shrimp post-larvae. Fish egg concentrations were highest in April and fish larvae concentrations were highest in June.



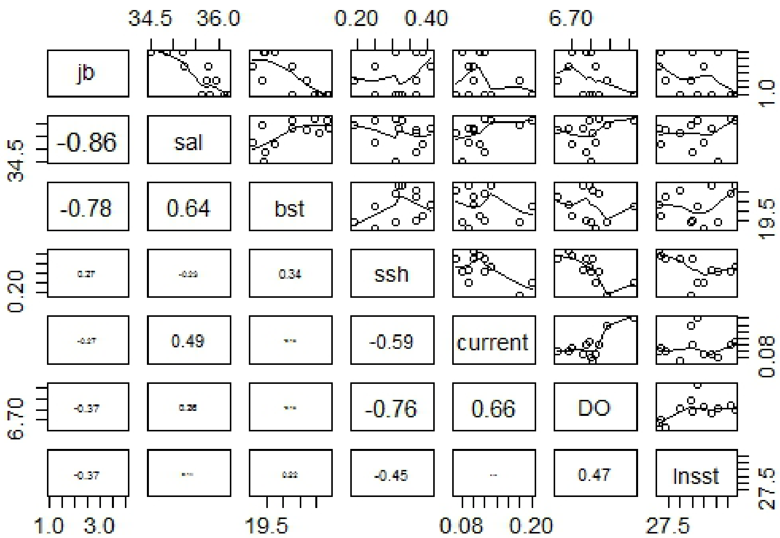
Correlation of occurrence of plankton, eggs and larvae with sea surface temperature off Visakhapatnam (2017-19)

Habitat preference and abundance of Indian mackerel in relation to environmental parameters along northwest coast of India

Studies on habitat preference of Indian mackerel with reference to environmental variables such as SST, Chl, Sea Surface Height (SSH), Sea Surface Salinity (SSS) and Mixed Layer Depth (MLD) revealed the preferred habitat range as 26-28°C (SST), 33-34.5 ppt (SSS), 0.37 m (SSH) and 10-15 m (MLD).

Jelly fish blooms

The abundance of jelly fishes during October, November and December months from Mumbai and Ratnagiri was correlated with the environmental parameters and found that the chances of bloom in Maharashtra are high when the salinity is below 35.5 ppt and the bottom sea temperature (BST) below 20.5°c.



Pair-plot of jelly fish abundance and environmental variables

Impacts on phenology of fishes

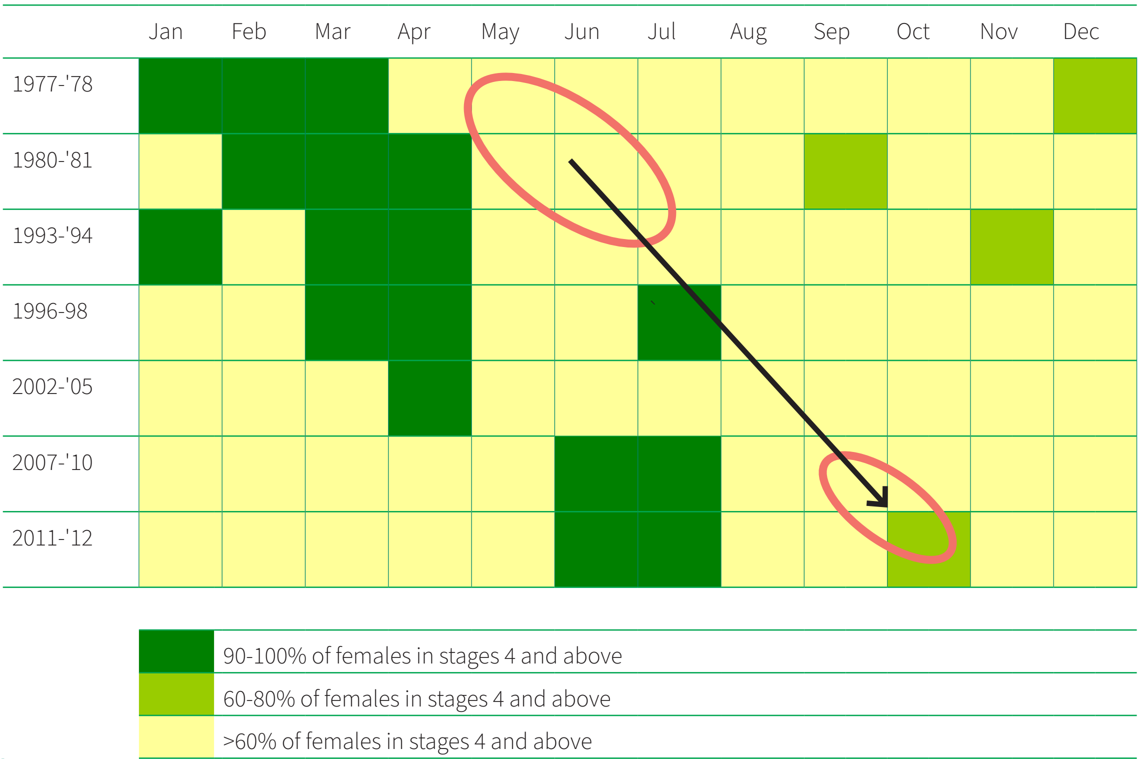
Shifts in peak spawning period of Indian oil sardine and Indian mackerel along southwest coast of India

Comparison of historic data of spawning periods of Indian oil sardine *Sardinella longiceps* and Indian mackerel *Rastrelliger kanagurta* were carried out. The period chosen was 1940-1966[4],[5],[6] and 1990-2011[7]. Peak spawning of *S. longiceps*showed a distinct shift from April-June in 1946 to June-August (monsoon season) in 2011.

Indian mackerel showed a shift of minor peak in spawning towards early part of the year when compared to 1962; however, the major peak was consistent during monsoon months.

Shift in peak spawning months of Indian oil sardine along southeast coast of India

A comparison of data collected (primary and secondary data) over a timeline on the availability of gravid and spawning females of Indian oil sardine along the north Tamil Nadu coast indicated a gradual shift in the spawning season from January-March during 1977-'78[8] to June in 2011-12[9].

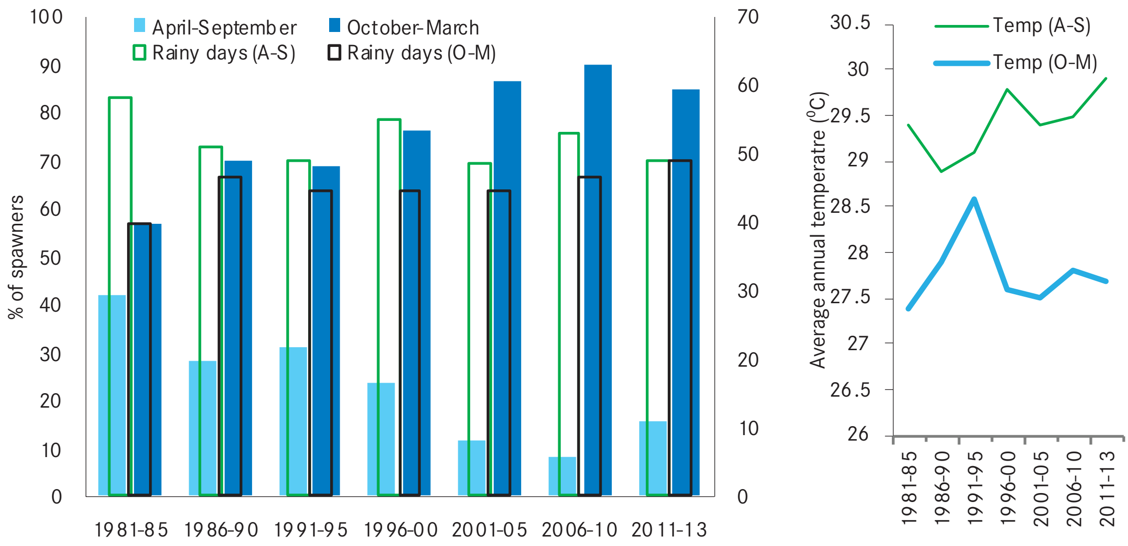


Distribution of Indian oil sardine females (gravid and spawning stages) in commercial fish landings at Chennai

4 *Chidambaram, 1950*
5 *Prabhuand Dhulkhed 1970*
6 *Rao, 1969*
7 *Database of ICAR-CMFRI at Mangalore RC and NICRA data*
8 *Girijavallabhan and Gnanamuttu, 1974*
9 *NICRA data at Madras RS of ICAR-CMFRI*

Temperature impacts on spawning and reproduction of major fishery resources along southeast coast of India

The Japanese threadfin bream *Nemipterus japonicus* showed a visible expansion in the spawning months over the years, with the spawning season extending to cooler months of November and December. Although the percentage of spawners showed variation between the years, the distribution of spawners remained higher in the colder months (October-March), which coincides with the NE monsoon and post-NE monsoon season along the Chennai coast. A positive correlation was found between spawning activity of the species and number of rainy days. Occurrence of adult *N. japonicus* showed positive correlation with rainfall and low temperature regimes.



Relation between % of spawners of N. japonicus, temperature and number of rainy days

Comparative study on spawning biology of the Japanese threadfin bream Nemipterus japonicus from Chennai and Mangalore coasts (2011-2013)

Although there is bound to be some overlap in the landings at different centres along both coasts due to migratory fishing practices, samples for this study were confirmed to have been obtained from the waters off the two study centres from the logbook records of the trawl boats and from enquiry with the fishermen. While latitudinal similarities exist, there are environmental differences between the east coast and westcoast, in terms of climatic conditions and hydrographic parameters. Initial comparisons were made on the basis of the SST and rainfall data available for the two coasts.

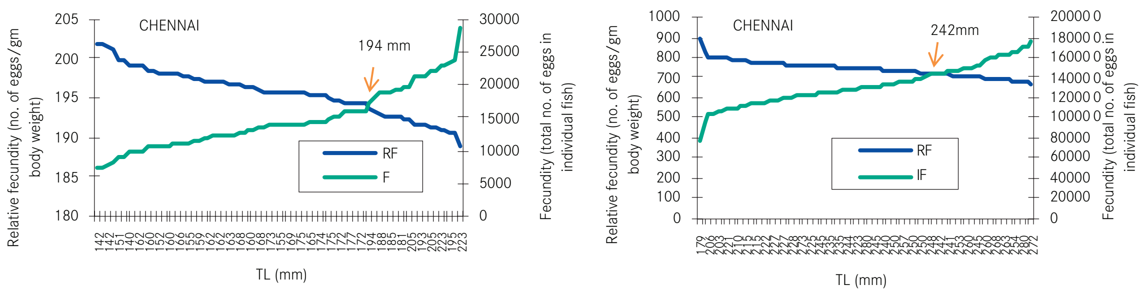
There is a marked difference in the length at first maturity, asymptotic length and fecundity of the species along the two coasts. The species appears to mature earlier, is of lower life span and has a lower fecundity along the southeast coast. Earlier studies have established a shift in the spawning peak of *N. japonicus* along the east coast towards cooler months (October-December[10]) in the recent decade. The analyses made in the current study also indicate a preference for lower temperatures with better reproductive output.

10 Vivekanandan and Rajagopalan, 2009

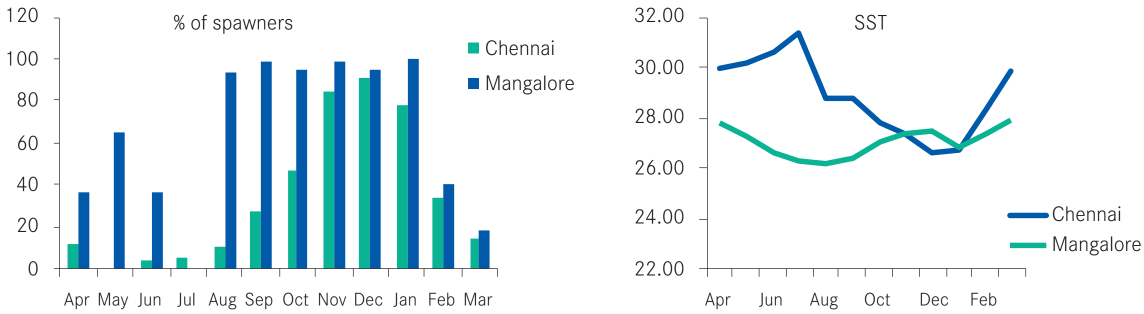
The Lm_{50} was in the range of 140-145 mm at Chennai while at Mangalore it was 165-180 mm at Mangalore. L_∞ estimates were 295 mm at Chennai and 330 mm at Mangalore. Lm_{50}/L_∞ (%) was 47.5% at Chennai and 50% at Mangalore. Fecundity estimates were 7,440-37,627 at Chennai and 38,500-5,71,913 at Mangalore.

The Relative Fecundity (RF, number of eggs produced per g body weight) was found to decrease with increase in total length (TL) at both Chennai and Mangalore while the Total Fecundity (TF, total number of eggs estimated for individual fish) increased with length. The point of crossover of RF and TF vs. TL was at 194 mm at Chennai and at 242 mm at Mangalore. These lengths were 66% and 73% in the L_∞ at Chennai and Mangalore respectively. As the viability of the eggs will decrease naturally with approaching senility, if maximum reproductive output occurs during the phase between Lm_{50} and 70-75% of L_∞ (i.e., about 80-85% of L_{max} recorded in the fishery), the proportion of decrease in RF towards the end of this phase is much higher in the species at Chennai than at Mangalore.

During 2011-2013, the average SST during April-September was 29.9°C at Chennai and 26.7°C at Mangalore while during October-March it was 27.8°C at Chennai and 27.3°C at Mangalore. The average SST off Chennai is always higher than that off Mangalore. However, corresponding to much higher SST during April-September off Chennai, the proportion of spawners was only 12.1% at Chennai, as against 60.1% at Mangalore. During October-March, the difference between the SST at the two centres was relatively less. The proportion of spawners was 74.7% at Mangalore and 58% at Chennai. The monthly SST was found to be higher at Mangalore during November, December and January. The proportion of spawners was greatest during these 3 months at Chennai, almost on par with the proportion at Mangalore, particularly in December.



Points of crossover between Relative Fecundity (RF) and Total Fecundity (TF) vs. Total Length (TL) for Nemipterus japonicus exploited off Chennai and Mangalore



Nemipterus japonicus spawner population vs. SST at Mangalore and Chennai

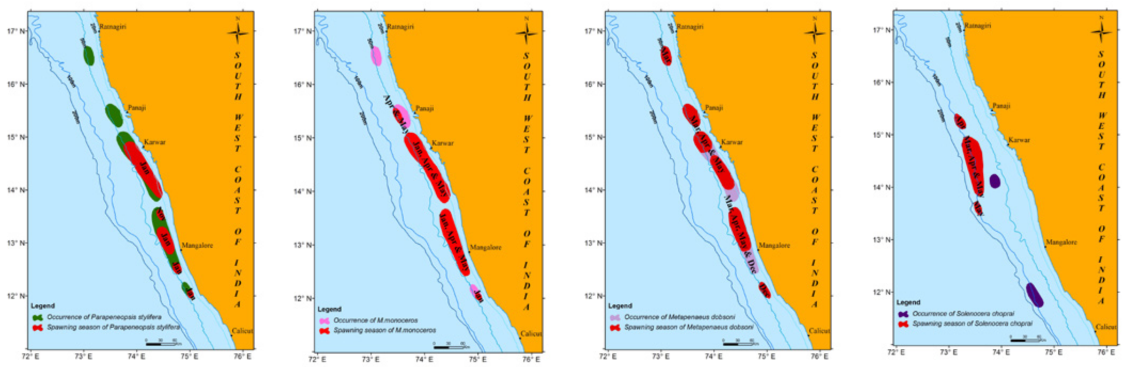
The results are indicative of the strong influence of temperature on the reproductive output of *N. japonicus*. The net reproductive output is always higher along the southwest coast, corresponding to relatively lower temperatures and higher rainfall. The species may respond to slight increase in temperature with early maturation and spawning, as evident along the southeast coast, but the net growth and recruitment may fall short of the optimum being realized at present. This will in turn affect the resilience of the fish (which is a commonly exploited resource) to bounce back into the fishery in the long term.

Role of environment in the spawning of commercial crustaceans along the southwest coast of India

Environmental characteristics, like temperature and salinity distribution in spawning grounds of crustacean resources off the southwest coast of India were investigated to understand the salinity/ temperature and depth preference in various species. Fishing grounds and spawning grounds of the prawns *Solenocera choprai, Metapenaus monoceros, Parapeanaeopsis stylifera* and *Metapenaeus dobsioni* and the crabs, *Portunus pelagicus, P. sanguinolentus* and *Charybdis feriata* were identified and illustrated with GIS mapping. Salinity and temperature features of these fishing grounds were collected during 2016-2019.

Table 1. Spatio-temporal and environmental profile of crustacean fishing and spawning grounds along southwest coast of India.

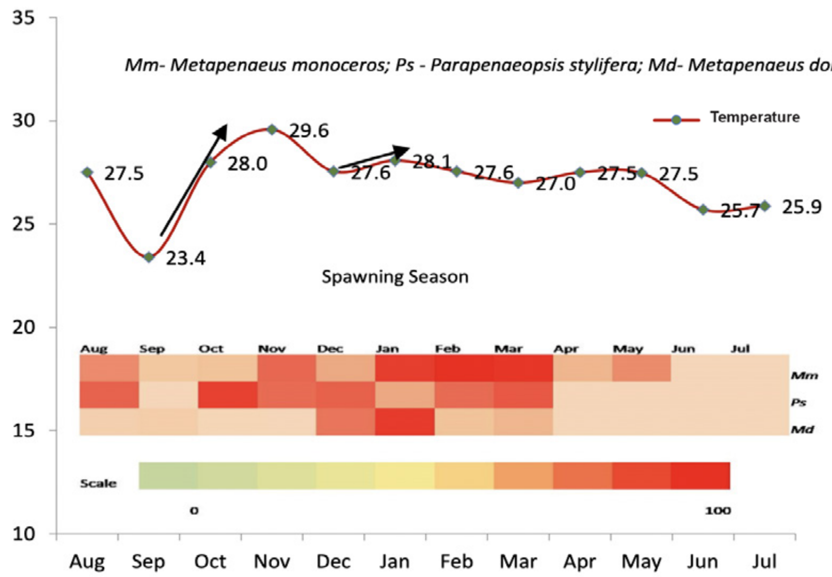
Species	Distribution range	Spawning, space, time and environment			
		Depth	Months	Salinity	Temperature
PRAWNS					
Solenocera choprai	30 -100m	70 -100m	Feb-Mar& Oct-Dec	32 to 35 ppt	27.1 to 28°C
Metapenaeus monoceros	upto 70m	20-70 m	Jan-Mar& Nov	33 to 35 ppt	27 to 28.5°C
Parapenaeopsis stylifera	upto 50m	20-50 m	Feb-Mar&Oct-Dec	33 to 34 ppt	27 to 30°C
Metapenaeus dobsoni	upto 50m	20-30m	Dec-Jan&Mar	33 to 35 ppt	27.5 to 29.5°C
CRABS					
Portunus pelagicus	upto 50m	20-30m	Sep-Nov&Feb-Mar	33 to 35 ppt	27.5to 29.5°C
Portunus sanguinolentus	upto 70m	20-50m	Feb –Apr & Aug	33 to 34 ppt	27 to 30°C
Charybdis feriata	upto 100m	30-100m	Sept-Nov	33 to 35 ppt	27.1 to 29°C



P. stylifera ***M. monoceros*** ***M. dobsoni*** ***S. choprai***

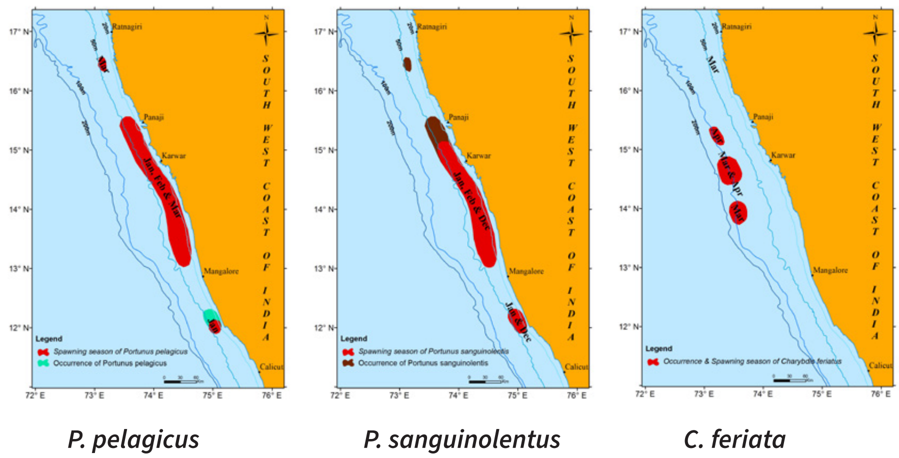
Spato-temporal mapping of fishing grounds of commercially important prawns along southwest coast of India.

To understand possible cues inducing maturity in commercial crustacean species along the Karnataka coast, the monthly distribution of the percentage of mature females was compared with the average bottom water temperature collected during respective months. Different temperature criteria were used for comparison for each species according to the distribution of matured females. In the case of *M. dobsoni, P. stylifera,* and *M. monoceros*, which had a wider distribution within 50 m, the average of the bottom water temperature profile of 50 m and less depth was used, whereas in *S. choprai*, which had matured female distribution beyond 50 m, the average temperature collected from 50 to 10 m depth was used for the analysis.

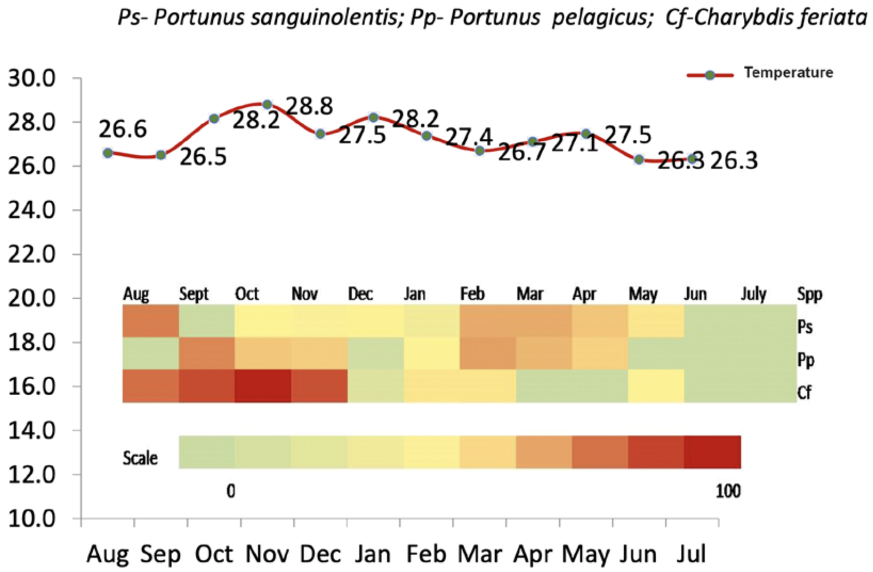


Spawning season of some commercially important prawns along southwest coast of India vis-à-vis sea bottom water temperature.

A temperature change from prevailing lower temperature to higher temperature was found to induce maturity in most of the prawns, as seen in October for *P.stylifera* and January-March in *M. monoceros* and *M.dobsoni.*In the case of *S. choprai,* where the bottom water temperature above 50 m depth was taken for comparison, the relationship was not conclusive.



Spatio-temporal mapping of fishing grounds of commercially important crabs along southwest coast of India.



Spawning season of some commercially important crabs along southwest coast of India vis-à-vis sea bottom water temperature.

In crabs, monthly profile of the temperature of all depths was compared with the maturity, and there also, the increase of bottom water temperature was found to induce maturity in all the crab species with varying intensity in a conclusive manner.

Climate change impacts on diet of marine fishery resources

Shift in diet of Indian mackerel Rastrelliger kanagurta

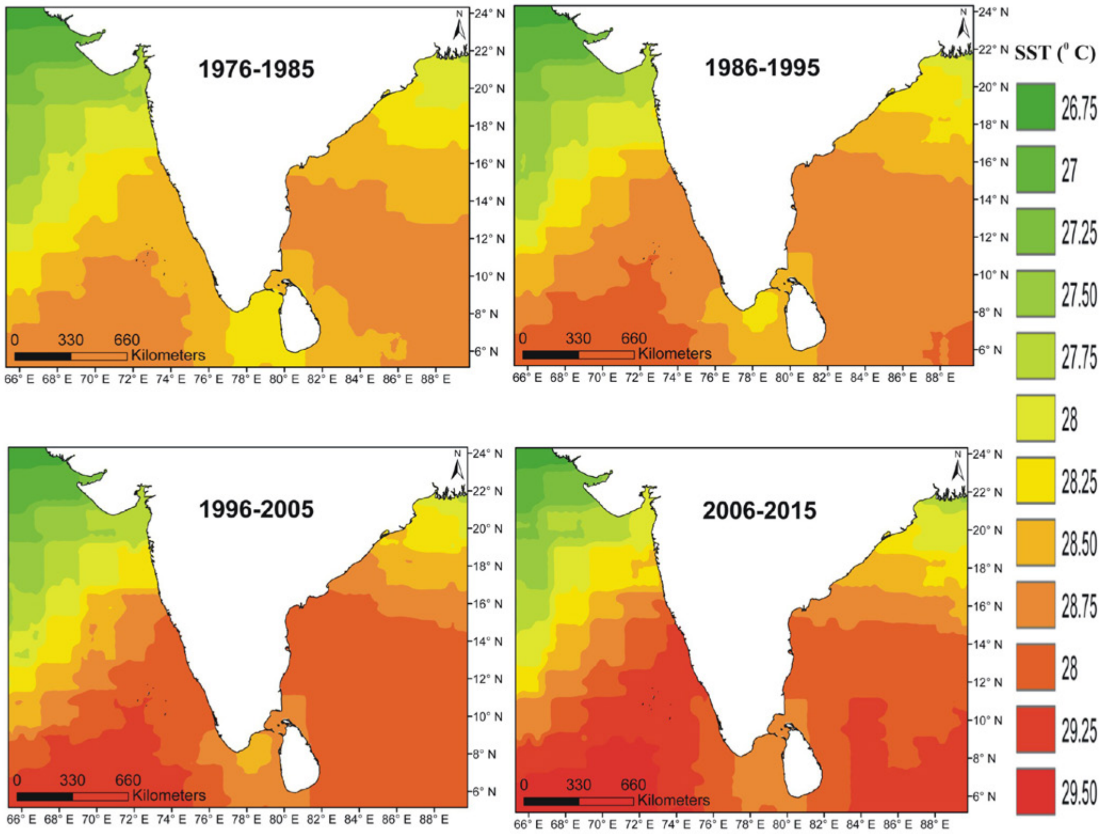
The seasonal and long-term variation in feed composition of mackerel and its relationship with sea surface temperature were studied to elucidate structural changes in food composition if any, over the period of time and its relationship to the primary and secondary productivity in the marine ecosystem in eastern Arabian Sea. The diet study during 1960-61[11] reported the dominance of zooplankton, copepods, whereas present observation showed a consistent dominance of phytoplankton comprised mostly of *Coscinodiscus* sp. during 2011-14. The present study shows that changes occurred in the feed composition of Indian mackerel over a period of 40 years. Increase in SST would have resulted in the changes in dominance of plankton community in the eastern Arabian Sea. The study also indicates that the mackerel is a facultative feeder adapting to the changes and is a resilient species.

11 Noble, 1962

Relative vulnerability of fishes

Assessment of the vulnerability of individual fish and invertebrate species to climate change is a prerequisite to understand or predict changes in the species composition and abundance in a particular region. While it is an established fact that climate change influences the marine environment, distribution and abundance of marine species and their phenology in spatial and temporal scales, the impact of climate change on marine organisms may not be uniform for all species and regions as it depends on the biological and behavioural characteristics of the organisms[12].

Investigations on the impact of climate change on many economically important marine species have been carried out in different parts of the world[13,14,15,16,17]. Such studies usually require considerable time and resources. A transparent assessment methodology was developed by Morrison et al., (2015)[11] to determine the relative vulnerability of fish stocks to changing climate. The assessment considers the impacts



Sea Surface Temperature anomaly during 1976-2015 in the Seas around India.

of climate change induced by anthropogenic influences and natural factors. Most vulnerability assessment methods are based on two components–exposure and sensitivity of the species to different criteria, which include environmental parameters (exposure attributes), species biological characteristics and anthropogenic influence on the species (sensitivity attributes). Several studies have been carried out using similar methodologies[18,11]. Some studies incorporate a third component, adaptive

12 Morrison et al. 2015
13 Hollowed et al. 2009
14 Hare et al. 2010
15 Hazen et al. 2012
16 Plaganyi et al. 2013
17 Wayte 2013
18 Pecl et al. 2014

capacity[19,20,21] defined by biological characteristics that aid the species to overcome the negative impacts of high sensitivity or exposure. Some studies combine adaptive capacity with sensitivity[22,11].

Need for a method suitable for Indian conditions: The criteria developed in earlier studies were most suitable for temperate and semitropical countries where species diversity is less, and there are relatively few methods of fishing operations. For a tropical country like India with wide variations in environmental parameters and a marine fishery which is characteristically multi-species, multi-gear, and multi-ground, these criteria are insufficient to present a true picture of species vulnerability. Moreover, in India which is spread over large geographical area with different climatic conditions, the exposure factors differ between regions. Therefore, following the methodology described in earlier studies, sets of environmental, biological and fishery-based criteria were developed to suitably define the characteristics of tropical Indian species of fishes and invertebrates and their fishery in the region, top-down approach was adopted for developing the criteria for vulnerability assessment[23] with baseline information classified through a series of expert opinion workshops on the subject. A working group of eighteen scientists working on different groups of finfishes and shellfishes, from different geographical zones of the Indian coast and an expert consultant with sound knowledge on stock characteristics, biology and ecology, interacted at three national workshops and evolved a suitably modified methodology to be adopted for different species in various zones.

Peninsular India extends down from the Arabian Sea bordering the Gulf of Kutch on the northwest coast up to Cape Comorin overlooking the Indian Ocean at the southern tip of the country and further north along the Coromandel coast bordering the Bay of Bengal, up to the Sunderbans on the northeast coast of India. The Indian coast exhibits wide diversity in climatic and oceanic conditions, in terms of temperature ranges, precipitation levels, length of seasons, rainfall, riverine flow, wind patterns, current patterns and coastal upwelling. The wide variation in climatic conditions demands evaluation of zone-wise species vulnerability along the coast. Based on this, the coast was divided into four different geographical zones viz. northeast (NE), northwest (NW), southwest (SW) and southeast (SE).

Selection of species

Preliminary analysis of historical data on fishery showed that there is a wide variation in the species composition and biological responses of the species in different geographical zones. Accordingly, about 30-36 major commercially important finfishes and shellfishes were selected for the study from each zone, with catch-dependent weighted representation of pelagic, demersal, crustacean and molluscan resources. In all, 68 species were selected, of which many were common to two or more zones and some were characteristic to a particular zone. Thirty-two species were selected from the NE coast, 36 from the NW coast and 30 each from the SE and SW coasts. Species selection was done based on abundance of a species in a particular zone, its contribution to the fishery, economic importance, growth and reproductive performance and prey-predator interactions. Considerable variation was observed in the distribution of adults and juveniles of the same species within the water column. The biology of the species was also diverse on many counts. Some species had wide distribution (seerfishes, ribbonfishes, mackerel sardine, lizardfishes, shrimps, cephalopods) and some restricted distribution (Bombay duck, some species of croakers, and shrimps). Most of the species were broadcast spawners with pelagic

19 Chin et al. 2010
20 Johnson and Welch 2010
21 Glick et al. 2011
22 Williams et al. 2008
23 FAO 2015

Table 2. Species selected for vulnerability assessment

No	Group	Scientific Name
1	Pelagic	*Chirocentrus dorab*
2	Pelagic	*Chirocentrus nudus*
3	Pelagic	*Coilia dussumeri*
4	Pelagic	*Coryphaena hippurus*
5	Pelagic	*Decapterus russelli*
6	Pelagic	*Encrasicholina devisi*
7	Pelagic	*Euthynnus affinis*
8	Pelagic	*Harpodon nehereus*
9	Pelagic	*Katsuwonus pelamis*
10	Pelagic	*Megalaspis cordyla*
11	Pelagic	*Mugil cephalus*
12	Pelagic	*Rastrelliger kanagurta*
13	Pelagic	*Sardinella fimbriata*
14	Pelagic	*Sardinella gibbosa*
15	Pelagic	*Sardinella longiceps*
16	Pelagic	*Scomberomorus commerson*
17	Pelagic	*Scomberomorus guttatus*
18	Pelagic	*Sphyraena jello*
19	Pelagic	*Sphyraena obtusata*
20	Pelagic	*Stolephorus indicus*
21	Pelagic	*Tenulosa ilisha*
22	Pelagic	*Thunnus tonggol*
23	Pelagic	*Thunnus albacares*
24	Pelagic	*Trichiurus lepturus*
25	Demersal	*Carcharhinus limbatus*
26	Demersal	*Cynoglossus macrostomus*
27	Demersal	*Epinephelus diacanthus*
28	Demersal	*Himantura imbricata*
29	Demersal	*Johnius carutta*
30	Demersal	*Lactarius lactarius*
31	Demersal	*Nemipterus japonicus*
32	Demersal	*Nemipterus randalli*
33	Demersal	*Otolithes cuvieri*
34	Demersal	*Otolithes ruber*
35	Demersal	*Otolithus biauritus*
36	Demersal	*Pampus argenteus*
37	Demersal	*Parastromateus niger*
38	Demersal	*Pennahia anea*
39	Demersal	*Plicofollisdussumieri*
40	Demersal	*Plicofollis tenuispinis*
41	Demersal	*Priacanthus hamrur*
42	Demersal	*Protonibea diacanthus*
43	Demersal	*Saurida undosquamis*
44	Demersal	*Saurida tumbil*
45	Demersal	*Scoliodon laticaudus*
46	Demersal	*Sphyrna lewini*
47	Demersal	*Upeneus sulphureus*
48	Demersal	*Upeneus vittatus*
49	Crustacean	*Acetes indicus*
50	Crustacean	*Charybdis feriata*
51	Crustacean	*Fenneropenaeus merguiensis*
52	Crustacean	*Metapenaeopsis stridulans*
53	Crustacean	*Metapenaeus dobsoni*
54	Crustacean	*Metapenaeus monoceros*
55	Crustacean	*Metapenenaeus affinis*
56	Crustacean	*Panulirus polyphagus*
57	Crustacean	*Fenneropenaeus indicus*
58	Crustacean	*Penaeus monodon*
59	Crustacean	*Penaeus semisulcatus*
60	Crustacean	*Parapenaeopsis stylifera*
61	Crustacean	*Portunus pelagicus*
62	Crustacean	*Portunus sanguinolentus*
63	Crustacean	*Solenocera crassicornis*
64	Molluscs	*Perna viridis*
65	Molluscs	*Sepia aculeata*
66	Molluscs	*Sepia pharonis*
67	Molluscs	*Sepiella inermis*
68	Molluscs	*Uroteuthis (Photololigo) duvaucelii*

eggs and larvae and occupied a range of trophic levels. Of the 68 species, 3 species were elasmobranchs, 45 teleosts, 15 crustaceans and 5 molluscs. Only one mollusc species, *Perna viridis*, was of sedentary nature.

Vulnerability Assessment Design and Selection of Attributes

The primary assumption behind the vulnerability assessment methodology used is that current biological performance indices and expected exposure to climate change can be used to evaluate the relative vulnerability of a species[24],[25],[26],[27],[28].

While exposure (E) is the projected magnitude of change in the physical environment due to climate variations, and defines the nature and degree to which a species is exposed to climatic variations, sensitivity (S) indicates the extent to which a species

Table 3. Exposure attributes with zone-wise and realm-wise weightage

Zone	Realm	Attribute & weightage			
		SST	Current speed	Current direction	Upwelling
NW	Pelagic	1.5	2	2	0.75
	Column	1.25	2	2	0.75
	Demersal	1.0	2	2	0.75
SW	Pelagic	1.5	2	2	0.5
	Column	1.25	2	2	0.5
	Demersal	1.0	2	2	0.5
SE	Pelagic	1.5	2	2	1.0
	Column	1.25	2	2	1.0
	Demersal	1.0	2	2	1.0
NE	Pelagic	1.5	2	2	1.0
	Column	1.25	2	2	1.0
	Demersal	1.0	2	2	1.0

Table 4. Sensitivity attributes with scale limits for impact scoring

Attributes	Low impact	Medium impact	High impact
	1	2	3
Fecundity	More than 0.5 million Eggs per spawner	1000 to 0.5 million eggs per spawner	Less than 1000 eggs per spawner
Complexity in early development	Parental care Pelagic eggs with simple larval development	Demersal eggs	Complex life cycle with different larval stages
Growth coefficient	More than 1	0.51 to 1	Less than 0.5
Trophic level	Less than 3	3-3.9	More than 4
Longevity/Life span	Less than 2.5 years	2.5 to 5 yrs,	More than 5
Length of capture (Lc)/ Length at maturity(Lm)	>0.8	0.6-0.79	<0.6
Anomaly in CPUE*	≥1	≥ 2	> 3
Exploitation rate	<0.5	0.51-0.7	>0.7
Price	Below Rs 100	100-350	More than 350

24 *Chin et al. 2010*
25 *Johnson and Welch 2010*
26 *Foden et al. 2013*
27 *Pearson 2014*
28 *Pecl et al. 2014*

Table 5. Adaptive capacity attributes with scale limits for adaptability scoring

Attributes	Low	Medium	High
	1	2	3
Horizontal distribution	Less than 5 states	5 to 7 states	Distribution in 8to 9 states (at least 0.5%)
Vertical Distribution	80% catch in depth specific gears	26-79% catch in 2 depth specific gears	Upto 25% catch from 3 or 4 depth specific gears
Duration of spawning	Less than 4 months	Extends from 4 to 7 months	Spawning extends for 8 months
Prey specificity/No. of prey groups/Niche breadth	Narrow (<0.3)	Medium (0.31-0.69)	Broad (>0.7)

is affected due to its life history traits influenced, either adversely or beneficially, by anthropogenic activities, and, adaptive capacity (A) defines the ability (or potential) of a species to adjust successfully to climate or environmental change. In this study, we chose to represent the three components as separate sets of attributes. Based on the attributes, each component was assigned a score. Vulnerability (V) was then estimated from the relation:

$$V = (E+S)-A$$

Observations

Out of 23 pelagic species assessed, 4 species in northwest zone, 1 species in southwest zone, 11 species in south east zone and 11 species in northeast zone were found to have high vulnerability index. Out of 15 crustaceans assessed, 1 species in northwest, 3 species in southwest, 4 species in southeast and 3 species in northeast were found to have high vulnerability index. Out of 24 demersal species assessed, 4 species in northwest, 6 species in southwest, 7 species in southeast, and 7 species in northeast were found to have high vulnerability index. Out of 5 molluscs species assessed, 1 species in northwest, 1 species in southwest, 1 species in southeast were found to have highvulnerability index.

Climate vulnerability

Increasing temperature was the most important driver in climate change. There was zone-wise differentiation in the exposure range for climatic variabilities. Except for the northeast zone, the ranking tended towards moderate vulnerability, with a scoring range of 1.33-1.73. In the northeast zone, the range was 1.66-2.21. The anomalies of climate variables were high along the northeast and northwest zone, whereas they were moderate in the other zones. Temperature anomalies were high along the northeast and southeast zones. Climate exposure ranking of pelagic species was comparatively higher than that of demersal species.

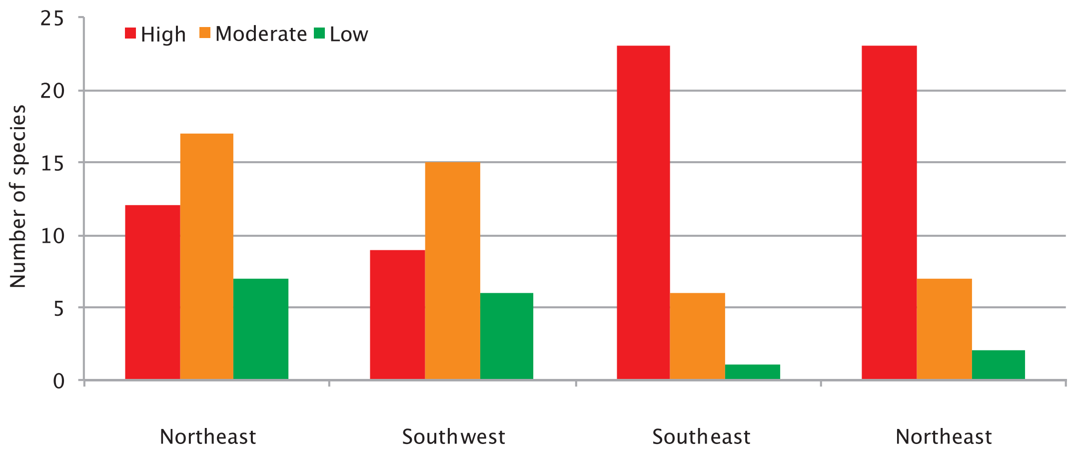
Impact on the species

Ranking of impact, an additive index of exposure and sensitivity attributes, was classified into high, medium and low for the 68 species assessed for vulnerability. There was zonal variation in the dispersion of species with respect to sensitivity and climatic vulnerability (Exposure). Mean sea surface temperature (SST) anomalies, mean upwelling index, current speed and current direction were considered to be important factors in climatic variability score. The climatic variability score was medium in all the zones. The exposure and sensitivity attributes scored high for some species in northeast. In general, most of the species showed medium vulnerability to climate along the Indian coast. In northwest zone, 23% of the species studied ranked high in sensitivity attributes, while it was 30% in southwest zone, 43% in southeast and only 6% in northeast zone. In the northeast zone 31% of the species had high exposure and sensitivity ranking (seerfishes, tunas, ribbonfishes, barracudas, threadfin breams, lizardfishes and croakers). Medium sensitivity and high exposure ranking was obtained for 59% of the species studied along northeast zone (sardines, mackerel, dolphinfish, hilsa, threadfin breams, goatfishes, bullseye, shrimps and crabs). The anomalies in climate variables in the northeast zone were high when compared to the other zones. Values of Lc/Lm and the exploitation rate which denotes the fishing pressure on individual species contributed significantly to the high vulnerability ranking of many species for sensitivity and exposure attributes.

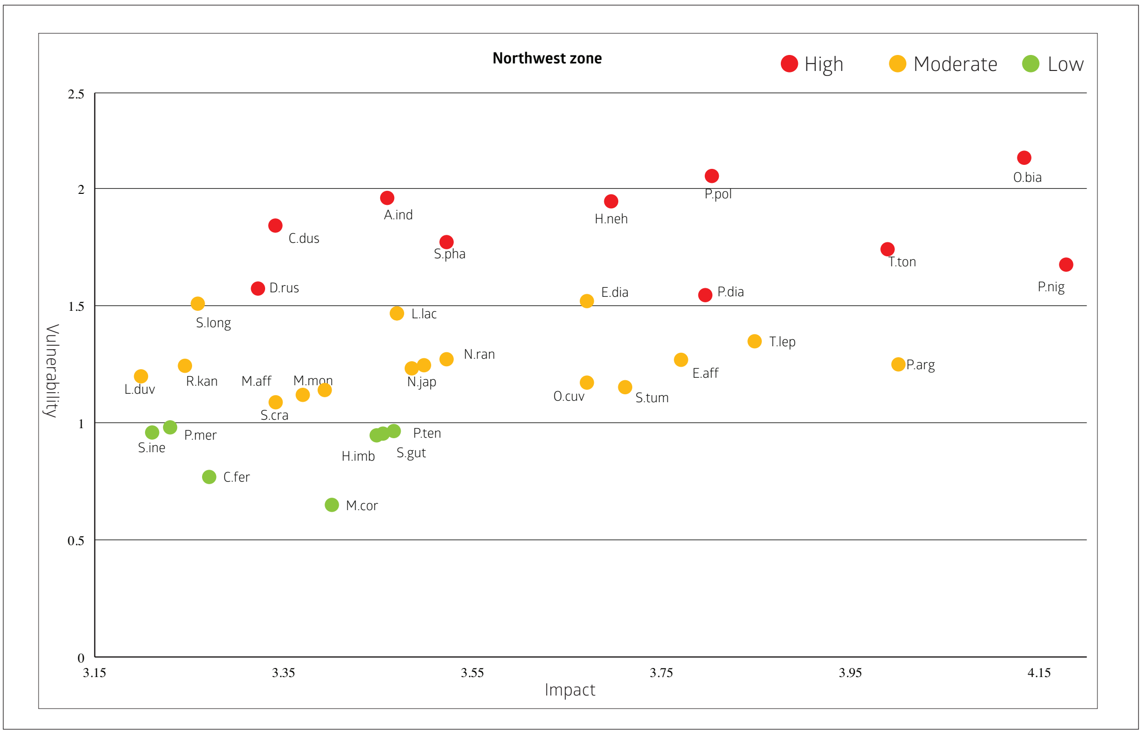
Impact and Adaptive Capacity scoring

Vulnerability scoring for each species was done zone-wise, based on the impact and its adaptive capacity. The results indicate that the east coast species are more vulnerable to climate change when compared to west coast. About 69% of the species studied were highly vulnerable along the Indian coast. Along the east coast, 72% of the species studied were highly vulnerable in the northeast zone, while 77% were highly vulnerable in the southeast zone. In the southwest and northwest zones, 30% and 33% (of the species studied) respectively were highly vulnerable.

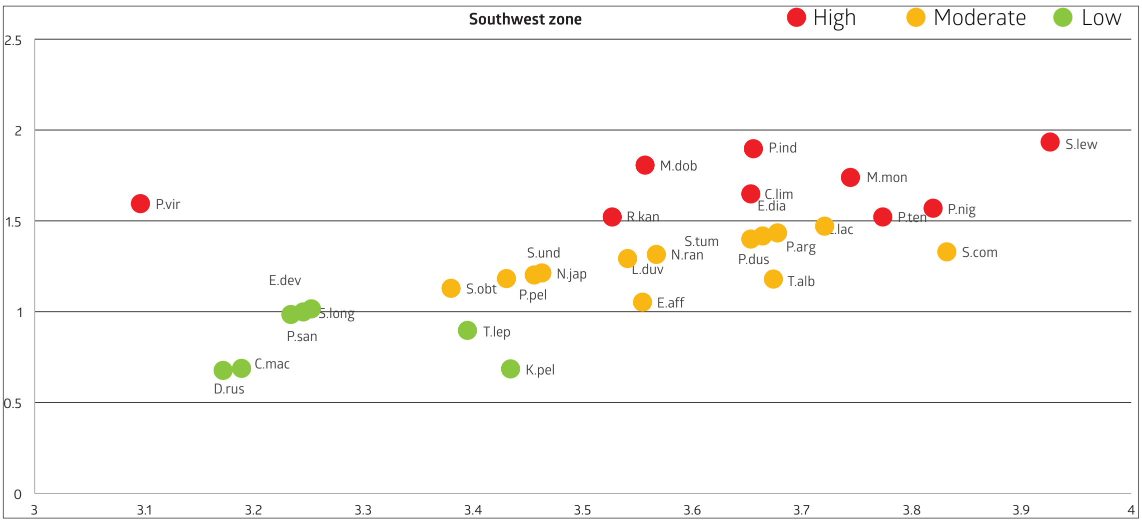
About 83% of the pelagic fishes studied were highly vulnerable, followed by demersal fishes (66%), molluscs (60%) and crustaceans (53%). *Metapenaeus monoceros* and catfish *Plicofollis tenuispinis* were assessed as highly vulnerable in the southwest, southeast and northeast zones. Black pomfret *Parastromateus niger* was assessed as highly vulnerable in the southwest, southeast and northeast zones. Tunas *Katsuwonus pelamis* and *Thunnus albacares*, threadfin bream *Nemipterus japonicus*, shrimp *Penaeus monodon*, lesser sardine *Sardinella gibbosa*, lizardfishes *Saurida tumbil* and *Saurida undosquamis*, seerfish *Scomberomorus commerson*, barracuda *Sphyraena*



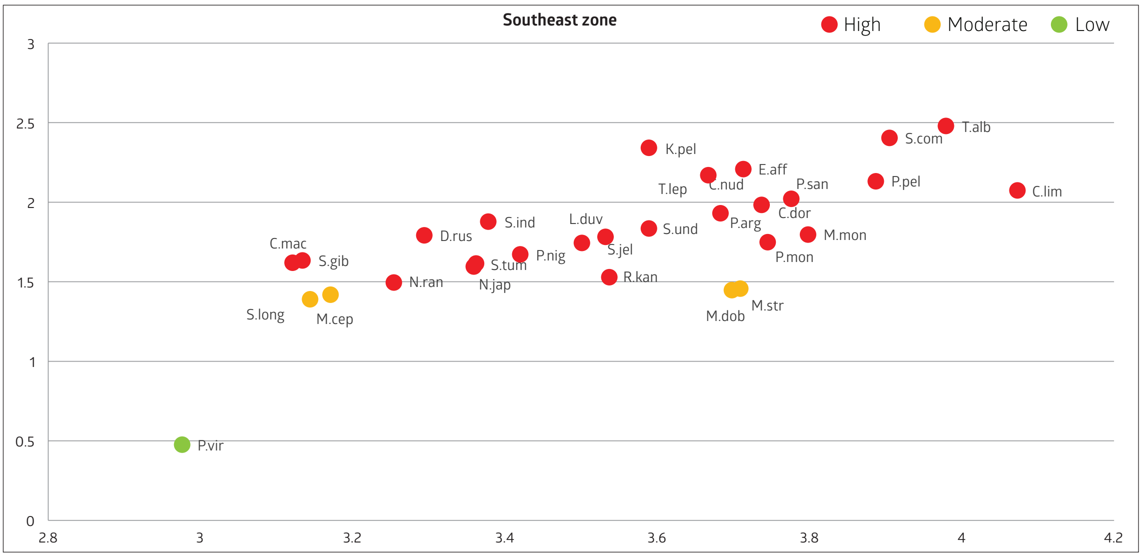
Zone-wise dispersion of species (numbers) based on vulnerability assessment.



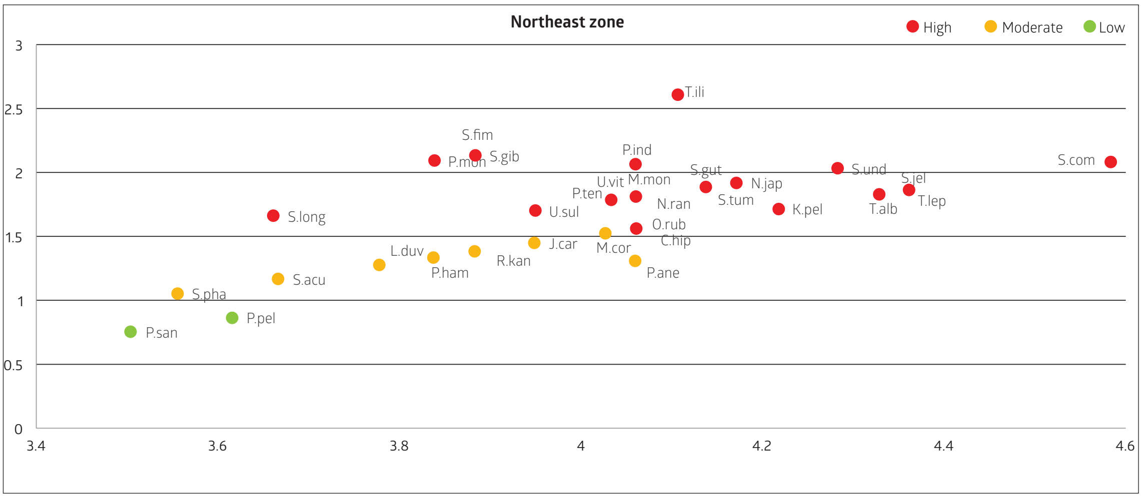
Acetes indicus (A.ind), Plicofollis tenuspinis (P.ten), Charybdis feriata (C.fer), Coilia dussumeiri (C.dus), Decapterus russelli (D.rus), Euthynnus affinis (E.aff), Epinehelus diacanthus (E.dia), Himantura imbricata (H.imb), Harpadon nehereus (H.neh), Lactarius lactarius (L.lac), Urotheuthis (Photololigo) duvaucelii (L.duv), Megalaspis cordyla (M.cor), Metapenaeus affinis (M.aff), Metapenaeus monoceros (M.mon), Nemipterus japonicus (N.jap), Nemipterus randalli (N.ran), Otolithoides biauritus (O.bia), Otolithes cuvieri (O.cuv), Pampus argenteus (P.arg), Protonibea diacanthus (P.dia), Fenneropenaeus merguiensis (P.mer), Parastromateus niger (P.nig), Panulirus polyphagus (P.pol), Portunus sanguinolentus (P.sang), Penaeus semisulcatus (P.semi), Parapeneopsis stylifera (P.sty), Rastrelliger kanagurta (R.kan), Solenocera crassicornis (S.cra), Scomberomorus guttatus (S.gut), Sepiella inermis (S.ine), Scoliodon laticaudus (S.lat), Sepia pharaonis (S.pha), Saurida tumbil (S.tum), Sardinella longiceps (S.long), Thunnus tonggol (T.ton), Trichiurus lepturus (T.lep).



Decapterus russelli (D.rus), Encrasicholina devisi (E.dev), Euthynnus affinis (E.aff), Katsuwonus pelamis (K.pel), Rastrelliger kanagurta (R.kan), Sardinella longiceps (S.long), Scomberomorus commerson (S.com), Sphyraena obtusata (S.obt), Thunnus albacares (T.alb), Trichiurus lepturus (T.lep), Carcharhinus limbatus (C.lim), Cynoglossus macrostomus (C.mac),Epinephelus diacanthus (E.dia), Lacatrius lactrius (L.lac), Nemipterus japonicus (N.jap), Nemipterus randalli (N.ran), Pampus argenteus (P.arg), Parastromateus niger (P.nig),Plicofollis tenuispinis (P.ten),Plicofollis dussumieri (P.dus), Saurida tumbil (S.tum), Saurida undosquamis (S.und),Sphyrna lewini (S.lew), Metapenaeus dobsoni (M.dob), Metapenaeus monoceros (M.mon), Fenneropenaeus indicus (P.ind), Portunus pelagicus (P.pel), Portunus sanguinolentus (P.san), Urotheuthis (Photololigo) duvaucelii (L.duv), Perna viridis (P.vir)



Sardinella longiceps (S.long), S.gibbosa (S.gib), Stolephorus indicus (S.ind), Rastrelliger kanagurta (R.kan), Katsuwonus pelamis (K.pel), Thunnus albacares (T.alb) , Euthynnus affinis (E.aff), Trichiurus lepturus (T.lep), Decapterus russelli (D.rus), Scomberomorus commerson (S.com), Chirocentrus dorab (C.dor), C.nudus (C.nud), Sphyraena jello (S.jel), Carcharhinus limbatus (C.lim), Saurida tumbil (S.tum), S. undosquamis (S.und), Nemipterus japonicus (N.jap), N.randalli (N.ran), Parastromateus niger (P.nig), Pampus argenteus (P.arg), Mugil cephalus (M.cep), Cynoglossus macrostomus (C.mac), Metapenaeus monoceros (M.mon), Metapenaeopsis stridulance (M.str), Metapenaeus dobsoni (M.dob), Penaeus mondon (P.mon), Portnus pelagicus (P.pel), Portunus sanguinolentus (P.san), Perna viridis (P.vir), Urotheuthis (Photololigo) duvaucelii



Sardinella longiceps (S.long), Sardinella gibbosa (S.gib), Sardinella fimbriata (S.fim), Rastrelliger kanagurta (R.kan), Scomberomorus guttatus (S.gut), Scomberomorus commerson (S.com), Thunnus albacares (T.alb), Katsuwonus pelamis (K.pel), Coryphaena hippurus (C.hip), Trichiurus lepturus (T.lep), Sphyraena jello (S.jel),Megalaspis cordyla (M.cor), Tenualosa ilisha (T.ili), Nemipterus japonicus (N.jap), Nemipterus randalli (N.ran), Upeneus vittatus (U.vit), Upeneus sulphureus (U.sul), Saurida undosquamis (S.und), Saurida tumbil (S.tum), Otolithes ruber (O.rub), Johnius carutta (J.car),Pennahia anea (P.ane), Priacanthus hamrur (P.ham), Plicofollis tenuispinis (P.ten), Metapenaeus monoceros (M.mon), Fenneropenaeus indicus (P.ind), Penaeus monodon ¸

Relative vulnerability of different species in the four maritime zones of India *jello* and ribbonfish *Trichiurus lepturus* were the species ranked as highly vulnerable in the southeast and northeast zones. These species are being exploited by trawl and the impact ranking was high while the adaptive capacity was low, rendering them vulnerable in the three zones. Indian oil sardine *Sardinellalongiceps* was found to be highly vulnerable in the northeast zone. Along the east coast of India, upwelling and the productivity is low and hence the abundance of the resource is also low. So, when exploitation increases stock become more vulnerable. Along the southwest coast, upwelling is high, which increases productivity in the area and contributes to the abundance of different resources, even though exploitation is high.

This study was aimed to provide a broad assessment of vulnerability of fishes and shellfishes due to climate change along the Indian coast.The study is the first of its kind in Indian marine fisheries and the results of the study will help in prioritizing strategies for adaptation and mitigation measures to cope with climate change. Since climate change in terms of increasing temperature, variations in current speed and directions etc., are projected with very high reliability in various IPCC scenarios, the only option left with the fishery managers for keeping the fisheries sustainable is to make needful alterations in the fishing pressure and fishing methods. The present vulnerability ranking of the species in different zones will be a handy tool to conserve the species which are ranked as highly vulnerable.

Modelling and projections

Setting

Though the overarching mandate of the project and the target resource viz marine fishery resources are highly enmeshed with a range of subjective positioning and objective reasoning, certain set of tasks were earmarked to fall exclusively under the modelling domain, wherein the focus was equal on the application of relevant methodologies, tools and routines towards achieving tangible and interpretable outputs that could lead to RCP scenario predictive qualifications and plausible outcomes with respect to fisheries off Indian EEZ.

The following tasks were set under the project -

- Single species modelling of fish biomass dynamics in multigear fishing with lagged environmental factors
- Multispecies and multigear modelling of the fishery in different regions of India with lagged environmental factors
- Catch predictions and fish phenology changes under RCP scenarios 4.5 and 6.0
- Projections of oceanographic variable under RCP 4.5 and 6.0
- Climate change modelling for fishery and ocean dynamics

RCP model validation

To accomplish validation of RCP model projections real time oceanographic parameters was done to obtain projections of oceanographic variables under presumable RCP 4.5 and 6.0.

Expected outputs at the beginning of the project

- Comparison of model and real-time oceanographic data and quantifying the difference between them.
- Region-wise projections of oceanographic variables using CMIP5 models.

Application of the results

- A common database on oceanographic parameters with access for scientific communities could help to identify the changing scenarios across Indian coast, which could further facilitate climate change research.
- Time series analysis and projections may pave way to identify the coast specific changes and shall be beneficial in formulating sustainable fisheries management plans, mitigation steps or resilient strategies.
- The discrepancies elucidated by the comparison of model and real time datasets points out the necessity to apply statistical and bias corrections while downscaling to regional models so as to make accurate resilient policies.

Thus, a strong base for analytics and validation and forecasting exercises was laid under these objective oriented tasks.

Methodology

Data: Observed data were obtained from International Comprehensive Ocean Atmosphere Data Sets (ICOADS). Model data output were obtained as the output of fifth phase of the Coupled Model Inter Comparison Project (CMIP5). Historic data during the period 1968 to 2005 and RCP 4.5 data from 2006 to 2017 were used for the comparison of SST variations. The historic data were taken from Max Planck Institute Earth System Model (MPI- ESM).

Analysis: Statistical trend analysis was used for comparison of coast wise sea surface temperature and chlorophyll with CMIP5 model. Using the statistical analysis techniques, seasonal and decadal variations of SST anomalies of observed and model data were studied. The least square method was used to fit the model and identify the existing trend of each coastal zone of India in different seasons. The trend values for each set of model and observed data were tabulated and the differences were computed. Python code and FERRET were used for time series and spatial analysis.

Results

Oceanographic database for 11 parameters for Indian Ocean was collated/ downscaled. Time series analysis and projections till 2100 under RCP 4.5 scenarios were obtained for SST and Chl along four coastal zones. The model and real time datasets of SST and Chl along Indian coastal zones for 3 seasons were validated and the discrepancies in them were identified.

This study helped to bring out the zone-wise SST variations along with the discrepancy among the CMIP5 modelled and observed data over a period of five decades, which highlight the necessity to address the discrepancy while downscaling from global to regional scale. In four Indian coastal zones the model and observed SST anomaly follows warming trend, but with noticeable differences in values among both.

Table 31. Comparison of seasonal variations of SST anomaly of observed and model data (1968-2017)

Zone	Season	Statistical trend (^{0}C/year)		Difference (M-O) (^{0}C/ year)
		Observed (O)	Modelled (M)	
NE	Winter	0.009	0.069	0.06
	Pre-monsoon	0.007	0.118	0.111
	SW Monsoon	0.004	0.046	0.042
	Post-monsoon	0.006	0.059	0.053
SE	Winter	0.008	0.032	0.024
	Pre-monsoon	0.012	0.048	0.036
	SW Monsoon	0.012	0.009	-0.003
	Post-monsoon	0.012	0.020	0.008
NW	Winter	0.013	0.047	0.034
	Pre-monsoon	0.016	0.084	0.068
	SW Monsoon	0.015	0.030	0.015
	Post-monsoon	0.016	0.042	0.026
SW	Winter	0.009	0.017	0.008
	Pre-monsoon	0.011	0.017	0.006
	SW Monsoon	0.011	0.016	0.005
	Post-monsoon	0.013	0.018	0.005

Modelling of Fish Biomass Dynamics

Expected outputs at the beginning of the project

- Information about the influence of environmental factors on biomass of different marine fishery resources.
- Models for biomass and catch prediction.

Application of the results

- Fishery management for reducing vulnerability of fishery resources to climate change and maintaining sustainability of the resources.

Methodology

The dynamics of fish population biomass can be examined by expressing the future biomass as a function in terms of the current biomass as well as the catch -

$$B_{t+1} = B_t + h(B_t) \square C_t$$

where, $h(B_t)$ is for calculating the growth in biomass as a function of current biomass and C_t is the fish catch. Different functional forms are suggested for $h(B_t)$ yielding different models. For modeling the fish biomass dynamics, the necessary inputs are time series data on fish catch and fishing effort (hrs/units). Time series data on catch of a species are available but the fishing effort is available for fishing gears and not for each species. This is due to the complex nature of the fishery -species is caught by more than one gear & each gear harvests many fish species.

Distributing of fishing effort for different species by developing standard procedures or through modeling is thus necessary for developing suitable models. Alternative methods attempted for standardization of fishing effort. A multi-species multi-gear model in the above line was developed by incorporating the parameters for gear standardization in the model. In the modeling approach for using standardized fish effort, the necessary parameters are included in the model itself in order to yield standardized fishing effort for the species.

Multi-species multi-gear biomass dynamics model

The popular Schaefer's production model (SPM) poularly referred to as Surplus Production Model, which falls in the category of growth models, has been put to use in a multi-gear scenario with special inherent computation of standardized efforts. Two variants were tried under this approach and they are as follows:

$$B_{sp,t+1} = B_{sp,t} + r_{sp}\, B_{sp,t} \left[1 - \left(\frac{B_{sp,t}}{K_{sp}}\right)^{\mu_{sp}}\right] - \sum_{gr} \left(\lambda_{sp,gr}\, p_{sp,gr,t}\, E_{gr,t}\right) q_{sp} B_{sp,t}$$

Equation- 1

cc tc b (A

$B_{sp,t}$ is the biomass of the species ***sp*** in year **t**

r_{sp} is the intrinsic growth rate for the species ***sp***

K_{sp} is the carrying capacity for the species ***sp***

μ_{sp} is the exponent parameter in the model for species ***sp***

$\lambda_{sp,gr}$ is the fishing gear effort standardization parameters for the species ***sp*** corresponding to the gear ***gr***

q_{sp} is the catchability coefficient

$p_{sp,gr,t}$ is the proportion of the species ***sp*** in the catch by gear ***gr*** in year t (computed from catch)

The second modeling framework was based on similar pair of equations, whereas in the state component the environmental factors too are included and all parameters get estimated simultaneously.

$$B_{sp,t+1} = B_{sp,t} + r_{sp} \exp\left\{\sum_{k=0}^{p} \beta_k x_{t-k}\right\} B_{sp,t}\left[1 - \left(\frac{B_{sp,t}}{K_{sp}}\right)^{\mu}\right]$$

$$C_{sp,t} = \sum_{l=1}^{g} \boldsymbol{\lambda}_l \, q_l \, P_{sp,l,t} \, f_{l,t} \, B_{sp,t}$$

Equation- 2

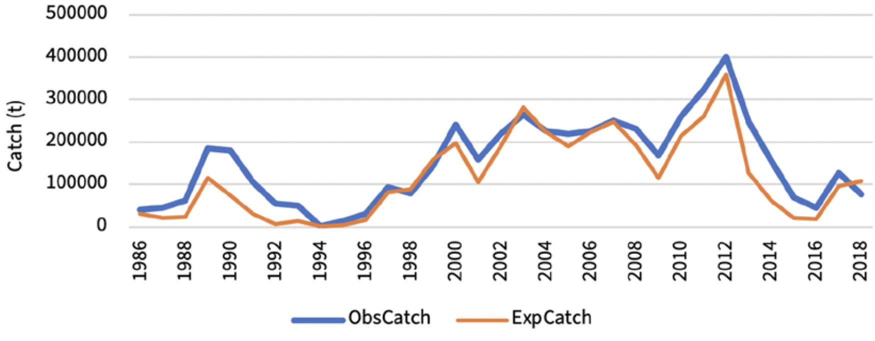
biomass of the species at time t
catch of the species at time t
catch proportion of the species in gear type in year t
value of the environmental variable at time t
fishing effort by gear in year t
carrying capacity for the species
intrinsic growth rate for the species biomass
catchability coefficient for gear
gear standardization parameter for gear
μ biomass ratio exponent parameter
parameter for environment variable for lag kc

Results

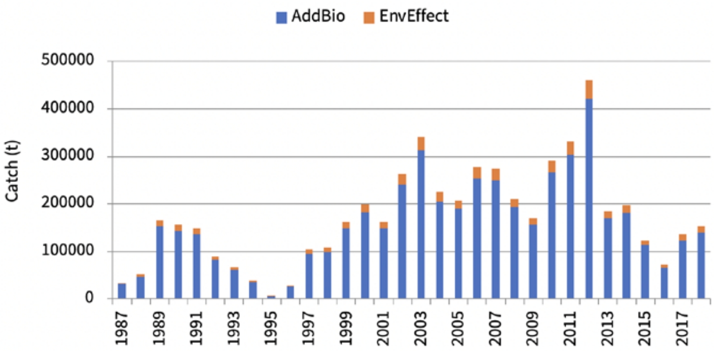
Multi-gear Biomass Dynamic Models were developed for different marine fishery resources of India. Calibration and validation of the model was done for selected fishery resources. Influence of different environmental variables on biomass of resources was assessed and coding for multispecies model in MATLAB was done.

Individual Biomass Dynamic Models with environmental factors were fitted for five major pelagic resources namely Indian oil sardine, Indian mackerel, seer fish, ribbonfishes and scads with SST and precipitation (PPT) at different lags as environmental variables, one species of demersal finfish namely threadfin breams, the major crustacean group penaeid prawns and the molluscan group cephalopods with upwelling index as environmental variables. Separate modeling was done for oil sardine and penaeid prawns in southwest coast of India with SST and PPT as environmental variables.

Using the computer software developed in MATLAB, model parameters namely catchability coefficients for each fishing gear, carrying capacity, growth rates, curvature parameter and coefficients for the lagged environmental variables were estimated using the time series data on catch, fishing effort and environmental time series. The



Fitted model for the oil sardine Sardinella longiceps observed and calculated catch with Sea Surface Temperature (SST) along the coast of Kerala.

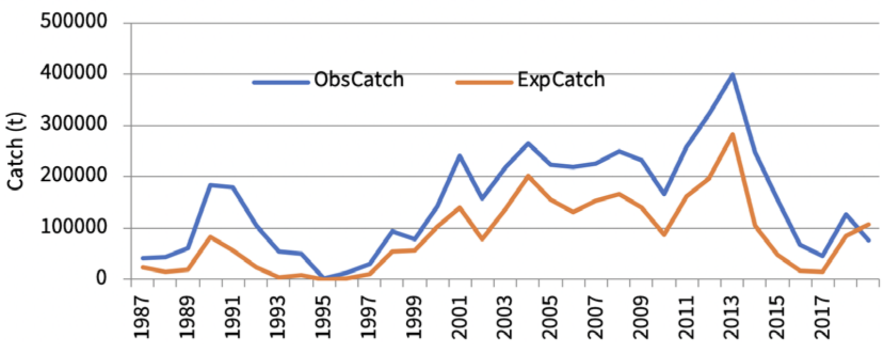


*AddBio refers to added Biomass and EnvEffect indicates the Environmental effect

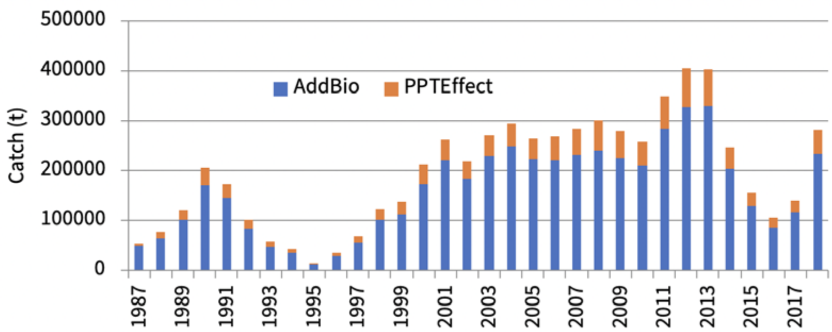
The effect of Sea Surface Temperature on the changes in biomass of the oil sardine Sardinella longiceps during 1987-2018 along the coast of Kerala.

share of environmental factors towards the intrinsic growth rate of biomass were calculated based on the estimated parameters from the model.

Fitted model for the oil sardine species showed a near-perfect one-to-one relation between the observed catch and expected catch which was calculated with SST along the Kerala coast. The significant effects of SST on the biomass of oil sardine species along the Kerala coast was also derived.



Fitted model for the oil sardine Sardinella longiceps observed and calculated catch with precipitation along the coast of Kerala.

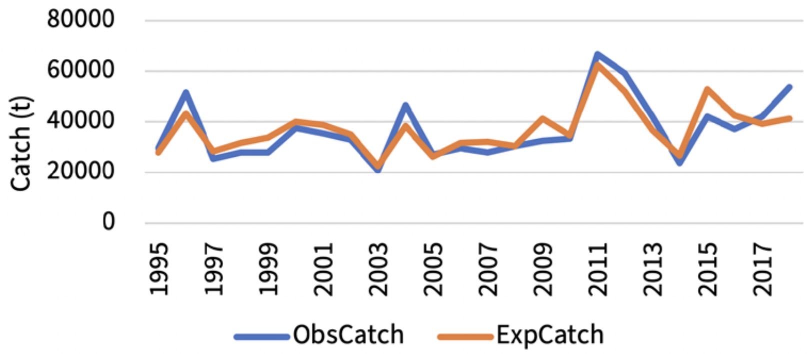


*AddBio refers to added Biomass and PPTEffect indicates the precipitation effect

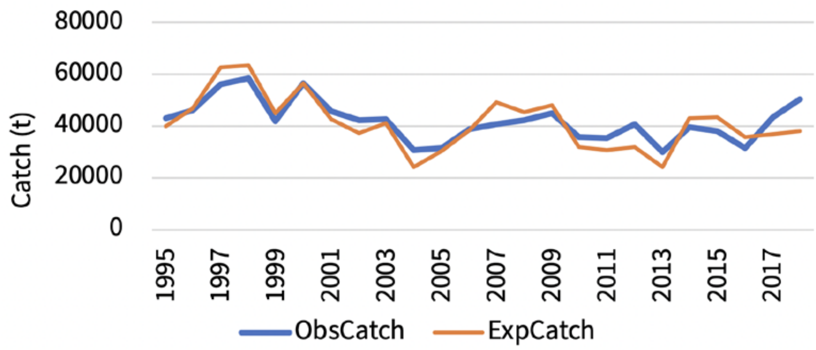
The effect of precipitation on the changes in biomass of the oil sardine Sardinella longiceps during 1987-2018 along the coast of Kerala.

Similarly, fitted model for oil sardine showed a good relation with observed and expected catch when calculated with the precipitation along the Kerala coast. Also, effects of precipitation on the biomass of oil sardine species of Kerala coast were clearly discernible.

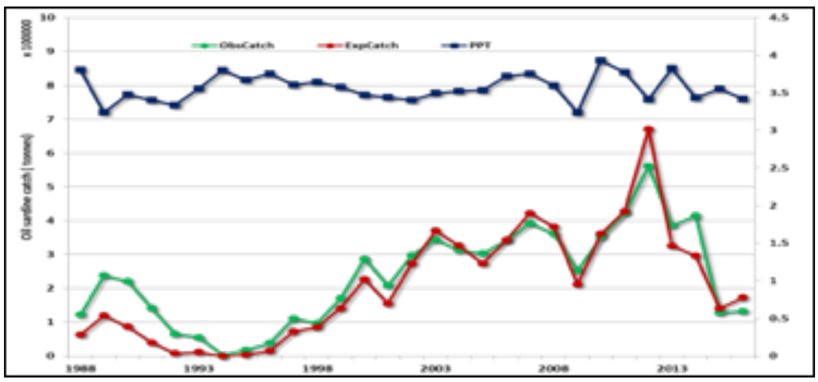
The fitted Biomass Dynamic Model for threadfin bream species along the Kerala coast showed that the expected and observed catch of threadfin breams calculated with upwelling index has a linear relationship along the Kerala coast. The Biomass Dynamic Model for penaeid prawns observed versus expected catch calculated with upwelling index indicated a direct influence of upwelling along the Kerala coast.



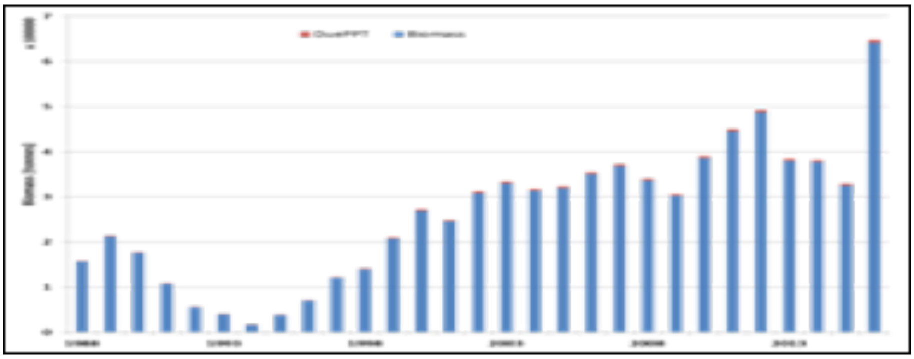
Fitted Biomass Dynamic Model for the threadfin breams observed and calculated catch with coastal upwelling index along the coast of Kerala.



Fitted Biomass Dynamic Model for the penaeid prawns observed and calculated catch with coastal upwelling index along the coast of Kerala.



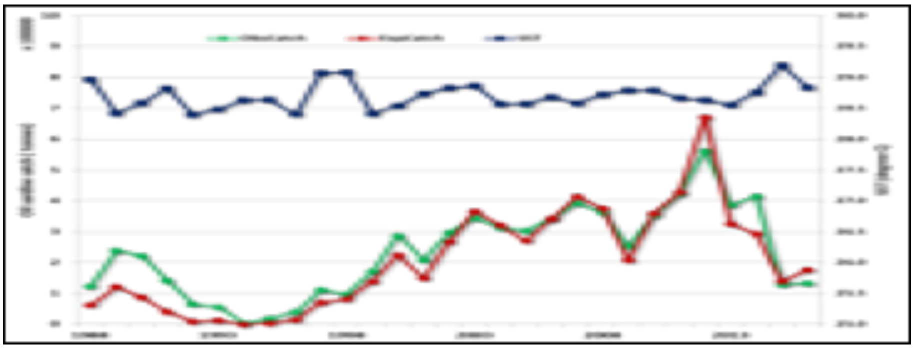
Fitted Biomass Dynamic Model for Multi-Gear with Environmental Variables–Modelling oil sardine catch with precipitation along southwest coast of India.



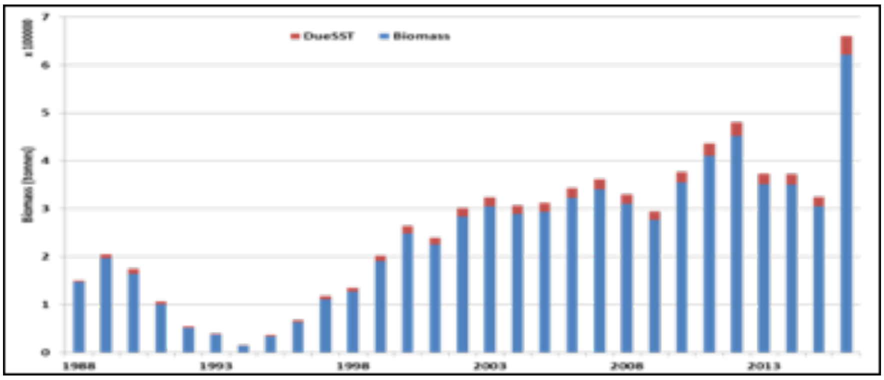
Effect of precipitation on the changes in biomass of the oil sardine Sardinella longiceps during 1988-2016 along the southwest coast of India.

Biomass Dynamic Models for multi-gear with environmental variables for oil sardine biomass with precipitation and SST along southwest coast of India were also done.

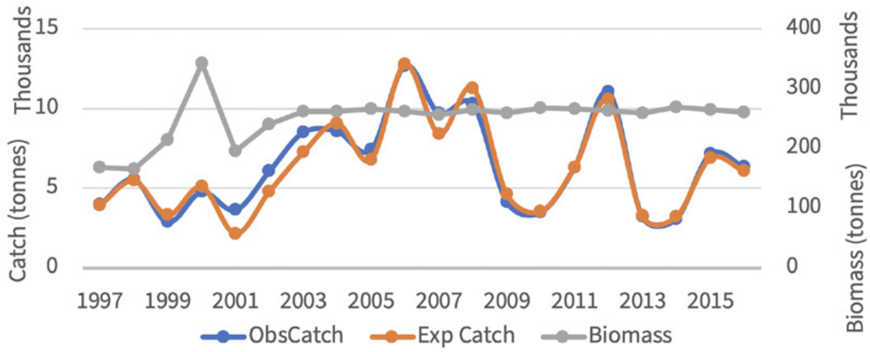
Similarly, a Biomass Dynamic Model for multigear with environmental variables was done for seerfish *Scomberomorus commerson* biomass with SST along the coast of Kerala. Using the RCP scenario 2.6 of SST, catch of *S. commerson* along the coast of



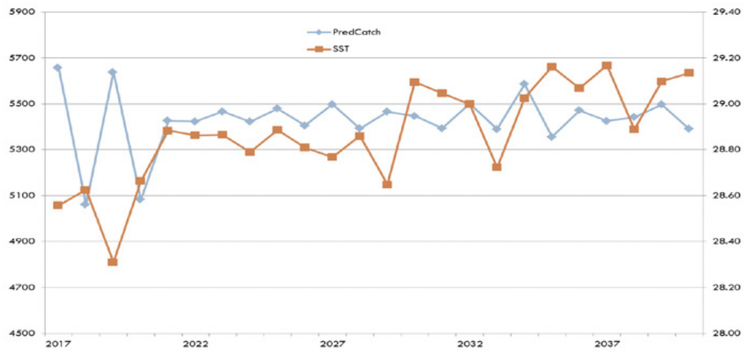
Fitted Biomass Dynamic Model for Multi-Gear with Environmental Variables–Modelling oil sardine biomass with SST along southwest coast of India.



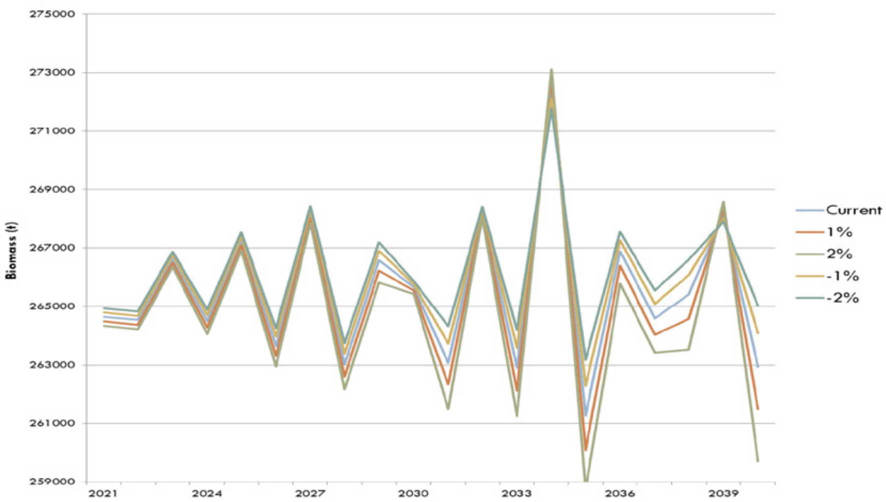
Effect of SST on the changes in biomass of the oil sardine Sardinella longiceps during 1988-2016 along the southwest coast of India.



Fitted Biomass Dynamic Model for multi-gear with environmental variables for seerfish Scomberomorus commerson biomass with SST along the coast of Kerala



Predicted catch of the seerfish Scomberomorus commerson along the coast of Kerala with SST in RCP 2.6 scenario.



Predicted changes in the biomass of the seerfish Scomberomorus commerson along the coast of Kerala with SST in RCP 2.6 scenario.

Kerala was predicted for future years. Likewise, biomass of the *S. commerson* along the coast of Kerala with SST in RCP 2.6 scenario was predicted.

Fishery & Ocean Dynamics

A developed Fisheries dynamics interdisciplinary model was used to explain the interannual variability of Indian oil sardine fishery from 1992 to 2015 in terms of upwelling during southwest monsoon and mixed layer temperature during pre-monsoon along the southwest coast of India. Impact of El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) on the fishery of Indian oil sardine along the southwest coast of India was analyzed. Study of chlorophyll and thermal frontal area and fishery distribution along the west coast of India was also done. Studies on the effects of warming along west coast of India on ocean dynamics and small pelagic fishery was studied revealed that the SST anomaly over the coast remarkably shows linear link with the IOD and ENSO events. Future climate projections for RCP 4.5, 6, 8.5 scenarios were projected.

Expected outputs at the beginning of the project

- Explain interannual variability and catch variability based on food and feeding and other characteristics.
- Examine possible effects of El Nino Southern Oscillation and Indian Ocean Dipole.
- Chl-a based analysis on catch variability, species composition and potential fishing zone identification.

Application of the Results

- The developed model can be further developed with the help of good resolution datasets and computational power, and can be helpful to predict good fishery locations by finding the optimum environmental window for fish aggregation.
- A further developed model can give possible warnings about the fishery conditions based on the data analysis.
- Integrating extreme climatic events such as cyclones, ENSO, IOD etc., to the model can also be considered in future.
- Findings of the ENSO and IOD and their effects on fishery can be treated as precautionary science knowledge for the possible loss and gain in fishery and will be helpful in taking necessary steps in preparedness plan phase.

Methodology

Methodology for model in NOAA-Ferret: In order to establish the influence of coastal upwelling due to the Ekman mass transport on Indian oil sardine fishery, a Fisheries Oceanography interdisciplinary model was developed. The model was made based on the available data on Indian oil sardine fishery, coastal upwelling data (derived from the meridional component of the wind speed) and mixed layer temperature (derived from 50m depth vertical temperature data). For this model, standardized oil sardine fishery data (SCPUE) from January to March, mixed layer temperature (MLT) during March to May and upwelling intensity (UI) during May to September was used as input base variables. To analyse the variability of the variables from the mean, each base variable was averaged over 24 years (1992 to 2015) and considered as the reference values. The model runs based on the rankings and produces the output accordingly on each rank. The rankings are made by defining the logical probability outcomes of variability of three variables. The outputs are the years that satisfy the rankings. The model was designed, coded and run on Ferret software.

Table 32. Rankings criteria for Indian Oil Sardine

Rank	Criteria
1	SCPUE greater than 3.678 and MLT greater than 29.16 and UI greater than 758.7
2	SCPUE greater than 3.678 and MLT less than 29.16 and UI greater than 758.7
3	SCPUE greater than 3.678 and MLT greater than 29.16 and UI less than 758.7
4	SCPUE greater than 3.678 and MLT less than 29.16 and UI less than 758.7
5	SCPUE less than 3.678 and MLT greater than 29.16 and UI greater than 758.7
6	SCPUE less than 3.678 and MLT less than 29.16 and UI greater than 758.7
7	SCPUE less than 3.678 and MLT greater than 29.16 and UI less than 758.7
8	SCPUE less than 3.678 and MLT less than 29.16 and UI less than 758.7

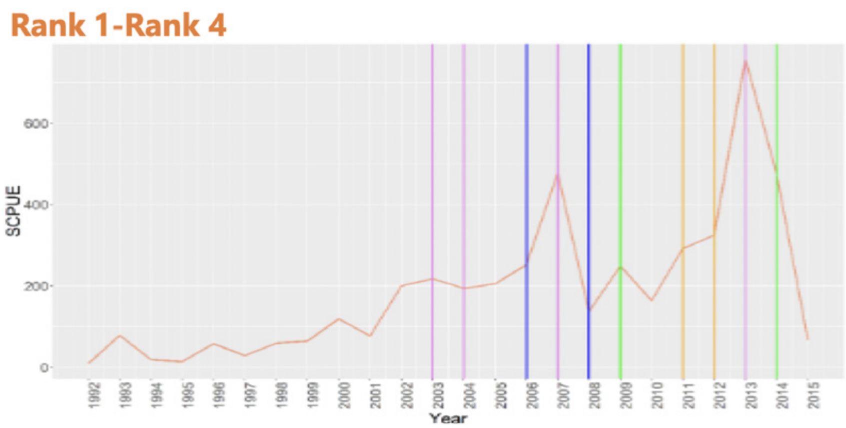
Using marine geo-spatial tools (MGET) version of ArcGIS, processing of SST and Chl-a images were done. MGET tool utilizes the SIED technique, which works under Cayula-Cornillon algebra. The output from the method was re-projected to Asia South Albers Equal Area Conic projection in order to calculate the area of frontal zone.

Various spatial (Long-term monthly/seasonal climatology, composite analysis, etc.) and temporal (time-series analysis,) data analysis methodologies were used during the analysis of the variability of variables in spatial and temporal scales respectively. Different statistical methodologies used were correlation, regression, mean, standard deviation (both spatially and temporally).

Results

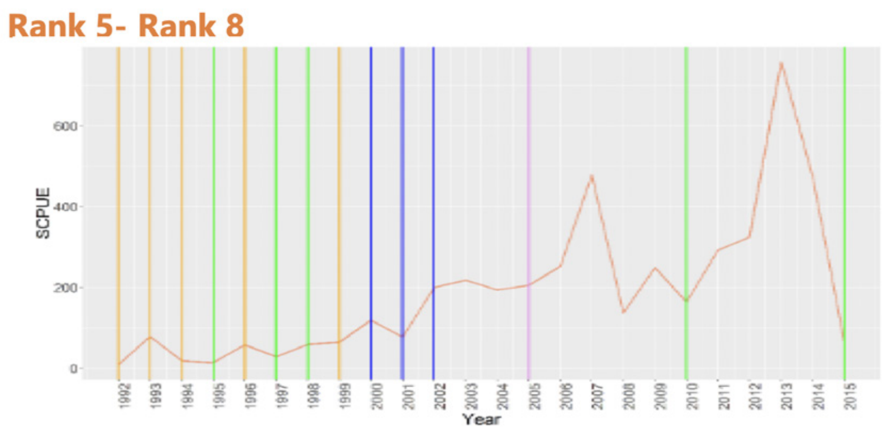
Role of temperature and upwelling on Indian oil sardine fishery: The model explains the interannual variability of Indian Oil Sardine from 1992 to 2015 in terms of mixed layer temperature during pre-monsoon and upwelling index during southwest monsoon.

The results revealed that annual catch will be low during Low 1st quarter standardised catch per unit effort and low upwelling during southwest monsoon (2009, 2011, 2012, 2014). Similarly, annual catch will be high during higher upwelling during southwest monsoon years (2000, 2001, 2002, and 2005). Also, other factors leading to higher annual catch is, higher 1st quarter standardised catch per unit effort (SCPUE) and upwelling, and low higher 1st quarter standardised catch per unit effort and high upwelling.



The trend observed in annual of SCPUE of Indian Oil Sardine during 1992-2015 overlaying with model-based ranks on the corresponding years. Ranks1 to Rank 4 is overlaid in the trend line.

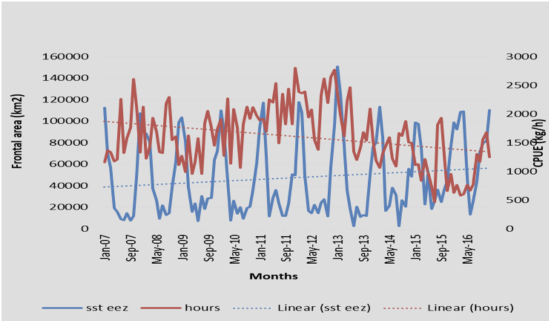
Further studies have revealed the impacts of climatic events such as El Nino, La Nina and Indian Ocean Dipole (IOD) on major small pelagic fishery along the southwest coast of India. From 2000 to 2007, high oil sardine fishery was observed in concurrence with intensified upwelling and Chl–*a* concentration, whereas, from 1990 to 1999, lowest oil sardine fishery was observed owing to more co-occurring ENSO and IOD events and low intensity of upwelling and current speed.



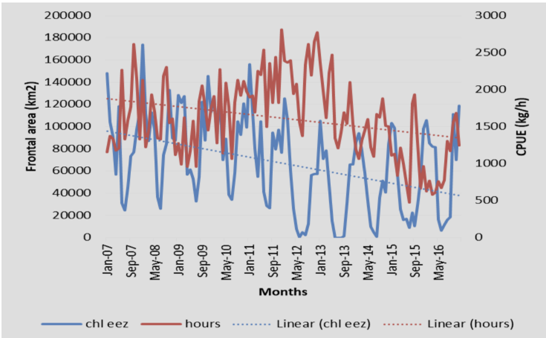
The trend observed in annual of SCPUE of Indian Oil Sardine during 1992-2015 overlaying with model based ranks on the corresponding years. Rank 5 to Rank 8 is overlaid in the trend line.

Rankings	Model results (years)	Colour indications on Figs. XX (a) and (b)
1	2003, 2004, 2007, 2013	Violet
2	2006, 2008	Blue
3	2009, 2014	Green
4	2011, 2012	Orange
5	2005	Violet
6	2000, 2001, 2002	Blue
7	1995, 1997, 1998, 2010, 2015	Green
8	1992, 1993, 1994, 1996, 1999	Orange

Chlorophyll and Thermal frontal area and fishery distribution along the west coast of India: There was an overall decreasing trend in both the variables. Chl-*a* frontal area and fish landings displayed resemblance in the pattern of variation over time. Both variables showed a sudden fall in values from early 2008 onwards which continued till mid-2009. Then chlorophyll frontal area amplified from July 2009 to January 2011 and then declined till 2017. Catch per unit effort sustained this increasing trend till the start of 2012 and declined till 2017. This specifies that the discrepancy in the catch per unit effort is similar to that of the chlorophyll frontal incidence. Catch per unit effort along the west coast of India showed an overall declining trend, whereas thermal frontal area within the EEZ specified an overall increasing tendency over time. Both the thermal frontal area and catch per unit effort started declining by late 2007. From June 2009 onwards, both the thermal frontal area and catch per unit effort amplified in value which continued till early 2013. From 2013 onwards, the thermal frontal area and catch per unit effort started declining, specifying the resemblance in their pattern of variability over time.



Time-series plot of chlorophyll frontal area and catch per unit effort in hours.



Time-series plot of thermal frontal area and catch per unit effort in hours.

Fish phenology & catch prediction

Another approach to predicting the production of fishery resources is to purely treat them as timeseries with due auto and cross correlated attributes. Juxtaposing relevant extraneous environmental variables alongside these timeseries may yield valid prediction. The sequence of influence of selected climatic variables (SST, Pr, Salinity, Chl-*a*, CUI and ENSO) on the fishery of Indian oil sardine and Indian mackerel along the southeast Arabian Sea was streamlined. Catch forecast of Indian oil sardine till 2030 was obtained using ARIMA models. Catch forecasts of Indian oil sardine and Indian mackerel were obtained for 2020–2100 based on oceanographic parameter projections under RCP 4.5 and RCP 6.0. Linkage between climate change and feeding habits of Indian Mackerel was deciphered. Escalating effects of climate change on mean length of Indian oil sardine was established. Coast-specific anomaly variations of SST, Pr, Salinity and Chl-*a* were elucidated for southwest coast of India. Vulnerability forecast of major fishery resources was done.

Expected outputs at the beginning of the project

- Catch forecast and vulnerability forecast of key species along the west coast of India
- Studies on fish phenology changes under climate change scenarios
- Coast-specific real-time and historic oceanographic variability studies

Application of the Results

- Support sustainable fishery management plans with specific focus on early catch of key species.
- Study on minimum legal size of key species and catch restrictions on spawning seasons.

- Species-wise catch forecast will support the state-wise fishery resources management plans.

Methodology

- Multiple correlation analysis (PerformanceAnalytics package in R)
- Path analysis (sem () and cfa() function in of lavaan package in R)
- Linear and Generalised dditive models (gam() function mgcv package in R)
- Time series analysis (ts() and arima() function of forecast package in R)

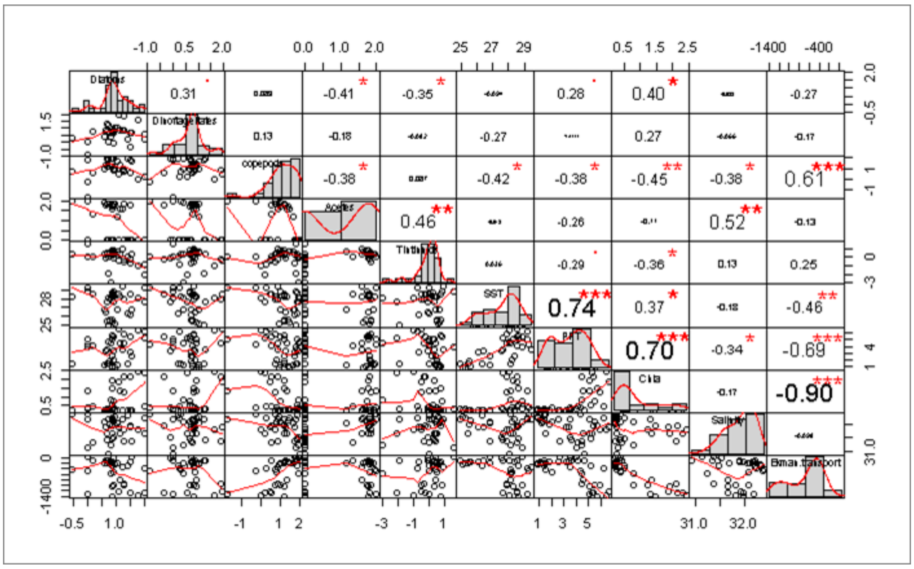
Results

Catch predictions and fish phenology changes under RCP scenarios 4.5 and 6: Prey index of the major diet components in the diet of Indian mackerel was used to estimate %IRI. The %IRI of each major prey item was correlated with climatic variables and then fitted into a GAM model. The model indicated a strong relationship between the environmental variables and diet composition of the fish. Historic data comparison showed variation in the diet components of the fish.

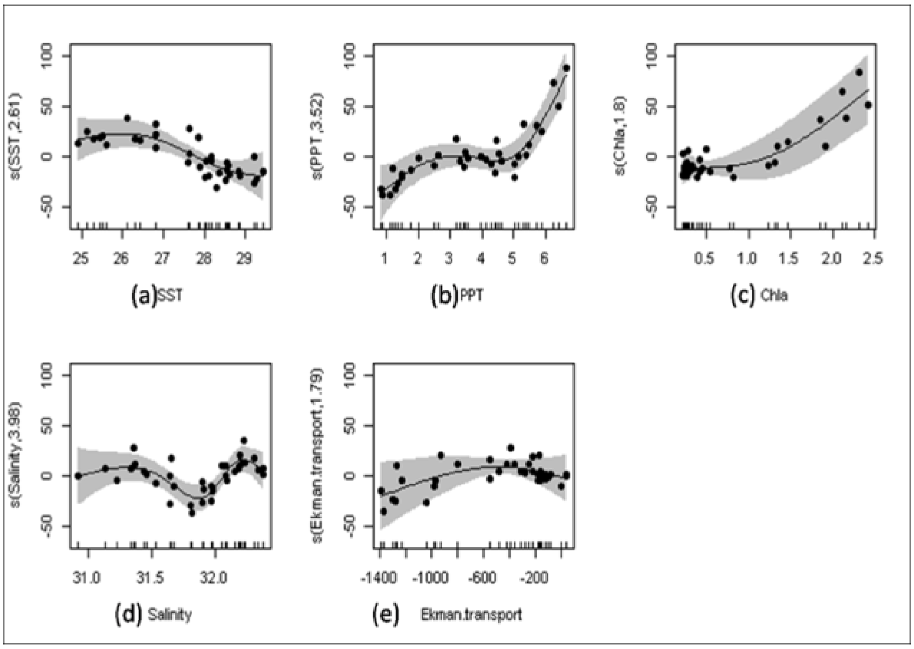
Linear model, GLM and GAM were fitted with W.cpue and Effort with environmental variables. LMs, GLMs as well as GAM models were then fitted. Model evaluation was done and prediction performance was tested. With the best fit, model prediction was performed for Lm, GLM and GAM for real time data. The results of the prediction showed that GAM models performed better than Lm and GLM models. Further GAM prediction was selected for catch prediction under 4 RCP scenarios. The cpue and effort were predicted using GAM prediction till 2100.

The predictions showed catch as RCP 8.5 < RCP 6 < RCP 4.5 < RCP 2.6. Since RCP 6 and 4.5 are considered to be more realistic, the average percentage change in catch over 5 years with reference to the average catch of 2005-2015 were observed. The results showed a decreasing trend in the catch of both RCP 6.0 and RCP 4.5.

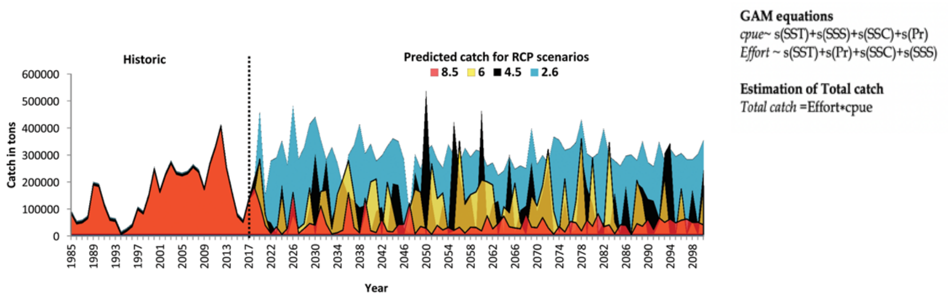
Thought the factors and resource abundance are very clearly deciphered in the data, the interplay of simultaneous relationship between the factors may at times lead to



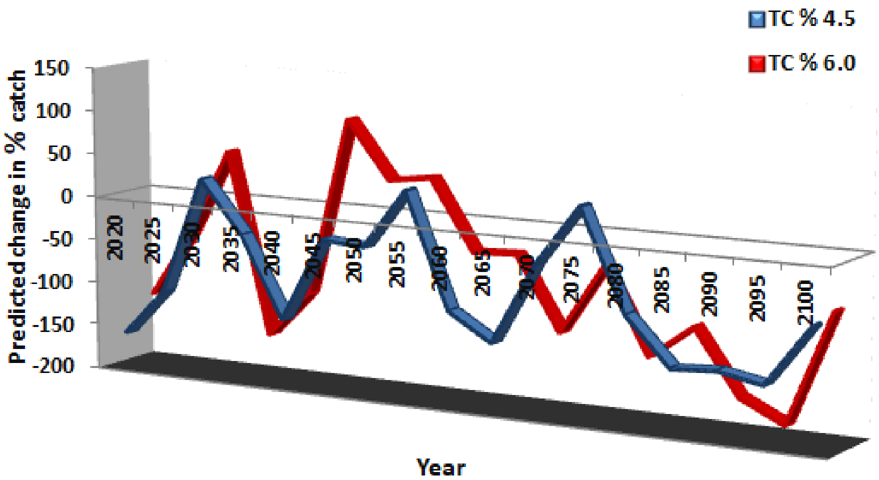
Correlation matrix showing the strong relation between prey items in the gut of Indian mackerel and climatic variables.



GAM model fitted for phytoplankton prey components in the diet of Indian mackerel and climate variables.

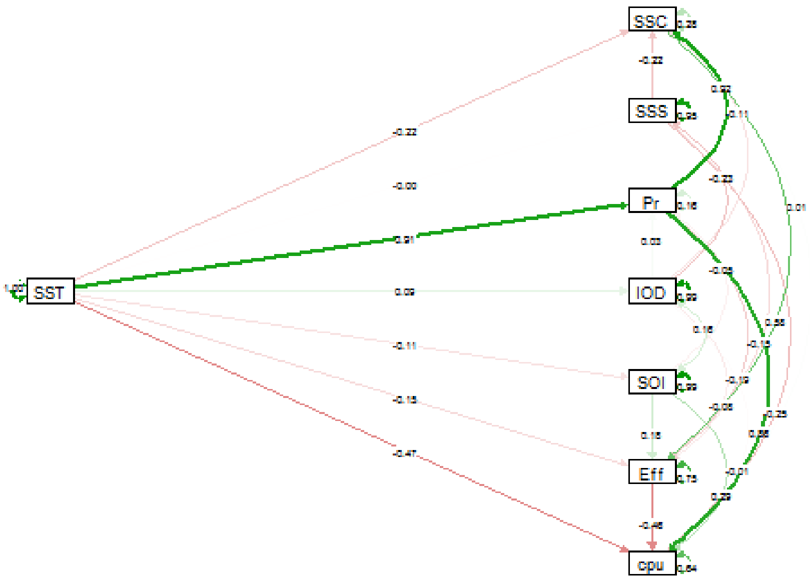


Catch forecast of IOS under all 4 RCP scenarios.

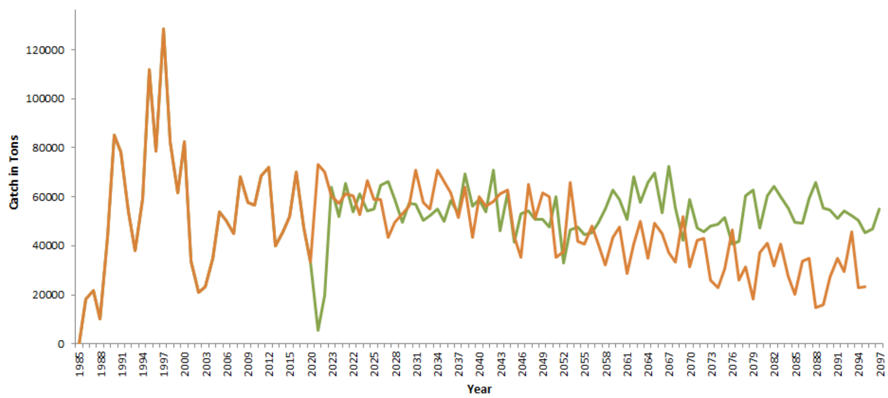


Predicted change catch of Indian oil sardine in RCP 6.0 and RCP 4.5.

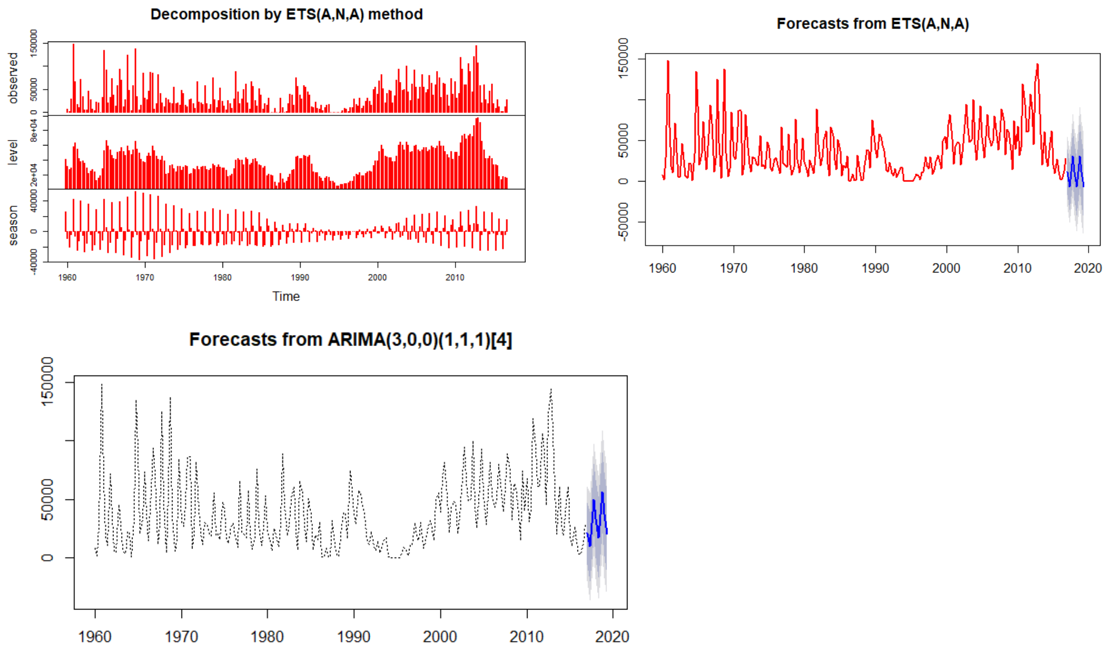
differential or new cause-effect relationships. Structural Equation modelling is an established tool to study such latent relationships. Weighted cpue and Relative effort of Indian mackerel were estimated. Path analysis was done using sem() function. The sem plots revealed the causal link between environmental variables and cpue and effort of Indian mackerel. The order of sequence of the effect of environmental variables on cpue of Indian mackerel showed that SST was the most significant variable. Using significant variables from this, prediction of cpue of Indian mackerel was done using the same methodology for sardine. The catch rate of Indian mackerel also showed reduction after 2050 under both RCP scenarios.



Path analysis of relationships using SEM.

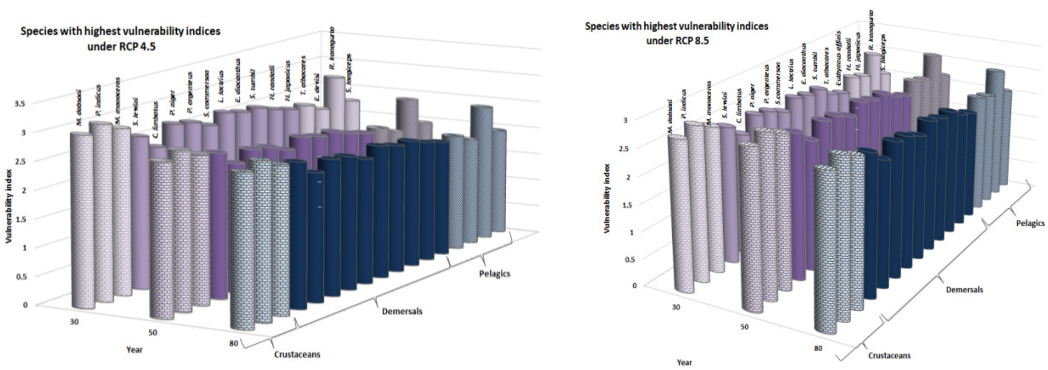


Present level and RCP 4.5 level of Catch of Indian mackerel.



Forecast results of Indian oil sardine catch trend using ARIMA and ETS models for 10 years.

Vulnerability indices on RCP scenarios: Twenty-nine species of fishes were studied (pelagics finfishes -7, demersal finfishes–16, crustaceans–5 and molluscs -1). The vulnerability was predicted under RCP scenarios 4.5 and 8.5. Of these, 3 pelagic finfishes, 10 demersal finfishes and 3 crustaceans had highest vulnerability indices.



Species with highest vulnerability indices under RCP 4.5 and RCP 8.5

Vulnerability of India's coastal villages

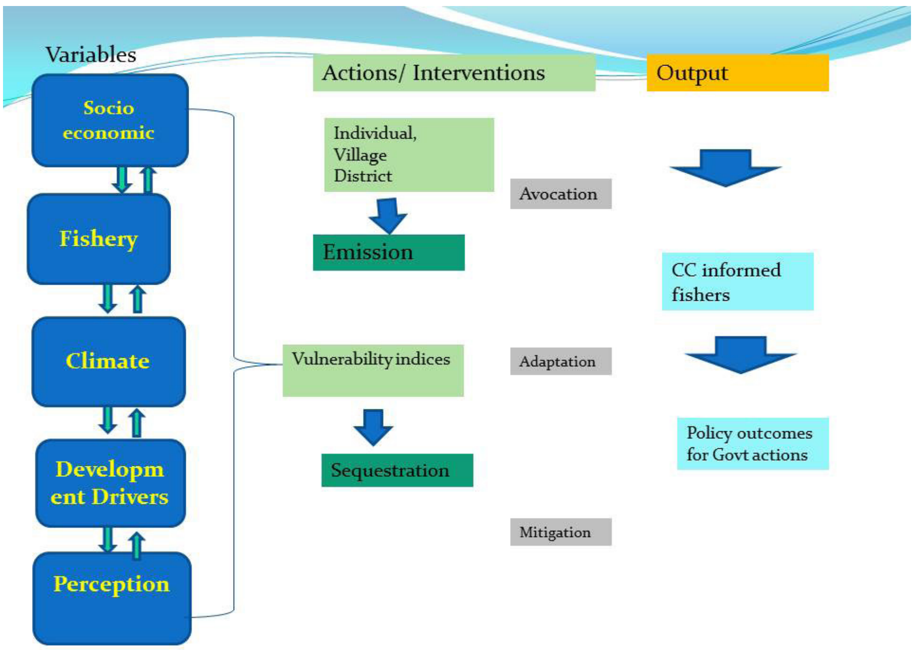
Coastal village vulnerability assessment

Developing Integrated District Level Adaptation and Mitigation (IDLAM)

A methodological framework was developed for assessing the vulnerability of coastal districts and to evaluate adaptation and mitigation options, and thereby subsequently employ adaptation and mitigation strategies for the vulnerable districts.

Developing an outline for accomplishing the goal

To bring about climate change awareness in fishers, the schematics given below were developed. Socio-economic data, fisheries data, climate data, development drivers and climate change perception were taken as variables to estimate the vulnerability indices. Carbon emission and sequestration potential were analyzed with the aid of the vulnerability indices by the bottom-up approach (individual, village and then the district). Employing the tools of avocation, adaptation and mitigation, government actions and policy outcomes pertaining to coastal climate change can be achieved; more importantly this framework helps in creating climate change informed fishers.



Schematic representation of steps involved in IDLAM studies

Vulnerability studies across the different states

Selection of coastal district

The selection of the districts was based up on computation of a Vulnerability Index[1]. Five different parameters viz, Demography, Occupation, Infrastructure, Climate components and Fishery components were derived for different coastal districts and based on which vulnerability indices the coastal district were derived -

$$VI = \left[\sum_{i=1}^{n} (AI_i)^{\alpha} \right]^{1/\alpha} \Big/ n$$

Where, *VI=Vulnerability index, (AI) is the average index for each source of vulnerability, n is the number of source of vulnerability and a=n.*

The selection of the district was based on assessment of coastal district vulnerability index estimated for different coastal districts. To assess the coastal district vulnerability selected parameters and attributes were -

1. Demography
2. Number of villages
3. Number of households
4. Total population
5. Literacy
6. Occupation-Fulltime labourers, part-time and occasional.
7. Infrastructure- Kutcha houses, Educational institutions, number of hospitals/ dispensaries, number of banks, number of fishermen co-operative societies, number of community centres.
8. Climate components- chlorophyll, coastal upwelling index, wind stress, temperature, sea level, salinity, wind velocity, rainfall.
9. Fishery components- mechanised, motorised, non-motorized, number of person to get training and catch over a 10 years period.

Selection of coastal villages

The selection of the different coastal villages from the selected coastal district was carried out using various parameters including socio-economic parameters, number of families below poverty line, adult- child ratio, average family size, gender ratio, literacy rate, dependency on fishing activities, craft and gear inventories, participation in cooperatives and ancillary activities.

In order to procure this data, schedules such as HSS (Household survey schedule), VSS (Village survey schedule) and CBS (Carbon budget survey) were prepared. In which details such as assets, fishing assets and livestock assets were gathered.

1 *Patnaik and Narayanan 2005.*

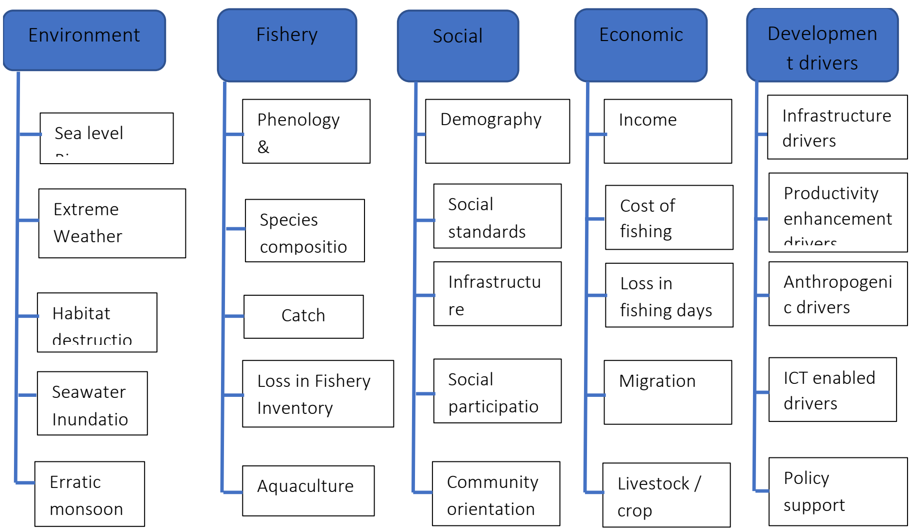
Climate change data, such as climate change awareness and perception, ecologically sensitive areas, such as mangroves, coral reefs, sea grass beds, sea water inundation, monsoonal fluctuations were found. Details on climate change and fisheries, like phenology and distribution were found. Social data, such as demography, social standards, infrastructure sensitivity, and community participation were procured. Climate change development drivers and indigenous technical knowledge on awareness, preparedness and mitigation were also found. From the survey schedules the coastal villages were zeroed in.

For the carbon budgeting survey, details of resources available, fishing activity (crafts, engine and gear used, fuel used, hauling speed, distance travelled), food expenditure of the houses, waste disposal, household energy consumption and transportation used were collected.

Developing the vulnerability indices for coastal districts

The vulnerability indices were constructed using PARS methodology, a conceptual framework was developed for assessing the climate change vulnerability of coastal livelihoods. PARS (Parameter, Attribute, Resilient indicator and Score), methodology provides prioritization and ranking of different impacts as perceived by the fishers. The framework allows adequate distribution between fishing. The fishers were asked

$$RankBasedQuotient = \sum_{i=1}^{n} (\mathrm{Fi})(\mathrm{n} + 1 - \mathrm{i}) X \frac{100}{Nn}$$



Parameters and attributes used in the PARS methodology framework.

to rank between 1 – 5 indicating the severity of the vulnerability 5 indicates very high, 4- high, 3- medium, 2- low and 1- negligible/marginal. So each and every parameters were again would lead to different attributes and the attributes will lead to different statements or resilient indicators which will be based up on different scores. The rank based quotient technique was used to analyse the scores and the ranks were given in a way the most affected attribute will get the highest ranking. PARS methodology was analysed using Rank Based Quotient (RBQ) formula (Sabarathnam, 1988) which is given below.

This methodology is very much useful to find out which parameter or which attribute of the parameter is the most vulnerable factor of the area in terms of climate change on a first-hand analysis itself. This kind of bottom-up approach would help the climatologists and policy makers to implement climate adaptation plans for the district, state and finally to the country.

Employing PARS methodology for vulnerability assessment across maritime states: The Climate Parameter Assessments across the coastal villages were carried out using the following parameters -

- Environment
- Fisheries
- Social
- Economic
- Development drivers

The vulnerability assessment studies were conducted in Alapuzha district in Kerala, Thiruvallur, Kancheepuram, Cuddalore, Ramanathapuram, Tirunelveli, Tuticorin and Kanyakumari districts in Tamil Nadu, Uttara Kannada, Udupi and Dakshina Kannada districts in Karnataka, Gir and Somnath districts in Gujarat and Krishna district in Andhra Pradesh.

The study revealed that fisheries is the most impacted parameter as a result of climate change, followed by economic, social and environment parameters. Poor fish catch and loss in fishing days due to bad weather during peak fishing seasons add to sufferings of the fishers. Increase in fishing efforts, decreasing dividends and increased landing of juveniles indicate the pressure on the existing fish stocks and the vagaries of climate change viz phonological shifts, disappearance of the fishery, habitat destruction etc adds to the cry. In order to make profits, the fishermen are putting extra effort to catch more fish by enhancing the endurance of the crafts and moving to distant grounds even without adequate lifesaving and communication gadgets at risk of their precious life. The increase in fuel cost, increase in fishing cost due to changed fishing grounds and damages of crafts and

Data collection for IDLAM

gears etc. are considered to be the impacts of climate change on the economy. The study clearly indicates that the fishers don't have adequate knowledge about the climate change and depends on indigenous method for their safety. As most of the fishermen population is uneducated, they are not able to take proper measures for adaptation to the ill effects of climate change. The lack of sanitation and health care facilities in the coastal villages make the fishers more vulnerable to spread of epidemics and pose a big threat in the events of flood or inundations caused due to increased sea level. Lack of dedicated cyclone and tsunami shelters, wireless weather communication tools, poor roads, inadequate health care facilities etc adds to the vulnerability of coastal villages to the climate change associated catastrophe. The study reveals that there is urgent need for awareness building among the coastal fisher folk on the climate change and related threats to the livelihood and the need the for adaptation through proper scientific interactions and trainings. It further reveals that the developmental and welfare activities in the coastal areas should be planned in a climate change perspective equipping the coastal population to adapt to the ill effects and mitigating the sufferings by providing adequate infrastructure in the working areas and also by creating opportunities for alternate avocations. The alternative avocations available across the different fishing villages need to be strengthened in order to negate the different risks and uncertainties of climate change and in ensuring a climate change informed fishers in the future. There is need to improve on the awareness of the fishers knowledge to climate change by involving them in the disaster preparedness and planning process. Thus, a bottom-up approach involving the primary stakeholders along with the community will adequately position them to climate change adaptation and mitigation by augmenting their traditional knowledge.

Table 23. Vulnerability indices developed for various coastal districts in India.

State	District	VI	State	District	VI
Gujarat	Valsad	0.13	Kerala	Malappuram	0.086
	Navsari	0.08		Kozhikode	0.121
	Surat	0.05		Kannur	0.044
	Bharuch	0.13		Kasaragod	0.038
	Anand	0.22	Tamil Nadu	Kanyakumari	0.124
	Bhavnagar	0.09		Thirunelveli	0.145
	Amreli	0.13		Tuticorin	0.102
	Junagadh	0.32		Ramanathapuram	0.219
	Porbander	0.14		Nagapattinam	0.189
	Jamnagar	0.18		Cuddalore	0.556
	Rajkot	0.09		Kancheepuram	0.728
	Kutch	0.19		Thiruvallur	0.701
Maharashtra	Raigad	0.488	Andhra Pradesh	Krishna	0.76
Karnataka	Uttara Kannada	0.362		Visakhapatnam	0.66
	Udipi	0.46		East Godavari	0.65
	Dakshina Kannada	0.418		Nellore	0.63
Kerala	Trivandrum	0.120		Guntur	0.57
	Kollam	0.077		Prakasam	0.56
	Alappuzha	0.122		Srikakulam	0.38
	Ernakulam	0.057		West Godavari	0.31
	Thrissur	0.052		Vizianagaram	0.21

This assessment shows that the level of knowledge is not consistent with the potential severity of the problem of climate change and coastal zones. Awareness of fisher folk about climate change can be increased through village knowledge centres which give day to day information on climate-related changes, disaster warnings, disaster preparedness as well as rehabilitation measures in the event of climate change causalities. Providing timely information on baselines of actual coastal changes, including local factors and sea-level rise, and the climate and non-climate drivers, through additional observations and expanded monitoring could be done through such centres. This would help establish the causal links between climate and coastal change which tend to remain inferred rather than observed and support model development.

Improving predictive capacity for future coastal change due to climate and other drivers, through field observations, experiments and model development: A particular challenge will be understanding thresholds under multiple drivers of change. Developing a better understanding of the adaptation of the human systems in the coastal zone. At the simplest this could be an inventory of assets at risk, but much more could be done in terms of deepening our understanding of the qualitative trends and issues of adaptive capacity.

Improving impact and vulnerability assessments within an integrated assessment framework that includes natural-human sub-system interactions: This requires a strong inter-disciplinary approach and the targeting of the most vulnerable areas, such as populated mega deltas and deltas, small islands and coastal cities. Improving systems of coastal planning and zoning and institutions that can enforce regulations for clearer coastal governance is required in many countries.

Developing methods for identification and prioritization of coastal adaptation options: The effectiveness and efficiency of adaptation interventions need to be considered, including immediate benefits and the long-term goal of sustainable development.

Developing and expanding networks to share knowledge and experience on climate change and coastal management among coastal scientists and practitioners. The results of these vulnerability studies have been put to good use in building effective networks between researchers and stakeholders particularly in the states of Karnaaka and Tamil Nadu, where extensive demonstration and capacity building programmes were carried out in selected villages to promote climate change awareness and build climate resilient communities. One of the major outcomes has been the developing of Climate Smart villages in the two states.

Carbon footprint of marine fisheries

Carbon footprint of marine fishing

Research on fisheries and climate change has primarily focused on "how fisheries will be affected by climate change"; for example, how climate change will likely decrease primary production, redistribute marine resources and increase the economic strain and vulnerability of already vulnerable countries. Now experiments are also focusing on knowing the role of marine fishing in increased GHC emission, and how it can be reduced to achieve greener production from marine fisheries. At present, global greenhouse gas (GHG) emissions are leading to the high-risk scenarios modelled by the IPCC, which suggests that 38 billion tonnes of Carbon dioxide (CO_2) emissions were released into the atmosphere in 2014[1]. Reducing GHG emissions and mitigating the effects of climate change depends on our understanding of what sectors are significant contributors to CO_2 emissions, and where reduction strategies can be effectively implemented. The marine fishing industry relies heavily on the use of fossil fuels, i.e., fuel costs can account for up to 60% of total fishing costs[2,3].

As per Marine Fisheries Census 2016, a total of 1,66,333 fishing crafts exist in the fishery in the marine fisheries sector, out of which 42,985 (25.8%) are mechanized, 97,659 (58.7%) are motorized, and 25,689 (15.4%) are non-motorized. In 2016 it was estimated that globally the industrial fishing sector releases an average of 2.0 t of $CO_2 \cdot$ t for every tonne of fish caught[4]. To understand the status of emissions in different fishing crafts in India, an extensive study was conducted throughout the Indian coast.

1 *Stocker et al., 2014*
2 *Wilson, 1999*
3 *Tyedmers et al., 2005*
4 *Greer et al, 2019*

Trawlers being the most significant contributor to marine fisheries production in India, the CO_2 emission from the trawlers operating along the Indian coast was studied from each zone. Since multiday operations across state boundaries dominate the trawl fishery, area-wise scenario of fuel usage and emission status per tonne of fish produced was estimated. To understand the carbon footprint of Indian marine fisheries, the emissions associated with the following activities were calculated:

Methodology

Pre-harvest

Under pre harvest, the major activities considered were boat building and gear fabrication.

Boat building & annual maintenance of the existing craft: There are different materials used for building the boat such as wood alone, wood and plywood, steel etc. But under this study, only the quantity of diesel used in the transportation of the material and the quantity of electricity or diesel used for the construction of a unit were taken into consideration. Wood is generally considered as carbon neutral due to its carbon sequestration history. In the case of steel boats, only the fuel used for transportation of the material to the boat yard and the quantity of fuel/electricity used for construction were considered as the emission from production of steel is accounted for by the factory. Similarly, the use of electricity/fuel for the annual maintenance of different units was also taken.

Gear fabrication: Since the making of a net at the landing centre involves only stitching or adding together of different net materials purchased from the stores, the emission is negligible during this process. Hence, the emission from net fabrication was excluded.

The information regarding the quantity of fuel/electricity used for transportation of the boat materials such as wood/steel to the boat building yard, the quantity of electricity/ diesel used for the construction of the craft, the total number of units constructed in a boat building yard etc. was collected from the boat owners, boat building workers using a structured proforma. The total number of different units present in a district or state was obtained from the Marine Fisheries Census data 2010 published by Government of India, Ministry of Agriculture, Department of Animal Husbandry, Dairying and Fisheries. It was found that the quantity of electricity/diesel required for maintenance was around 10% of the quantity required for construction of the unit.

Harvest

Under this, the quantity of fuel used by different craft & gear combinations for a trip was collected, along with the quantity of ice bars. The total catch as well as the species-wise catch composition were also taken.

Fishing: The average quantity of fuel and ice required per trip for each unit was collected through enquiry. The average quantity of fuel and ice for each unit was multiplied with the average annual effort to obtain the annual quantity of fuel and ice used by different units in a year. For the annual catch and effort of different units, the average gear wise catch and effort for the period 2012-2016 from each state was obtained from the National Marine Living Resource Data Centre of ICAR-Central Marine Fisheries Research Institute. In some cases, average for the period 2015-16 alone was used.

Post-harvest:

Under this, only transportation of the catch to the point of destination (either the market or the processing unit) was taken along with the quantity of ice required for preservation of catch during the transportation.

Transportation: In the case of transportation, wherever data on the number of vehicles and the average quantity of fuel used were available, it was used. Otherwise, an indirect method was used to obtain these estimates. First the catch was converted into number of baskets of fish, assuming a basket of fish weighs 35 kg. The average number of vehicles was found out by the number of baskets that a vehicle carries. The gear-wise catch was apportioned in percentage based on information obtained locally into catch taken to distant places and catch dispensed to local areas which were within a radius of 5 km. The average distance of the distant destination was also taken. As the vehicles going to distant places have different load capacities, the average number of baskets that a distant vehicle would carry was taken as 90 and that for local vehicles was taken as 40. Based on this, the total number of vehicles required to transport the gear-wise catch into distant and local areas was calculated by dividing the number of boxes by 90 and 40 respectively. From the average distance of travel and the average mileage of a vehicle, the quantity of fuel required for a vehicle was found out. This quantity was multiplied by the total number of vehicles to get the total quantity of fuel used in the transportation. The quantity of ice required for transportation was also found out in this way. It was found that for distant transportation, the fish ice ratio was 1:1.4 kg and that for local transportation; it was 1: 2.1 kg. Based on this, the total quantity of ice in kg required to transport the catch was estimated. This was divided by 50 to get the number of ice bars by taking the weight of an ice bar as 50 kg

Conversion

The carbon footprint of fishing is the quantity of greenhouse gases (GHG), expressed in carbon dioxide equivalent (CO_2e), emitted per kilogram of a fish harvested. It is a life cycle assessment with the analysis limited to emissions that have an effect on climate change. The use of fuels leads to emissions of carbon dioxide (CO_2) and small quantities of other greenhouse gases, including methane (CH_4) and nitrous oxide (N_2O). For a given quantity of a gas, the equivalent quantity of CO_2 that would be needed to give the same greenhouse effect can be calculated using its 'global warming potential'. This quantity is quoted in units of kilograms carbon dioxide equivalent ($kgCO_2e$).

Fuel: In the case of diesel, the conversion factor used is 2.6676 $kgCO_2e$ for the use of one litre of diesel[5]. In the case of petrol, the emission factor is 2.3117 $kgCO_2e$ for 1 litre of petrol.

Electricity: In the case of electricity, it is 0.5246 $kgCO_2e$ for one unit (1 kWh) of electricity consumed[4].

Ice bar: The emission in the case of ice bar production was calculated based on the average consumption of electricity for production of a fixed quantity of ice per month and this electricity was converted into carbon dioxide equivalent using the conversion factor of 0.5246 $kgCO_2e$ for one unit of electricity. The average requirement of electricity for production of an ice bar of 50 kg was worked out as 2.147 kWh and as 1 kWh unit of electricity releases 0.5246 $kgCO_2e$, the release of GHGs as a result of production of one ice bar was worked out as 1.126 $kgCO_2e$.

Vehicles: In the case of vehicles, the quantity of fuel used by a vehicle was converted into GHGs using the conversion factors and it was then multiplied with the total number of vehicles.

According to United Nations Intergovernmental Panel on Climate Change (IPCC), LPG is not a greenhouse gas, meaning it is assigned a global warming potential (GWP)

5 *Defra, 2011*

factor of zero. Hence the LPG cylinders used for cooking in fishing vessels were not studied.

Results (preliminary studies 2011-2015)

The annual zone-wise fuel consumption (million litres) during the three stages of marine fisheries was found to be highest in the harvest stage in the southwest zone. The total fuel consumption was also highest for the southwest zone, amounting to 645 million litres of fuel. The carbon dioxide emission for the production of 1 kg of fish by trawlers and by all crafts combined, were highest for the southwest zone.

Table 11. Maritime zone–wise annual fuel consumption (million litres) during different stages of marine fisheries.

	SE	NE	SW	NW	Total	%
Pre-harvest	2.41	1.63	1.14	1.44	6.62	0.4
Harvest	444.4	229.75	581.73	474.74	1730.62	93.8
Post-harvest	33.89	10.17	62.13	2.12	108.31	5.9
Total	480	242	645	479	1846	

Table 12. Ice bars used (in million) during different stages of fishing activity.*

	SE	NE	SW	NW	Total
Harvest	30.3	14.8	58.8	48.5	152.4
Post-harvest	13.5	4.1	12.6	13.5	43.7
Total	43.8	18.9	71.5	62	196.2

Table 13. Zone-wise annual CO_2 emission (million $kgCO_2e$) during different stages of marine fisheries

	SE	NE	SW	NW	Total
Harvest	1219.6	642.8	1380.8	1321	4564.2
Post-harvest	109.2	31.7	180.1	19.5	340.5
Total	1342.4	679.2	1566.7	1345.3	4933.6

Table 14. All-India carbon emission (million $kgCO_2e$)/year during different stages of marine fisheries

Emissions ($kgCO_2e$)	($kgCO_2e$)	%
Pre-harvest	29	0.6
Harvest	4564	92.5
Post-harvest	340	6.9
Total	4934	

Table 15. Carbon dioxide emission for the production of 1tonne of fish by trawlers from different maritime zones of India

	SE	NE	SW	NW	Total
Catch (t)	677224	137293	527120	555109	1896746
CO_2e (t)	1047357	222452	1142208	592027	3004044
Total	1.5465	1.6203	2.1669	1.0665	1.5838

Table 16. Carbon dioxide emission for the production of 1 tonne of fish from different maritime zones of India

	SE	NE	SW	NW	Total
Catch (t)	1107098	322242	1024033	1059859	3513232
CO_2e (t)	1342379	372900	1566785	1345244	4627308
Total	1.2125	1.1572	1.5300	1.2693	1.3171

The study showed that the harvest phase (active fishing) used more than 90% of the fuel used in the fishing sector. Monitoring fuel use in this phase is necessary to make marine fish production greener. Annual CO_2 emission from the harvest phase was about 4,934 million kg. It was estimated that trawlers from India emit 1.588 t of CO_2 to produce 1t of fish, much below the global figure of >2 t of CO_2 per tonne of fish. For calculating the Indian emission status, emissions from the mechanized and motorized sectors were considered. While pooling the production from these sectors, CO_2 emission was only 1.32 t per tonne of fish. If the production from the non-mechanized sector is also considered, the emission of CO_2 from one tonne of fish production from Indian marine fisheries will be lower than 1.32, which indicates that as per global standards, emissions from Indian fishing units are significantly less. However, it is necessary to implement management measures to reduce CO_2 emissions further to make India's marine fisheries greener.

Mariculture

Harnessing the beneficial impacts of changes in temperature for mariculture

How resilient are finfishes to rising temperature?

Effect of incubation temperature on incubation, early embryonic development, hatching and larval growth of cobia *Rachycentron canadum*

Effect of temperature on the fertilized eggs of cobia, hatching and growth of larvae was studied at different temperatures. The minimum incubation period (18:04±0:12 h) was at 34°C and the same increased as the temperature decreased. The hatching rate was significantly reduced (P<0.01) at 33 and 34°C. The highest hatching rate (89.06±1.48 %) was at 31°C. The time taken for the opening of mouth and complete formation of alimentary tract was significantly reduced (P<0.01) with increase in temperature. The minimum time taken for formation of mouth opening (36:53±1:39 h) and for complete development of alimentary canal (43:06±0:01 h) was at 34°C. The metamorphosis period significantly reduced (P<0.01) with increase in temperature; the minimum duration was 17.84±0.01 days at 34°C.

Table 6. Influence of temperature on the embryonic and larval parameters of R. canadum.

Parameters	Control (27.5-29.5)	31°C	32°C	33°C	34°C
Incubation period (h)	$21:39\pm0:36^{a}$	$20:22\pm0:10^{b}$	$19:32\pm0:07^{b}$	$18:38\pm0:07^{c}$	$18:04\pm0:12^{c}$
Hatching rate (%)	88.31 ± 1.60^{a}	89.06 ± 1.48^{a}	84.67 ± 1.82^{a}	62.96 ± 1.33^{b}	16.50 ± 1.50^{c}
Time taken for mouth opening (h)	$53:58\pm0:47^{a}$	$49:49\pm1:05^{b}$	$43:29\pm1:07^{c}$	$38:56\pm0:34^{d}$	$36:53\pm1:39^{d}$
Time taken for complete development of alimentary tract (h)	$60:29\pm2:42^{a}$	$54:56\pm1:23^{b}$	$52:04\pm1:20^{b}$	$44:12\pm1:25^{c}$	$43:06\pm0:01^{c}$
Metamorphosis period (days)	23.28 ± 0.26^{a}	22.58 ± 0.53^{a}	20.65 ± 0.55^{b}	19.11 ± 0.27^{c}	17.84 ± 1.01^{d}

**Means in the same row followed by the same superscript letter are not significantly different (Duncan's, P-value)*

The yolk-sac volume decreased proportionate to the rise in temperature. At the end of 52 hours, the lowest yolk-sac volume was recorded at a temperature range of 31 to 33°C. Survival of cobia larvae between 20th dph to 40th dph maintained in 30 l tanks at different temperature regimes, *viz.,* ambient (27.5–29 °C), 31, 32, 33, 34 and 35 °C was observed to be as low as 26.67% at 34°C.

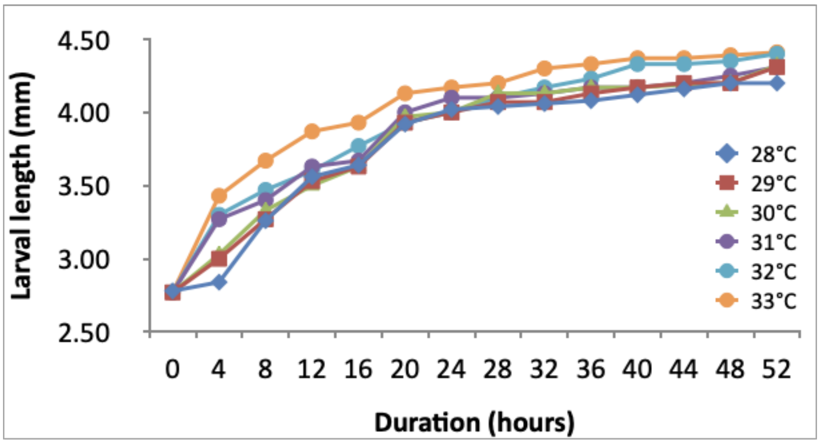
The maximum length of larvae on 28DPH (53.41±1.54 mm) was at 33°C. As the temperature increased the survival rate reduced. The maximum survival rate was at ambient temperature (8.65±0.82 %) and the minimum at 34°C. The overall specific growth rate (SGR) calculated for the entire period of the experiment was not significantly different between the temperatures.

Table 7. Survival and growth rates of cobia larvae from day 1 to day 28 post hatch at different temperatures.

Parameters	Control (27.5-29.5)	31°C	32°C	33°C	34°C
Survival rate (%, 28DPH)	8.65±0.82[a]	7.75±0.98[a]	7.91±0.79[a]	4.55±0.43[b]	2.12±0.32[c]
SGR (overall) (% d^{-1})	9.89±0.53	10.35±0.68	9.23±1.06	10.24±1.56	9.70±0.54
SGR1 (% d^{-1})	13.24±0.31[a]	15.58±0.54[bc]	14.40±0.65[ab]	19.34±0.26[c]	17.04±0.73[d]
SGR2 (% d^{-1})	10.44±0.32[a]	9.76±1.79[a]	11.79±0.70[a]	9.95±1.15[a]	5.59±0.77[b]
SGR3 (% d^{-1})	9.57±1.06[abc]	10.81±0.89[bc]	12.29±0.64[c]	7.48±0.57[a]	9.24±1.26[ab]
SGR4 (% d^{-1})	7.95±0.74[a]	7.25±0.45[ab]	4.50±0.44[c]	5.93±0.43[bc]	1.89±0.61[d]

**Means in the same row followed by the same superscript letter are not significantly different (Duncan's, P-value)*

The larval lengths were higher at higher temperatures. The maximum length recorded was 4.41 ± 0.11 at 33°C at the end of the experiment. However, the larvae showed faster growth when maintained at 32°C at 40th dph, whereas at 34°C all the larvae exhibited retarded growth and movement, with deformities.



Larval length (mm) of cobia, Rachycentron canadum at different temperatures.

Cobia fingerlings showing deformities due to raise in the temperature to 34°C.

Effect of salinity on embryonic development and larviculture of cobia

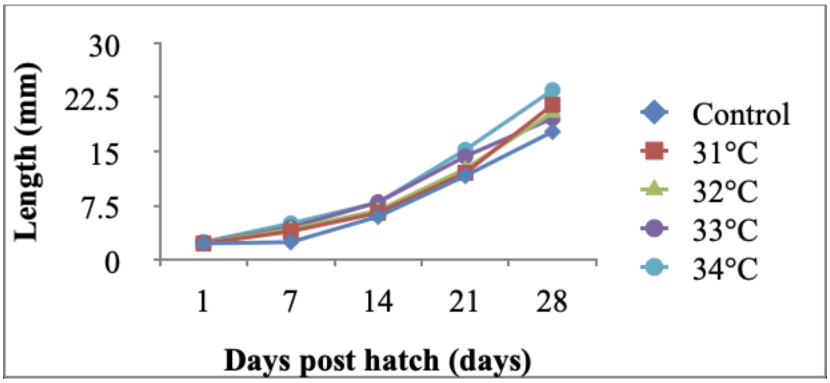
Experiments on fertilized cobia eggs stocked @ 3000 nos. in 10 l tanks with mild aeration in seawater with salinities of 25, 28, 31, 34, 37, and 40 ppt, maintained at ambient temperature of 29.0-30.5°C indicated that hatching rate was higher (78.89%) 31 ppt salinity; a very poor hatching rate of 15.18% was noticed in low salinity of 25ppt.

The effect of light intensity on growth and survival of cobia larvae

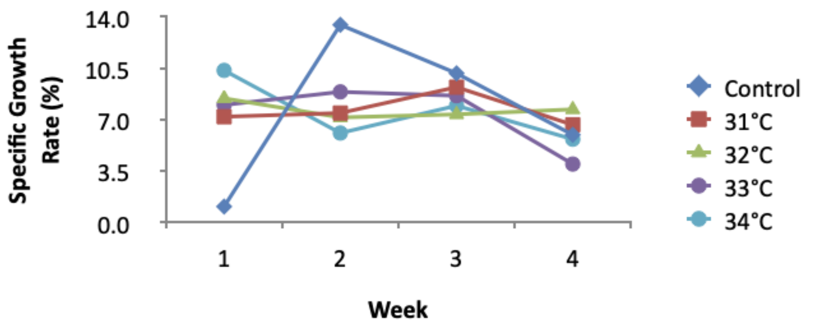
A two-month study on the effect of light intensity on growth of cobia larvae exposed to different light intensities revealed that at higher light intensities, the larval growth was good. At intensities above 2500 lux, growth was comparatively faster while at intensities less than 1000 lux, growth was slow.

Effect of temperature on incubation, hatching, development and larval growth of silver pompano Trachinotus blochii

Silver pompano *Trachinotus blochii* is one of the candidate species for coastal mariculture as it grows in low salinities and has a good market demand. The influence of water temperature on the incubation of eggs, hatching rate, larval survival and growth of silver pompano *Trachinotus blochii* was studied. Four temperature regimes *viz.*, 31°C, 32°C, 33°C and 34°C maintained with submersible aquarium heaters were tested and the control group was maintained at ambient temperature. The incubation period was minimum (14:03±0:16 hours) at 34°C and the same increased as temperature decreased. However, the increase in temperature reduced the hatching rate. The time taken for mouth and anal opening, and metamorphosis significantly reduced ($P<0.01$) with increase in temperature. The maximum length recorded (23.48±0.65 mm) was at 34°C. However, the maximum survival rate (33.88±0.63%) was at ambient temperature and it proportionately declined with increase in temperature.



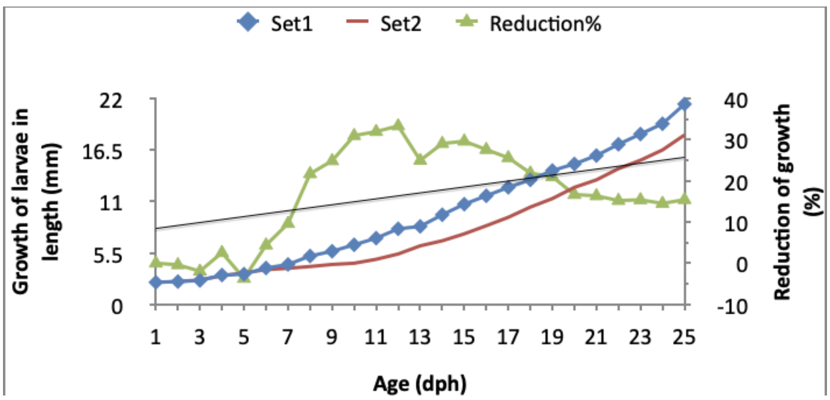
Mean total length of *T. blochii* larvae from 1 to 28 dph at different temperatures.



Weekly specific growth rates of *T. blochii* larvae at different temperatures.

Influence of high temperature and light intensity on growth and metamorphosis of silver pompano (*Trachinotus blochii*)

Temperature and light intensity play a vital role in the larval development of marine finfishes. Experiments conducted with the larvae of silver pompano have shown that an average increase of 2°C in water temperature resulted in reduced growth of about 10 to 33% from 7 dph to 12 dph. Thereafter, the percentage reduction stabilized. A delay of 3 days was noted in the metamorphosis in the high temperature set. The larval pigmentation became translucent white (8 to 14 dph), brown (15 to 20 dph) and silver (21 dph onwards) in the higher temperature set. The reduced growth rate coupled with change in pigmentation of larvae can be taken as the resilience response of the larvae to combat temperature stress.



Total length (mm) of silver pompano larvae (1 to 25 dph) at different temperature regimes (set 1 & set 2) and the percentage reduction of growth.

Table 8. Influence of temperature on the embryonic and larval parameters of *Trachinotus blochii*

Parameters	Control (27.5-29.5)	31°C	32°C	33°C	34°C
Incubation period (h)	18:58±0:56	17:00±0:31	15:40±0:21	15:03±0:18	14:03±0:16
Hatching rate (%)	73.40±2.32	63.76±1.26	48.98±2.11	32.56±2.53	27.61±8.67
Time taken for mouth opening (h)	49:26±1:34	41:45±1:21	35:09±0:38	32:23±0:34	28:38±0:39
Time taken for complete development of alimentary tract (h)	54:24±1:17	48:35±0:47	43:50±1:02	39:56±0:59	36:34±0:44
Metamorphosis period (days)	24.83±0.31	22.83±0.17	22.00±0.00	20.00±0.26	18.83±0.31
Survival rate as on D28PH (%)	33.88±0.63	31.99±0.59	28.41±0.61	25.14±0.83	22.15±0.79

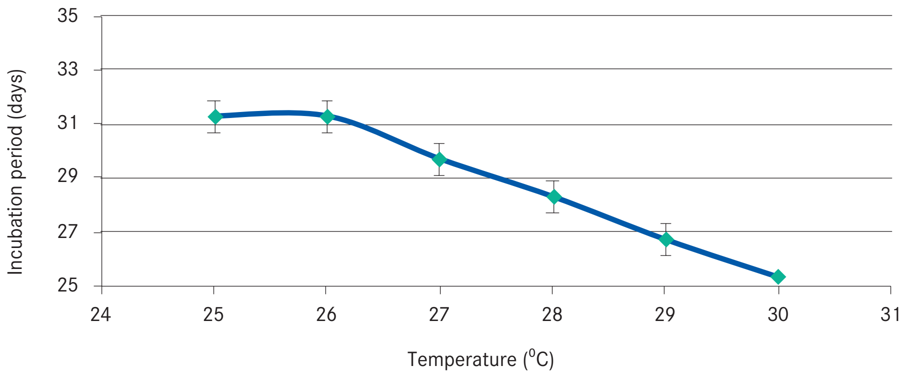
It was also found that rotifers maintained at 35°C with *Nannochloropsis* sp. as feed multiplied to a maximum of 360 numbers per ml in 48 hours. Salinity variation studies on the growth of rotifers revealed that highest multiplication of rotifers (150 numbers) was recorded in the range of 30 ppt followed by 25 ppt (145 numbers) and least growth was recorded at 15 ppt.

Are the shell fishes impacted by rising temperature?

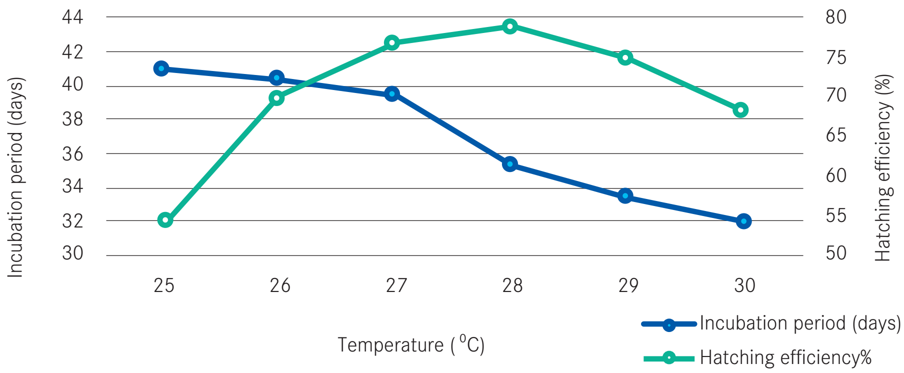
Effect of temperature on reproductive output and larval efficiency in lobsters

The effect of temperature on the incubation period, hatching efficiency, egg diameter, larval size, survival and larval conversion rate in different species of spiny and sand lobsters was studied through real-time observations on captive-reared broodstock and larvae and from data collected from previous studies and published information. All the characteristics studied were found to be impacted by slight variations in the water temperature. Some of these effects can be turned to advantage in manipulating environmental conditions to effect better breeding and growth performance in captivity.

In the mud spiny lobster *Panulirus polyphagus* reared at 36-37 ppt salinity & 8-8.2 water pH, the incubation period was found to decrease from 30-32 days at 25-27°C to 25-28 days at 28-30°C. In the sand *Thenus unimaculatus* reared at 36-37 ppt salinity & 8-8.2 water pH with minimum light exposure, the incubation period was found to decrease from 39-41 days at 25-27°C to 32-35 days at 28-30°C.



Incubation period in mud spiny lobster reared at different temperatures.



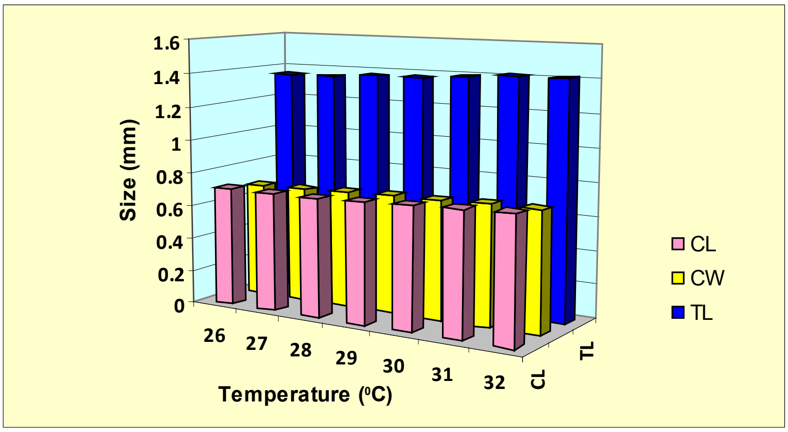
Incubation period & hatching efficiency (%) in sand lobster at different temperatures.

Incubation period in the spiny lobster *Panulirus homarus* was also found to decrease at higher temperatures. When spiny lobsters, held at 29°C for incubation till eye development, were shifted to 26°C, hatching was observed after 6-7 days. When spiny lobsters, held at 29°C for incubation till eye development, were shifted to 32°C, hatching was observed after 4 days.

Table 9. Incubation period in Panulirus homarus at different temperatures.

Temperature (°C)	Days of incubation
26	31
27	29
28	27
29	26
30	26
31	24
32	23

Increase in egg diameter and larval size at the time of hatching is seen in eggs of *P. homarus* incubated at higher temperature. The initial egg diameter ranges from 0.46-0.47 mm from the time of spawning till the 10th day when uniformly the diameter increases to 0.47-0.49 mm at all temperatures (26-32°C). After this, differences are seen at different temperatures. At 30-32°C, the eggs measure 0.52mm by the 15th day while at 26-29°C, this size is attained only by the 16-17th day. In the former case, the eggs measure 0.54 mm by the 18-19th day while in the lower temperature regime, this happens only by the 24th day (at 26°C), 22nd day (27°C) and 20th day (28-29°C). At 30-32°C, the egg diameter increases to 0.56 mm on the 21st day and further, to 0.58 mm just prior to hatching. These sizes are attained only in this higher temperature regime. Larval lengths at the time of hatching were also found to be higher at higher temperatures.



Larval measurements in Panulirus homarus at the time of hatching after incubation at different temperatures.

How resilient are phytoplankton to rising temperature?

Experiment on the culture of phytoplankton in relation to temperature

Experiments were conducted to assess growth and multiplication of marine phytoplankton *Nannochloropsis sp*. in relation to different temperatures. Since the average temperature in the hatchery tank was 28˚C, the experiments were conducted in the temperature range of 28 to 32˚C. The temperature difference between the treatments was 1˚C. The experiment was carried out in 20 l pet jars with 18 l filtered and UV-treated water. A thermostable heater with auto cut was fixed in the jar to control the required temperature. F/2 medium was added at required quantity before adding the inoculums of *Nannochloropsis sp*. at concentration of approximately 0.85 million cells per ml. The algal density in each jar was counted daily at morning 10.00 hrs.

The algal count was significantly similar on the first day of culture at all the cultured temperatures, since the inoculums were added from the same stock of algae. A significant difference at 5% level in growth and density of algae occurred from fourth day onwards. On fourth day of culture, the highest algal count was found at 29˚C and the lowest at 32˚C. The algal biomass crashed on the fifth day in culture tank which was maintained at 32˚C. During the culture period of seven days, a significantly higher growth and multiplication of phytoplankton was found in the culture which was maintained on 29˚C.

Table 10. Algal cell count (1-7 days post inoculation) at different temperatures

Temp (˚C)	*Nannochloropsis* sp. count (million/ml)						
	Day1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
28	0.85 ± 0.005	1.27 ± 0.23	1.60 ± 0.25	1.99^{ab} ± 0.09	2.77 ± 0.37	2.85^{b} ± 0.05	3.49^{b} ± 0.04
29	0.85 ± 0.00	1.40 ± 0.01	1.60 ± 0.25	2.07^{a} ± 0.13	3.15 ± 0.05	3.67^{a} ± 0.17	5.47^{a} ± 0.27
30	0.85 ± 0.005	1.55 ± 0.25	1.55 ± 0.07	1.70^{bc} ± 0.05	2.43 ± 0.07	3.00^{b} ± 0.05	4.27^{b} ± 0.32
31	0.85 ± 0.001	1.71 ± 0.14	1.41 ± 0.06	1.90^{ab} ± 0.01	2.70 ± 0.01	2.89^{b} ± 0.01	4.35^{b} ± 0.21
32	0.86 ± 0.001	1.60 ± 0.01	1.60 ± 0.05	1.60^{c} ± 0.05	crashed	——	—-

a, b, c–Values with different superscripts in each column are significantly different at 5% level of significant

Success stories - Climate resilient technologies and products

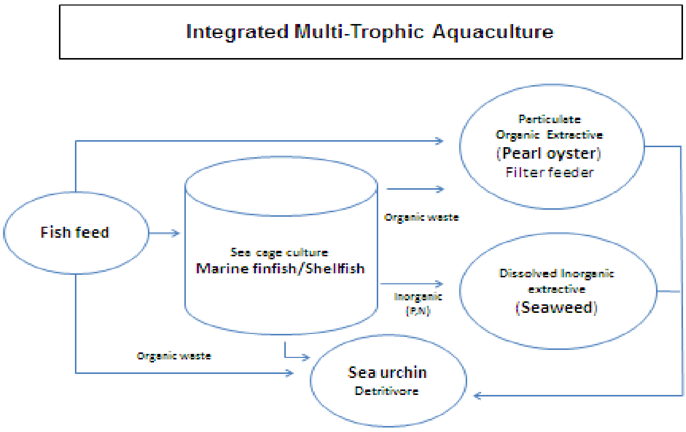
Integrated Multi-Trophic Aquaculture -IMTA

The expansion of sea cage farming of marine finfishes faces the challenges of environmental degradation and consequent disease problems, for which the bio-mitigation could be attained through co-culture of various groups of commercially important species with varying feeding habits. Integration of seaweed with cobia cages generates additional revenue through increased yields of both cobia and seaweed. Sea cage farming of cobia *Rachycentron canadum* along with the rafts of seaweed *Kappaphycus alvarezzi* was developed and demonstrated to the fishermen SHG's and at the end of the farming operations an additional production of cobia (12%) and seaweed (50%) were achieved. ICAR-CMFRI has successfully implemented Integrated Multi-Trophic Aquaculture (IMTA) under participatory mode with a fishermen group at Munaikadu (Palk Bay), Ramanathapuram district, Tamil Nadu by integrating seaweed with cage farming of cobia. Nearly 100 fishers in the district, have been benefited through this technology and they are continuously adopting this technology with their own investment. IMTA is efficient in mitigating both organic and inorganic pollution in the natural open waters and thereby ensuring ecological balances.

IMTA Design

A total of 16 bamboo rafts (12× 12 feet) with 75 kg of seaweed per raft were integrated for a span of 4 cycles along with one of the cobia cages. A GI cage of 6 m diameter and

Seaweed rafts (16 nos.) integrated with cobia cage



Diagrammatic representation of IMTA

3.5 m depth with 750 cobia fingerlings was integrated with the above seaweed raft system. One complete cycle of seaweed extends for an average of 45 days duration and four such cycles were performed in a row. As a control, a separate set of rafts of the same number were grown in a distant location without any integration with the cages.

Economic benefit through increased seaweed production under IMTA

The total seaweed production of the integrated rafts after 4 cycles was 1280 kg, while that of non-integrated rafts was only 576 kg. So, an additional yield of 704 kg of seaweed was achieved due to the integration with cobia cage farming.

View of portion of harvested seaweed Kappaphycus alvarezii from IMTA

Table 28. Comparison of cost and returns of seaweed cultivation with and without IMTA (16 rafts/ one cage/4 cycle)

Particulars	IMTA	Non-IMTA	Difference
Dried seaweed production (for 4 cycle, 16 rafts)	1280 kg	576 kg	704 kg
Price of dried seaweed (Rs.per kg)	37.50	37.50	-
Revenue (Rs.)	48,000	21,600	26,400
Costs (Rs.)	16,000	16,000	-
Net Profit (Rs.)	32,000	5,600	26,400
Profit Margin (%)	67		41

View of portion of harvested seaweed Kappaphycus alvarezii from the integrated raft

There was an increased number (average 90-100 nos.) of newly emerged apical portion/tips in a bunch of harvested seaweed from the rafts integrated with the cobia cages, whereas the same was less (average 30- 40 nos) from the rafts which were not integrated. The bunches with more newly emerged apical portion/tips, when used for replanting, would be ready for harvest within 40 days, whereas those with less numbers of newly emerged apical portion/tips, would be ready for harvest in 54 days.

Although the operational costs of rafts in either case were the same, there was an additional revenue generation/additional net profit of Rs. 26,400 realized with an increased profit margin of 41 per cent through integration of seaweed rafts with cobia cages.

Economic benefit through increased cobia production under IMTA

The integration of the cage with seaweed also generated favorable returns for the farmers with respect to the finfish production.

Table 29. Comparison of economics of sea cage farming of cobia with and without IMTA (for one cage & one crop of 6 months duration)

S.No	Particulars	With IMTA (Rs)	Without IMTA (Rs.)	Difference
750 cobia seeds were stocked in a 6m dia and 3.5m depth GI cage				
1	Fixed cost (one cage)	61,600	61,600	0
2	Total Operating cost	1,30,000	1,30,000	0
3	Total cost of production (Six months)	1,91,600	1,91,600	0
4	Yield of farmed fish (in kg) (in six months average wt. 2.2 kg)	1220	960	260 kg
5	Gross revenue in Rs. (@ Rs. 290 per kg)	3,53,800	2,78,400	75,400
6	Net income	1,62,200	86,800	75,400
7	Net operating income (Income over operating cost)	2,23,800	1,48,400	75,400
8	Price realized	290.00	290.00	0
9	Capital Productivity (Operating ratio)	0.37	0.47	-
10	Cost of production per kg	157	199	42
	Profit Margin (%)	85	45	40

View of harvested cage farmed cobia from the integrated cages

In a six-month production cycle of cage farming of cobia (along with 4 cycles for the integrated seaweed), an average yield of 1,220 kg was achieved in contrast to the non-integrated one where the cobia yield was only 960 kg. The gross revenue generated from the yield (average weight of 2.2 kg/fish and @ Rs. 290/kg) was Rs. 3,53,800 for the integrated and Rs. 2,78,400 for the non-integrated cages. So, an additional net operating income of Rs. 75,400 was realized from the integrated cage. With seaweed integration, operating ratio decreased from Rs.0.47 to Rs.0.37 and cost of production per kg from Rs. 199 to Rs. 157 for non-integrated and integrated cages respectively augments the marginal profit percentage by an additional 40 per cent.

Environmental benefits under IMTA

It was found that the organic waste mitigation of integrated system of *Kappaphycus* farming is more efficient than the non-integrated system of farming. Biochemical analysis of water and sediments from the experimental rafts and cages indicated a mutual beneficial effect for seaweeds and cobia in the integrated aquaculture system. The analyses for organic matter load and water quality parameters indicated that the organic wastes from the feed waste and excreta of fish were sequestered by the integrated seaweed. While the sequestration of the organic waste by seaweed acts as a fertilizer for itself, decreased the organic pollution and helps the fish to save and minimize its energy expenditure towards warding off environmental stress, thus helping it to have better growth rate over its counterpart cultured in non-integrated manner. The total amount of CO_2 sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 223 kg and 100 kg respectively. Hence there is an addition of 113 kg carbon credit due to integration of 16 seaweed rafts (4 cycles) with one cobia cage (one crop).

Table 30. Comparison of carbon sequestration potential of seaweed cultivation with and without IMTA

Particulars	With IMTA	Without IMTA
Fresh seaweed production (for 4 cycle, 16 rafts)	12800 kg	5760 kg
Average dry weight percentage of the harvested sea-weed (%)	8.75	8.75
Average carbon content (%)	19.92	19.92
Total amount of carbon sequestered (1)× (2)× (3)		100 kg

Seed stock of seaweed brought from Palk Bay and floating raft brought to shore for cleaning.

Co cultivation of red seaweed *Kappaphycus alvarezii* integrated with green mussels in Padanna backwaters, Kasaragod, Kerala

As an alternative livelihood option to the mussel farmers as well as to diversify the aquafarming activities in Padanna Estuary of Kasaragod, Kerala, the Carrageenan yielding red seaweed *Kappaphycus alvarezii* being cultivated in large scale at Palk Bay was brought to Padanna village and introduced in floating rafts (2 x 2 m) and kept afloat in mussel rens with active participation of local mussel farming self-help groups. Water quality and growth were monitored fortnightly and the rafts were cleaned to remove the adhering abiotic and biotic seston. The biomass after 60 days was harvested to find that the Padanna Estuary supports seaweed growth without affecting the mussel production. The water quality in the farming site recorded reduction in ammonia levels and increase in dissolved phosphate levels significantly.

Integration of fin fish culture with paddy-shrimp farming in Pokkali in Ernakulam district of Kerala

The pokkali paddy is both saline and flood tolerant. It grows over the flood waters and does not get damaged in submerged conditions. Due to global warming and associated sea water rising, saline water intrusion into freshwater systems and associated damage to the paddy fields is becoming common in the coastal areas of the country. This farming system is highly climate dependent as the sowing requires low salinity in the fields, subsequent to onset of southwest monsoon in Kerala. Pokkali farming is under loss due to climate dependency, lack of suitable machinery, high labour cost, low productivity of rice, disease infection in shrimps. Out of the 20,000 ha pokkali fields spread over three districts, the farming is now restricted to less than 1,000 ha.

A package was developed for pokkali fields by KVK (Ernakulam) of ICAR-CMFRI under NICRA to increase the income from unit area by integrating high value finfish farming in cages towards sustainability of this farming system. Mr. Saigal, a young farmer from Ezhikkara readily agreed to experiment the new method in his pokkali field. The KVK team trained him in pond preparation, catwalk construction, cage construction, nursery rearing, fish transportation, feeding, cage maintenance, etc.

Finfish culture with paddy-shrimp farming in pokkali field in Ernakulam.

Small cages were placed in the field using PVC material as floats, sinkers and top cover. Nursery reared mullet (*Mugil cephalus)* and pearlspot *(Etroplus Suratensis)* were stocked in cages during 1st week of September. The initial stocking density of mullet was 250 nos. per cage and that of pearl spot was 500 nos. per cage. The mullet attained average size of 400 gm with survival of 60% and pearl spot 180 gm with a survival of 90%. The fish harvest was celebrated as a festival by the local pokkali farmers where the Additional District Magistrate, Shri. Ramachandran inaugurated the programme. The fixed cost invested for the cage culture in 1 ha pokkali field was INR 88,200/-. Since the assets can be used for 5 years, the fixed cost per year would be INR 17,640/. The operational cost per year was INR 90,000/-. The gross income per year was INR 1,90,000/- and the profit per year was INR 83,000/-. Earlier, the profits raised were INR 15,000/- from paddy crop alone and INR 50,000.- only from combined paddy and shrimp cultivation from 1 ha field. As a token of appreciation, Director General ICAR Dr

Token of appreciation by Director General ICAR, Dr S. Ayyappan.

Harvested pearl spot and pompano from cages of pokkali fields in Kerala.

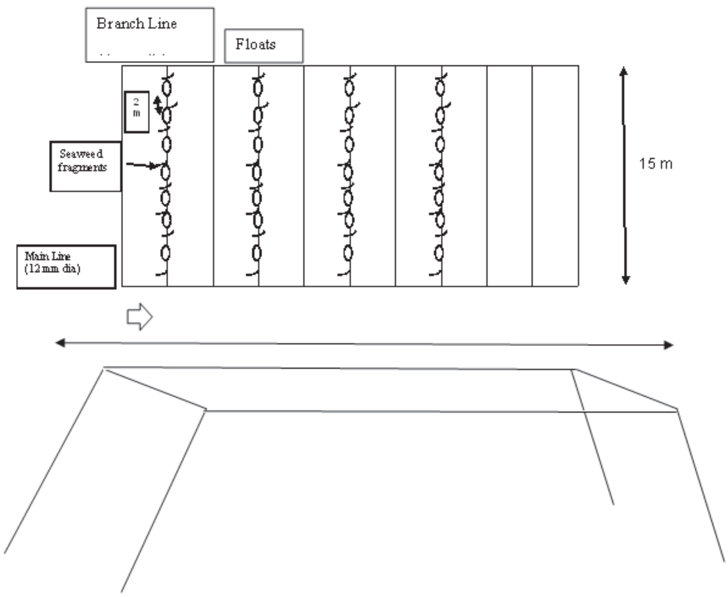
S. Ayyappan felicitated Mr. Saigal on 12th May 2013 at Mandapam Regional Centre of CMFRI, Mandapam.

Owing to the success of NICRA Technology demonstration in pokkali farmers field, the Fish Farmers Development Agency (FFDA) under the state government has initiated a scheme – *Integrated fish farming in pokkali fields* through which the agency supports fish farming both in open pokkali fields and also in cages sited in pokkali fields. Introduction of Pompano (*Trachinotus blochii*) for culture in low saline waters for first time in Kerala was also done. The fish is performing well in pokkali fields.

Improved monoline seaweed culture

Climate resilient seaweed farming practices using improved monoline rope culture was carried out in Mullakadu village, Tuticorin district, Tamil Nadu. The vegetative fragments of *K. alvarezii* (average 200.0 ± 5.0 g fresh weight) were inserted at 2 m gap intervals between the twists of the rope. It was tied to a mono line HDPE rope (4mm dia.). For floating, HDPE floats were tied using (2.5 mm dia) rope and dead weight used for anchoring in four corners. The main line (15m) length rope was tied to the (12 mm dia.) sideline ropes. Every branch line had 2 feet gap in the sideline ropes. Hundred replicates were done, each containing 80 numbers of fragments in 15 m rope of single branch line. A monoline plot with 100 coir ropes had an initial mass of propagules of 2000 ± 50.0 kg fresh wt raft^{-1}. In the first trial, after 35 days, *K. alvarezii* for one branch monoline was 200 ± 10.0 kg fresh biomass per rope; a total wet weight of 10,400 of ± 50.0 kg was achieved from a single plot.

Tuticorin Research Centre of ICAR-CMFRI established the improved monoline seaweed farming technique as a climate smart practice along the Kovalam coast of Mullakadu. The seaweed farmers were able to realize a yield of up to 12 tonnes of wet weight from a single monoline plot (100 numbers of monolines) after a culture period of 30-35 days with a net revenue gain of Rs.35,000-40,000/- per crop. The farm gate price of harvested seaweed (wet wt. basis) is Rs.5/kg and Rs. 40/kg for dried seaweed with 30%



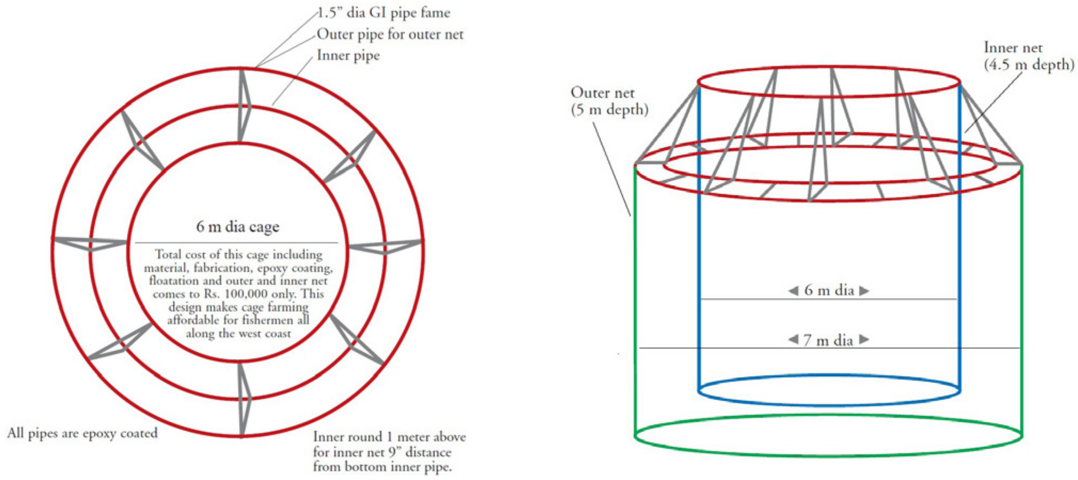
Diagrammatic representation of seaweed culture in monoline method

Seaweed harvest at Tuticorin

moisture. They were able to get nearly 4-5 fold growth of seaweed from the seeded material in a span of 30-35 days culture at this site. They could optimally perform the culture activities for nearly 6 months from April to September or June to November in a year. An individual farmer can manage four plots of improvised monolines at a time.

Low-cost cages

CMFRI has developed a standard cage that can be constructed using readily available low cost materials such as galvanized iron pipe and fibre barrels. These cages cost only a small fraction of HDPE cages of equivalent size. Efforts were made to reduce the cost of the cage and mooring systems so as to make it more affordable for the fishers. This resulted in fifth generation low cost cages, costing less than Rs. 1,00,000/- and lasting at least for 5 years. It is more sustainable and economical in the long run.



Design and technical details of the low cost cage

Bioproducts

Feed for the culture of pearl spot, *Etroplus suratensis*

A specialized pellet feed to be used in the rearing of pearl spot, *Etroplus suratensis* was formulated under the CADALMIN brand, bearing the trade name '*Pearl Plus*'and introduced to the market. '*Pearl Plus*' could be used for feeding pearl spot during Pokkali-finfish integrated farming.

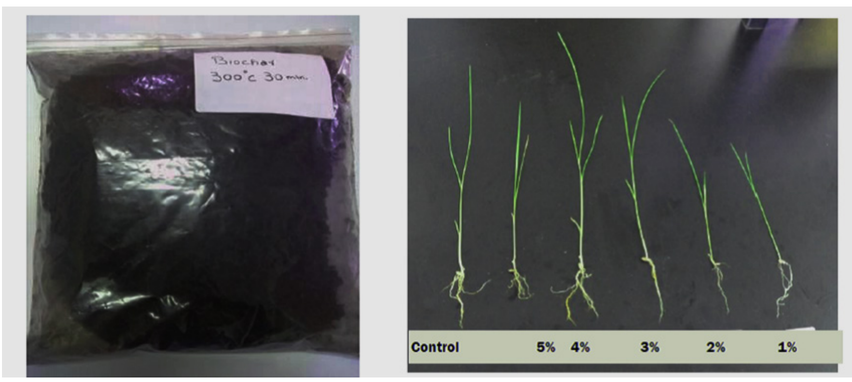
Biofuel and Biochar production from seaweeds and water hyacinth

Compositional analyses such as carbohydrate, cellulose, and lignin content of seaweeds (*Kappaphycus alvarezii* and *Gracillaria corticata*) revealed the suitability of the substrate for biofuel production via pre-treatment, hydrolysis and fermentation pathways. Pretreatment with hydrogen peroxide, followed by acid hydrolysis and subsequent fermentation using yeast *Saccharomyces cerevisiae* yielded bioethanol, which was detected by High Performance Liquid Chromatography. Same procedure followed on substrate water hyacinth (*Eichhornia crassipes)* also yielded bioethanol.

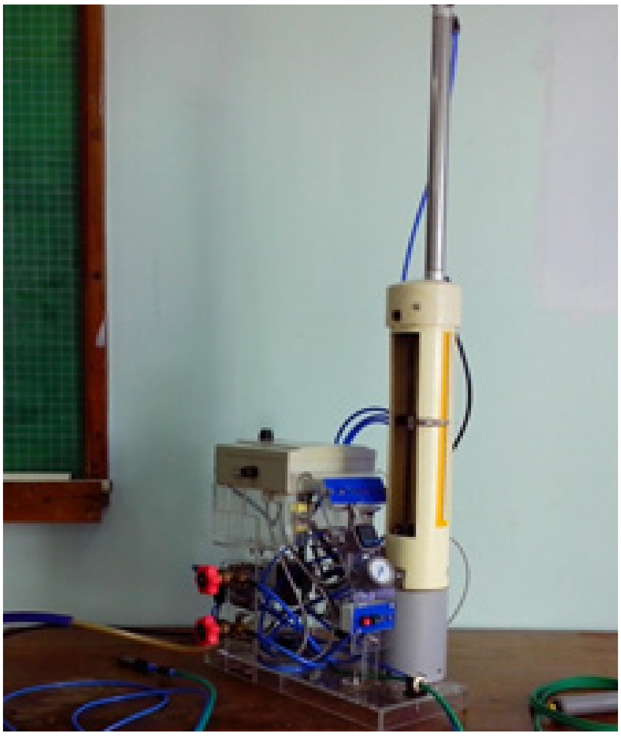
Pearl Plus feed

Seaweed pre-treatment and hydrolysis for biofuel production

Biochar production from seaweed and water hyacinth was done by pyrolysis technique in a muffle furnace under the pre-optimized conditions. The biochar produced from water hyacinth was further subjected to heavy metal (Zn) remediation under lab conditions which resulted in ~50% reduction of Zn concentration within 3 days of treatment. The residual substrate of biofuel process pathway could also be converted into biochar, which could bring more sustainability in waste to resource conversion with beneficial climatic implications.



Biochar produced from water hyacinth and pokkali grown in biochar enriched soil



Carbon dioxide flow regulator and recorder

Biochar as Tilapia feed enrichment and as soil mixture: Conversion of water hyacinth to climate resilient product 'Biochar' endorses the sustainable concept of waste to resource conversion and ensures cheap substrate as raw material. The experimentation of biochar incorporation on a representative pokkali-tilapia system resulted in improved growth performance of tilapia, pokkali paddy growth enhancement and water quality improvement. Weight and length of tilapia were found to be enhanced in biochar mixed feed and the highest was recorded for 1% of biochar mixed feed system. Biochar-mixed soil resulted in pokkali growth with highest observed in 4% biochar-soil mixture. Improvement in water quality profile was also observed in biochar amended system. Slight changes were observed for pH, dissolved oxygen and total alkalinity. The work demonstrates new horizons towards aquaculture application using biochar generated from water hyacinth.

Carbondioxide flow regulator & recorder

(Prototype-1)

Ocean acidification is increasingly evident as a consequence of temperature rise in the oceans. An Ocean acidification lab has been set up in CMFRI to study the impact of pH on marine organisms especially shellfish and juveniles. A major bottle neck for the study is the absence of instruments which releases CO_2 in minute quantities to water. Institute has developed a prototype of Carbon dioxide flow regulator and recorder. Input phase consist mainly of the input from the safety regulator cum analogue pressure gauge of external CO_2 cylinder and this in turn connected with the liquid separator. In the processing phase, the input of CO_2 gas is channelled to a precision regulator assembly with a needle valve and analogue pressure gauge which accurately displays the input CO_2 gas pressure. The output phase consist of the controlled CO_2 gas release unit with minute precision solenoid valve and external release probe with terminal weight controlled valve mechanism to hold the gas inside the system when it is lifted from the seawater.

Coastal ecosystems

Mapping of coastal wetlands

Wetland information app and e-platform

National Wetland information mobile app and website developed and transferred by SAC-ISRO to NICRA project of ICAR-CMFRI

Climate change events induced influxes of runoffs, storm water discharges and flood waters change the physico-chemical profile of several wetlands, while fish farmers suffer economic losses owing to compositional changes of wetlands, loss of cages, stock loss, etc. A national resilience framework envisaging e-platform to bridge the field level datasets with spatial data was developed through NICRA project to facilitate the monitoring and forecasting of regional wetland impacts. Indian Space Research Organization (ISRO)–Space Applications Centre (SAC), Ahmedabad already has datasets of smaller wetlands (<2.2ha) of the country, which is being updated. Discussions were held with SAC-ISRO to develop a mobile app and centralised portal so as to facilitate field level datasets collection of smaller coastal wetlands and subsequent integration of physical data with spatial dataset, which was agreed on. Accordingly, ICAR-CMFRI, Kochi and ISRO-SAC, Ahmedabad signed Memorandum of Understanding (MoU) through National Innovations in Climate Resilient Agriculture (NICRA) project on 8th April 2019 at SAC campus at Ahmedabad. The mobile application and associated website with access to scientific communities as per the project requirement has been developed by ISRO-SAC and transferred to NICRA project of ICAR–CMFRI of 30th September 2019. This is the first national instance that a fisheries institute is collaborating with ISRO to develop a comprehensive climate resilient framework for fisheries and wetlands. The data generated will be stored in the SAC server with access to authorized scientific communities and ICAR-CMFRI will be the nodal center for approving coastal wetland data of the partnering stakeholder institutions.

The framework developed in the project involves four interconnected components viz., regional wetland mapping, field level wetland data generation, online GIS platform and continuous monitoring.

MOU signing event between NICRA, ICAR-CMFRI Kochi and Space Applications Centre (ISRO), Ahmedabad

ICAR-CMFRI – SAC (ISRO) Collaboration: Press release

Features of the e-platform

The app and portal will enable integration of additional field level datasets of wetlands to the existing wetland database of ISRO-SAC. NICRA project of ICAR-CMFRI is entrusted as the national level admin for coastal wetlands and the scientific stakeholders are being identified through the project.

Scientific institutions, Universities and concerned departments/schools, wetland research organizations and environmental bodies can be partnered as stakeholders for data collection.

In the initial stage the mobile application enables collection and integration of physico-chemical datasets of wetlands into a common portal. In the next stage, a continuous monitoring system will be evolved with access for scientific communities/subject experts to the common portal, so as to allow analysis of the datasets and to identify vulnerable wetlands to provide advisories regarding mitigation steps to be taken.

The mobile application works in both modes of Online (with internet) and Offline (without internet) and can be further synchronized once internet is available. A preapproved user can, log in to the installed mobile application and tap the 'get location' button to automatically load the data such as latitude, longitude, state, district and taluk. The mobile application was used to take and upload real-time picture of the wetlands. Field data on parameters such as pH, water and air temperature, salinity,

Handing over of mobile app technology developed for wetland data collection by ISRO-SAC to CMFRI

humidity and turbidity are to be entered as values. Visible observations such as nearby vegetation, pollution sources and colour can also be directly fed into the application. Associated web portal will used to input the result of lab analysis for physico-chemical parameters such as dissolved oxygen, nitrates, ammonia, phosphate, and silicate. To maintain data quality, the user-fed information must be approved by an associated expert and further by the admin, so as to be visible in the common portal. Once visualized, a click on the wetland point source in the spatial map displays information on real time water and sediment quality, species health and climatic threats.

Current status

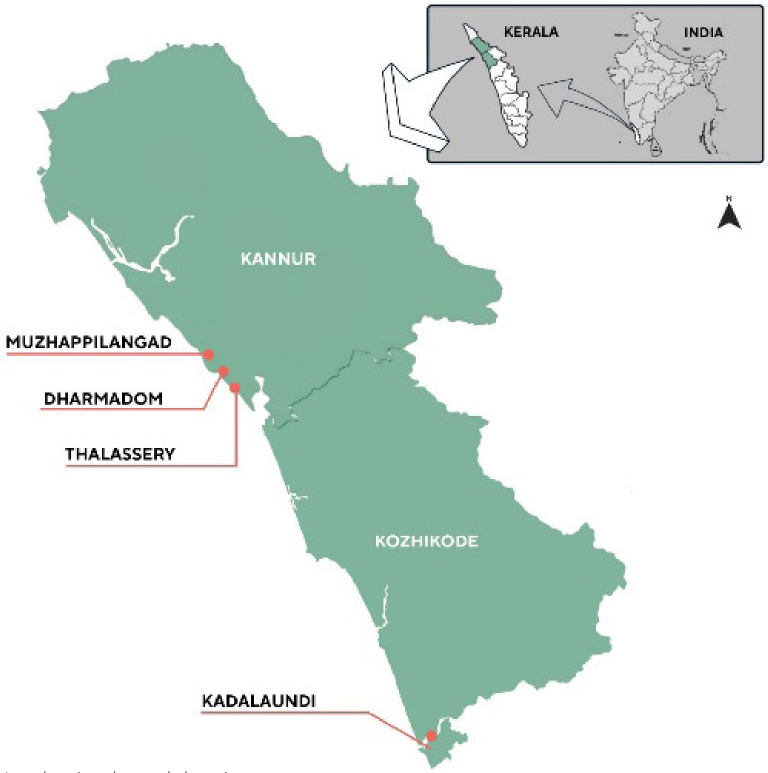
Field level utilization of the developed android mobile application with ground-truthing has been done for around 30 wetlands of Ernakulam district including 20 from coastal regions, 5 from flood affected areas and 5 fronting saline water intrusions.

A wetland of around 5 acre were restored and made suitable for aquaculture practice at Edakochi, Kerala. Restoration works includes side bund construction and fortification of sluice gates so as to enable aquaculture practices in a large scale. The restored wetland through the project could withstand the Kerala Floods, though some stocks were lost the side bund constructed remained strong along with the fortified sluice gates. The restored wetland was used for multispecies farming of milk fish, pearl spot and prawns and a partial harvest was done with moderate yield. Subsequent farming was undertaken with the juveniles produced from the first stock.

Blue carbon potential of coastal ecosystems

The concentration of atmospheric carbon-di-oxide has been on the rise since the beginning of the industrial revolution resulting in consequences like warming of the planet, change in precipitation patterns and rising sea level. The forests are reservoirs of sequestered carbon stocks and the global community has already started realising the importance of forest ecosystems in the light of climate change. The tropical forests which are important components in the global carbon cycle represent ~30-40% of the terrestrial net primary production[1,2].

The coastal ecosystems of mangroves, tidal marshes and seagrass meadows are reservoirs of carbon stored over centuries. These ecosystems have the potential to sequester and store large quantities of carbon (often referred to as 'blue carbon') per unit area when compared to the terrestrial forests. As a result, the blue carbon ecosystem is recognized for its significant role in mitigating climate change. Although mangroves contribute only a mere 0.7% of tropical forests of the world[3], these forests have the potential to store up to 20 billion tons of carbon, which is much higher than the carbon stock in tropical upland, temperate and boreal forests[4]. Mangrove forests sequester four times more carbon per unit area than the terrestrial forests of the tropics[5].



Map showing the study locations

1 Malhi and Grace, 2000
2 Clark et al., 2001
3 Giri et al., 2011
4 Donato et al., 2011
5 Khan et al., 2007

An aerial view of Kadalundi

Biomass and carbon stocks in selected mangrove wetlands of Kerala

In India, mangroves are spread over an area of 4,975 sq. km, which is about 3.3% of the mangrove vegetation distributed globally[6]. Considering the vastness of mangrove cover in India, substantial amounts of atmospheric carbon-di-oxide is expected to be sequestered and stored by this halophytic vegetation. Under the NICRA, studies were conducted in some of the important estuarine wetlands of Kerala *viz*., Kadalundi, Muzhappilangad, Thalassery and Dharmadom, to understand the carbon sequestration potential of mangroves.

Materials and methods

Field Sampling: The sampling plots were of 10 m x 10 m size, established through a non-destructive stratified random quadrat sampling technique to determine the composition of mangroves, tree density and carbon stock. The total sampling area covered was 0.24 ha, 0.13 ha, 0.17 ha and 0.30 ha in Kadalundi, Muzhappilangad, Thalassery and Dharmadom wetlands respectively. A Global Positioning System, GPS (Garmin GPSmap 76CSx) was used to mark the exact location of each sampling station.

Tree Measurements: The girth of every individual mangrove tree of the study quadrat was measured. The tree girth measurements were taken at breast height which is 1.3 m above the ground. The tree girth measurements were then converted to diameter at breast height (DBH) measurement by dividing by π (Frontier Madagascar, 2005). All adult trees and saplings of height 1.3 m and above were considered for the measurement of DBH. In *Rhizophora mucronata*, the trunk diameter at 30 cm above the highest prop root was measured (Komiyama *et al*., 2005). The mangrove plants/trees were classified as seedlings, saplings and adults based on their total height and girth at breast height. The plants which were less than 1 m tall were classified as seedlings. The plants taller than 1 m, but less than 4 cm girth at breast height were

6 *Forest Survey of India, 2019*


DBH measurements of (a) *Avicennia officinalis* – 1.3 m from the ground, and (b) *Rhizophora mucronata* – 30 cm above the highest prop root

Sediment sampling using PVC core sampler

classified as saplings, while the plants taller than 1m with greater than 4cm girth at breast height were considered as adults (Frontier Madagascar, 2005).

All adult trees present in each of the quadrats were measured for the estimation of above-ground biomass, below-ground biomass and carbon stock. However, the understory vegetation of seedlings and herbs is considered to be negligible and hence not considered for measurement of ecosystem carbon pools[7]. Also, litter being a small component of the total ecosystem, carbon stock is not usually sampled. All the dead trees were also taken into consideration and the biomass of dead trees was estimated based on the 'decay status' categories.

Biomass and carbon stock estimation: For the estimation of carbon, three pools of carbon *viz*., above-ground biomass, below-ground biomass (root) and sediment were considered. The allometric equations developed[8] for southeast Asia were used for the estimation of above-ground biomass (W_{top}) and below-ground biomass (W_R). The allometric equations are:

7 *Kauffman and Donato, 2012*
8 *Komiyama et al., 2005*

$W_{top} = 0.251\ \rho D^{2.46}$ (1)

$W_R = 0.199\ \rho^{0.899} D^{2.22}$ (2)

where, ρ is the wood density of the respective species and D is the Diameter at Breast Height (DBH). The wood density of different mangrove species was obtained from the World Agroforestry Database[9].

The total biomass of mangrove trees was obtained by summing up the values obtained for the above-ground and below-ground biomass for all the plots. These values were then averaged to get the mean total biomass, which was finally converted to tonnes per hectare. The biomass values were converted to carbon through the use of a carbon fraction value of 50%.

Soil Sampling and Analysis: A PVC core sampler having a length of 1 m and 4 cm diameter was used to collect sediment samples from each quadrat in the study area. The sediment samples from surface to 30 cm depth were collected during core sampling for the estimation of organic carbon and bulk density. The sediment samples for estimation of bulk density were oven-dried and the bulk density was calculated by dividing the dry weight of the core sample by the volume of the core. The organic carbon in sediment samples was estimated[10] using the formula:

Sediment organic carbon (t/ha) = Bulk density (g cm^{-3}) x sediment depth (cm) x organic Carbon (%)

Results

Floristic composition: The species, size and structure of the mangroves distributed in the wetlands have a strong influence on the biomass and carbon stock. The mangrove diversity was found to be more at Dharmadom (9 species), followed by Thalassery (8 species), Kadalundi (6 species) and Muzhappilangad (4 species). The species *Avicennia officinalis* and *Rhizophora mucronata* were found distributed in all the wetlands.

Tree density and Diameter at Breast Height (DBH) of mangroves: At Kadalundi, *A. officinalis* was the dominant species which registered the highest tree density of 1,300 individuals ha^{-1} and this species also registered the highest DBH value of 10.01±7.07 cm, thus contributing substantially to the total carbon stock. At Muzhappilangad, although *Avicennia marina* was the dominant species (1,592 individuals ha^{-1}), the highest DBH value was recorded in *A. officinalis* (13.32 ± 0.96 cm). In Thalassery estuarine wetland, the highest tree density (729 individuals ha^{-1}) and the highest DBH (9.86±4.03) were recorded in *A. officinalis*. Dharmadom mangrove wetland was characterised by the predominant growth of *R. mucronata* with the highest tree density of 1,071 individuals ha^{-1}; however, the highest DBH value was recorded in *Sonneratia alba* (13.78±3.74 cm) which had a higher trunk girth compared to *R. mucronata*.

Table 18. Average tree density of mangroves in different wetlands (nos./ha)

Sl. No.	Mangrove species	Mangrove wetland			
		Kadalundi	Muzhappilangad	Thalassery	Dharmadom

9 *World Agroforestry Centre, 2011*
10 *Walkley and Black 1994*

Table 17. Floristic composition of mangroves in the study area

Sl. No.	Mangrove species	Mangrove wetland			
		Kadalundi	Muzhappilangad	Thalassery	Dharmadom
1	*Avicennia marina*	x	√	√	√
2	*Avicennia officinalis*	√	√	√	√
3	*Rhizophora mucronata*	√	√	√	√
4	*Bruguiera cylindrica*	√	√	x	√
5	*Bruguiera gymnorhiza*	x	x	x	√
6	*Bruguiera sexangula*	x	x	√	x
7	*Sonneratia alba*	√	x	√	√
8	*Excoecaria agallocha*	√	x	√	√
9	*Aegiceras corniculatum*	x	x	√	√
10	*Kandelia candel*	x	x	√	√
11	*Acanthus ilicifolius*	√	x	x	x

√–Present; x – Absent

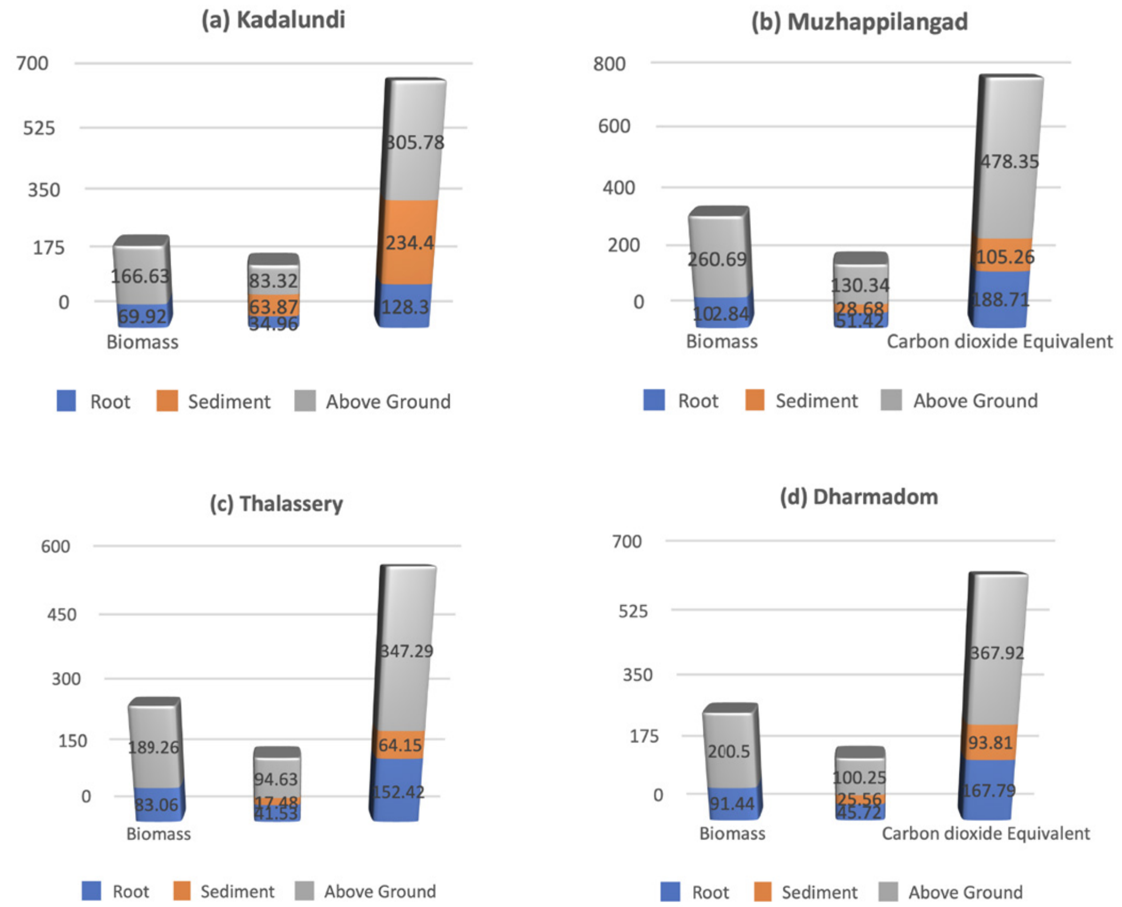
A dense patch of Rhizophora mangrove wetland mucronata at Dharmadom

1	*Avicennia marina*	-	1,592	471	190
2	*Avicennia officinalis*	1300	169	729	659
3	*Rhizophora mucronata*	220	54	419	1071
4	*Bruguiera cylindrica*	270	8	-	14
5	*Bruguiera gymnorhiza*	-	-	-	108
6	*Bruguiera sexangula*	-	-	63	-
7	*Sonneratia alba*	146	-	478	322
8	*Excoecaria agallocha*	42	-	10	55
9	*Aegiceras corniculatum*	-	-	6	148
10	*Kandelia candel*	-	-	275	189

Table 19. Average DBH (cm) of different mangrove species in the study area

A view of the mangrove stand of *Avicennia marina* in Thalassery estuary

Sl. No.	Mangrove species	Mangrove wetland			
		Kadalundi	Muzhappilangad	Thalassery	Dharmadom
1	*Avicennia marina*	-	11.90±8.23	8.35±4.96	13.01±6.87
2	*Avicennia officinalis*	10.01±7.07	13.32±0.96	9.86±4.03	9.83±3.26
3	*Rhizophora mucronata*	5.61±2.15	6.65±0.96	3.31±2.05	4.74±1.47
4	*Bruguiera cylindrica*	3.89± 2.26	-	-	4.01±1.09
5	*Bruguiera gymnorhiza*	-	-	-	3.48±1.72
6	*Bruguiera sexangula*	-	-	3.04±1.45	-
7	*Sonneratia alba*	4.59±2.15	-	11.80±4.02	13.78±3.74
8	*Excoecaria agallocha*	6.09±5.14	-	5.73±3.57	4.28±1.51
9	*Aegiceras corniculatum*	-	-	4.52±4.52	7.90±6.46
10	*Kandelia candel*	-	-	4.29±1.18	2.89±1.47

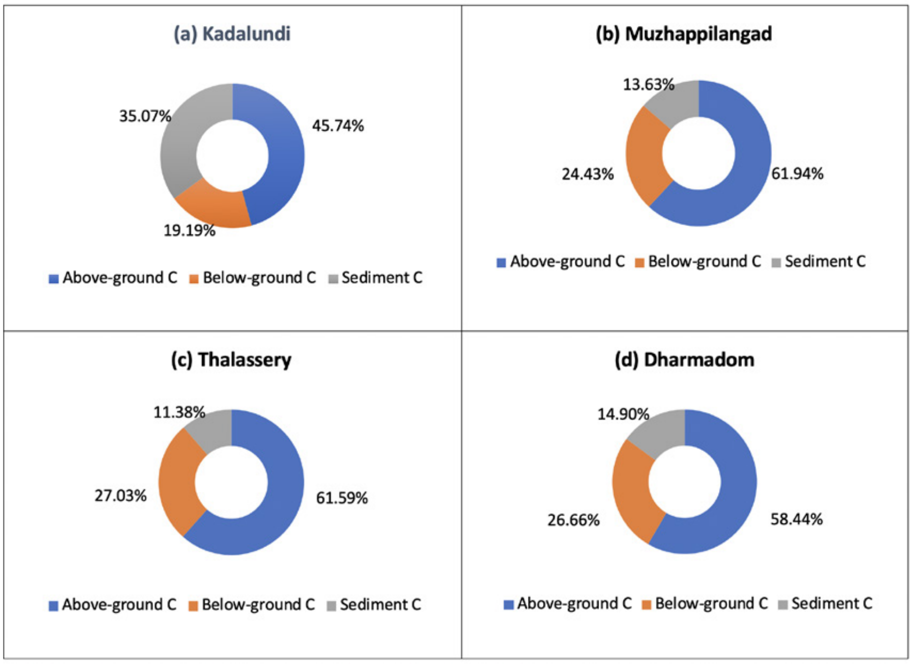


Mangrove biomass, C-stocks and CO_2 equivalent potential of different wetlands

Biomass and C-stock: Muzhappilangad wetland showed the highest mangrove biomass of 363.53 t ha^{-1} followed by Dharmadom (294.64 t ha^{-1}), Thalassery (272.32 t ha^{-1}) and Kadalundi wetlands (236.56 t ha^{-1}). The total mangrove tree C-stock was also the highest in Muzhappilangad wetland (181.76 t ha^{-1}) (Table 5). The sediment C-stock ranged from 17.48 t ha^{-1} in Thalassery wetland to 63.87 t ha^{-1} in Kadalundi. Although, the sediment C-stock was less at Muzhappilangad (28.68 t ha^{-1}), the total C-stock recorded in this wetland was the highest (210.44 t ha^{-1}) mainly due to the higher above-ground and below-ground (root) biomass.

Table 20. Biomass of mangroves in different estuarine wetlands

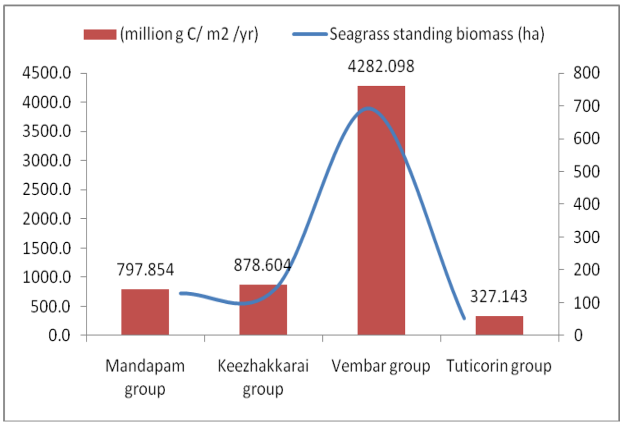
Wetlands	Biomass (t ha^{-1})		
	Above-ground biomass (t ha^{-1})	Below-ground biomass (Root) (t ha^{-1})	Total biomass (t ha^{-1})
Kadalundi	166.63	69.92	236.56
Muzhappilangad	260.69	102.84	363.53
Thalassery	189.26	83.06	272.32
Dharmadom	200.50	91.44	294.64



Percentage contribution of above-ground, below-ground (root) and sediment carbon stocks of mangrove wetlands

Table 21. Carbon stock of three different carbon pools in the study area

Wetlands	Above-ground C-stock (t ha^{-1})	Below-ground C-stock (Root) (t ha^{-1})	Total mangrove tree C-stock (t ha^{-1})	Sediment C-stock (t ha^{-1})	Total C-stock (t ha^{-1})
Kadalundi	83.32	34.96	118.28	63.87	182.15
Muzhappilangad	130.34	51.42	181.76	28.68	210.44
Thalassery	94.63	41.53	136.16	17.48	153.64
Dharmadom	100.25	45.72	145.97	25.56	171.53



Carbon assimilation potential of seagrass from Gulf of Mannar
Available seaweed biomass (8,445 tonnes) in the Gulf of Mannar can absorb 450.3 CO2 tonnes per day of which 14.5 tonnes of CO2 were emitted per day.

Total C-stock of Kadalundi: The estimates of mean combined C-stocks in the mangrove biomass and sediment of Kadalundi shows that this estuarine mangrove wetland stored 182.15 t C ha-1 (above-ground 83.32 t C ha-1, root 34.96 t C ha-1 and sediment 63.87 t C ha-1), which was equivalent to 668.48 t CO2 ha-1 (above-ground 305.78 t CO2 ha-1, root 128.30 t CO2 ha-1 and sediment 234.40 t CO2 ha-1). Of the three carbon pools, the above-ground C-stock was the highest (45.74%), followed by the carbon stock of sediment (35.06%) and the carbon stock of root biomass (19.20%). The mangroves in Kadalundi wetland which cover an area of 13.23 ha is assumed to have a potential to sequester and store 2,409.84 t C which is equivalent to 8,844.11 t CO2.

Total C-stock of Muzhappilangad: Total ecosystem carbon stock of Muzhappilangad wetland showed that this mangrove wetland stored 210.44 t C ha^{-1} (above-ground 130.34 t C ha^{-1}, root 51.42 t C ha^{-1} and sediment 28.68 t C ha^{-1}), which was equivalent to 772.32 t CO_2 ha^{-1} (above-ground 478.35 t CO_2 ha^{-1}, root 188.71 t CO_2 $ha^{-1}$and sediment 105.26 t CO_2 ha^{-1}). Of the three carbon pools, the above-ground C-stock was the highest (61.94%), followed by the carbon stock of root biomass (24.43%) and the sediment carbon stock (13.63%). The mangrove forests of Muzhappilangad wetland cover an area of 8.9 hectares. Considering an estimated total C-stock of 210.44 t C ha^{-1}, it can be assumed that this wetland can sequester and store 1,872.92 t C, equivalent to an estimated 6,873.61 t CO_2.

Total C-stock of Thalassery: The estimates of mean combined C-stocks in mangrove and sediment showed that this mangrove wetland stored 153.64 t C ha^{-1} (above-ground 94.63 t C ha^{-1}, root 41.53 t C ha^{-1} and sediment 17.48 t C ha^{-1}) which was equivalent to 563.86 t CO_2 ha^{-1} (above-ground 347.29 t CO_2 ha^{-1}, root 152.42 t CO_2 ha^{-1} and sediment 64.15 t CO_2 ha^{-1}). The percentage share of carbon in the three carbon pools indicated that the above ground C-stock was the highest (61.59%), followed by the below-ground (root) C-stock (27.03%) and the C-stock of sediment (11.38%). The mangroves of Thalassery wetland cover an area of 5.8 ha and with an estimated total carbon stock of 153.64 t C ha^{-1}, it can be assumed that the Thalassery wetland has the potential to sequester and store 891.11 t C, equivalent to an estimated 3,270.37 t $CO_{2.}$

Total C-stock of Dharmadom: The mean combined C-stocks in mangrove and sediment of Dharmadom showed that this wetland stored 171.53 t C ha^{-1} (above-ground 100.25 t C ha^{-1}, root 45.72 t C ha^{-1} and sediment 25.56 t C ha^{-1}) which was equivalent to 629.52 t CO_2 ha^{-1} (above-ground 367.92 t CO_2 ha^{-1}, root 167.79 t CO_2 ha^{-1}

and sediment 93.81 t CO_2 ha^{-1}). The percentage share of carbon in three carbon pools indicate that the above-ground C-stock was the highest (58.44%), followed by below-ground (root) C-stock (26.65%) and the C-stock of sediment (14.91%). The mangroves of Dharmadom wetland cover an approximately 9.7 ha and thus it can be assumed that this wetland has the potential to sequester and store 1,663.84 t C which is equivalent to an estimated 6,106.30 t CO_2.

Climate change has been a major concern across the globe and measures for mitigation of climate change have been a major challenge faced by man during the last few decades. The enormous potential of mangroves to sequester and store carbon in their biomass and sediments, as evident from the present study as well as from the studies conducted elsewhere undoubtedly signifies the importance of mangrove ecosystems in mitigation of climate change. Mangroves, besides being large store houses of carbon, render numerous ecological services; yet they are fragile and vulnerable to natural and man-made disturbances. Conservation of existing mangroves and restoration of mangroves in degraded habitats is therefore an urgent need to harness the benefits of these blue carbon ecosystems.

Carbon assimilation potential by seagrass biomass from Gulf of Mannar

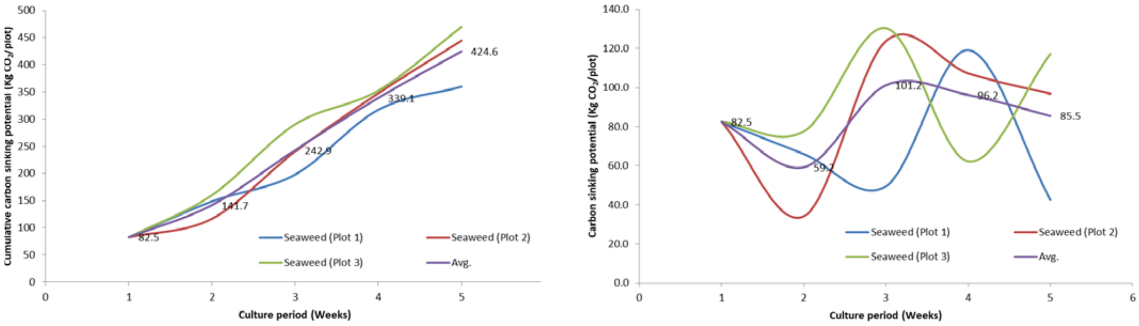
The carbon assimilation potential of different seagrass (million $gC/m^2/yr$) from Mandapam, Keezhakkari, and Vembar and Tuticorin group of Island, Gulf of Mannar was estimated from the available literature. The study revealed that the carbon assimilation potential was more in the Vembar group of Island due to abundance of seagrass biomass in this region.

Table 22. Carbon assimilation potential of different seagrass biomass from Gulf of Mannar

Species	Biomass	Efficiency to absorb CO_2	CO_2 absorbed	Efficiency to emit CO_2	CO_2 emitted
	(tons)	(mg/g/h)	(t/day)	(mg/g/h)	(t/day)
Sargassum sp.	6736	2.35	379.9	0	0
Turbinaria sp.	224	2.35	12.6	0	0
Cystoseira sp.	40	2.35	2.3	0	0
Hypnea sp.	965	1.60	37.1	1	9.7
Gracilaria edulis	225	1.60	8.6	1	2.3
Gelidiella acerosa	42	1.60	1.6	1	0.4
Gracilaria sp.	213	1.60	8.2	1	2.1
Total	8,445		450.3		14.5

Carbon sequestration potential of farmed seaweed *(Kappaphycus alvarezii)*

The experiment involving the culture of seaweed (*Kappaphycus alvarezii*) in three bamboo rafts to estimate its carbon sequestration potential was conducted at Munaikadu, Ramanathapuram district and Tamil Nadu, by ICAR-CMFRI, Mandapam. In each of the rafts (12 ft × 12 ft), 3 pre-weighed bunches of seaweed were tagged and their weights were periodically (once in 15 days) measured. Further, sub-samples from each bunch were collected, dried and preserved. The samples were analyzed for their carbon content using CHN- elemental analyzer. The average carbon content was 19.92%.



Cumulative carbon assimilation rate from improvised method

The specific growth rate of the seaweed multiplied with % composition of carbon (C) and 3.667 (mass of CO_2= 44/ mass of C= 12) gives an estimate of specific rate of sequestration (per unit mass of seaweed per unit time) of carbon dioxide by the seaweed. The specific rate of sequestration of CO_2 per gram dry weight of seaweed is 0.018673 g day^{-1}(0.02557 x 0.19915 x 3.667). The specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 by the seaweed was estimated as 19 kg CO_2/day/tonne dry weight of *K. alvarezii* (= 760 kg CO_2/day/tonne dry weight/ha).

Carbon sequestration (per unit mass of seaweed /day/16 rafts/4 crops) into the cultivated seaweed in the integrated and non-integrated rafts was = 47.4 kg CO_2/day/tonne dry weight of *K. alvarezii* vs 30.4 kg CO_2/day/tonne dry weight. Hence, an additional 17.0 kg CO_2/day/tonne dry weight credit was achieved by integrating 16 seaweed rafts (4 cycles) with one cobia farming cage (per crop).

Carbon assimilation rate from improvised monoline seaweed culture method

Estimated average cumulative carbon sinking potential: 424.6 CO_2 kg/plot (1 Plot = 100 Monolines each of 15 m breadth and 60 m length = Total area of the plot 900 m^2). The estimated average cumulative carbon sinking potential during the second, third and fourth week of culture period was 82.5, 141.7, 242.9, & 339.1 CO_2 kg/plot.

Empowering coastal communities to adapt to climate change impact

Technology demonstration & training

Conduct of awareness and training programs to coastal communities on marine and brackishwater cage farming under Karwar Regional Centre

Technology demonstration programs on "Open sea cage farming" were initiated by Karwar Research Centre of CMFRI by conducting awareness programs among the fishermen communities of at Karwar and Kumta in Karnataka, Polem, Talpone in Goa and Ratnagiri in Maharashtra. During 2011-2016, 59 training programs were conducted for officials and stakeholders; the number of beneficiaries included 81 officials, 570 fishermen and 100 fisherwomen. In addition to this, 11 training programs were conducted for fisher SHGs, under which 122 fisher members were trained.

All the participants were given hands on training on low-cost cage technology, all weather mooring system and efficient net exchange technologies developed by Karwar Research Centre of CMFRI. Awareness was created to local fishermen community on the benefits of cage culture of temperature resilient species especially

Participants of National Training programme on open sea cage culture of finfish and shellfish organized during the month of March 2011

Asian seabass, *Lates calcarifer*, as their alternate livelihood. The trainees were also trained to carry out feeding, monitoring of growth and environmental parameters and on the management practices in cage farming to achieve better production. They were given awareness about the risk factors which may occur during rainy seasons like salinity and temperature variations. They were provided with the standard protocols to follow on daily basis for cage maintenance and suggested them to keep records.

Two farmers who underwent training at the centre were selected for participatory farming at Karwar. 6000 numbers of cobia seed and 2000 numbers of Pampano seed procured from Mandapam Regional Centre were cultured in 6 m and 10 m diameter cages as participatory programme of the centre. In addition to this programme, the centre also helped the trained fishermen of Karnataka, Goa and Maharashtra to form self-help groups and undertake the cage culture at Karwar and Kumta in Karnataka, Polem, Talpone in Goa and Ratnagiri in Maharashtra.

Participants of cage culture demonstration programme organized for fishermen of Goa and Maharashtra (2013-14)

Cage culture activities under participatory demonstration in Polem, Goa

With the successful demonstration programs and the profit achieved by the self-help groups in Goa, Polem village in South Goa district of Goa state was identified a as model NICRA village to establish cage culture activity for fishermen communities of that village and also to create awareness among other villages of the state about mariculture as an alternate livelihood activity to ensure social security.

Technology demonstration by Mangalore Regional Centre of ICAR-CMFRI in selected estuaries

Demonstration of the customized cages with CMFRI design was done in northern part of Tharapathi village and Alvaekodi estuary in Karnataka. The fishermen of the village showed extra ordinary skills in improving feasibility and production and the fish production per cage have risen to 1 ton/cage (6 x 2 x 2m) for one year 3.2t. per cage in 20 months. Overall production from first demonstration cage was 400 kg of Seabass and 200 kg of red snapper which fetched total revenue of Rs. 1.8 lakhs. In 2017 the fish production from the estuary was 20 t (from about 80 cages @ 250 kg). The success story of the village have attracted media attention and all important print media and visual media including Doordarshan telecast the success story with great importance.

Customized cage demonstration

Technology demonstration and training programs at Tuticorin Regional Station of ICAR-CMFRI

Around 52 fishermen of 15 coastal villages of Thoothukudi district, Tamilnadu were empowered fishermen to harness positive impact of climate change by capture-based aquaculture, sea cage farming of high-value fishes, low-cost cage construction, mooring of cages in the sea. Hands on trainings were given to 40 fisherwomen from Chinnapalam village on broodstock development, breeding, larval and juvenile rearing of clown fishes, grow-out techniques, livefeed culture, water quality and disease management. Training programs were initiated to impart the already available technology of breeding of major marine ornamental fishes to small scale fishermen/ farmers at Mandapam, Tamilnadu.

Technology demonstration and training programs by Mandapam Regional Centre of ICAR-CMFRI

A total of 10 training programmes were organized at Mandapam Regional Centre since 2011. The training was imparted on marine finfish seed production of Cobia and Silver Pompano, mass production of live feeds, protocols for larviculture, marine ornamental fish culture, seaweed farming and Integrated Multi Trophic Aquaculture (IMTA). A total of 365 participants including fishers and hatchery technicians were benefitted by the training which includes.

Inauguration of a training program

Training on larviculture

Training on algal culture and marine ornamental fish culture

Feedback by trainees

Certificate distribution

Training and awareness programs by Veraval Regional Station of ICAR-CMFRI

Five training and awareness programs were conducted by Veraval Regional Station of ICAR-CMFRI, including marine cage fabrication and installation, management practices in open sea cage farming of lobsters and awareness on climate change and Gujarat fisheries.

Trainees involved in the fabrication works of sea cages CMFRI at Veraval, Gujarat.

Trainees of 'Marine cage fabrication and installation techniques' with scientists of CMFRI and CIFT, Veraval

Dr. Training sessions in progress

Inaugural Session of Training Programme "Best Managment Practices in Sea Cage Farming of Lobsters"

Hands-on training: launching of sea cage

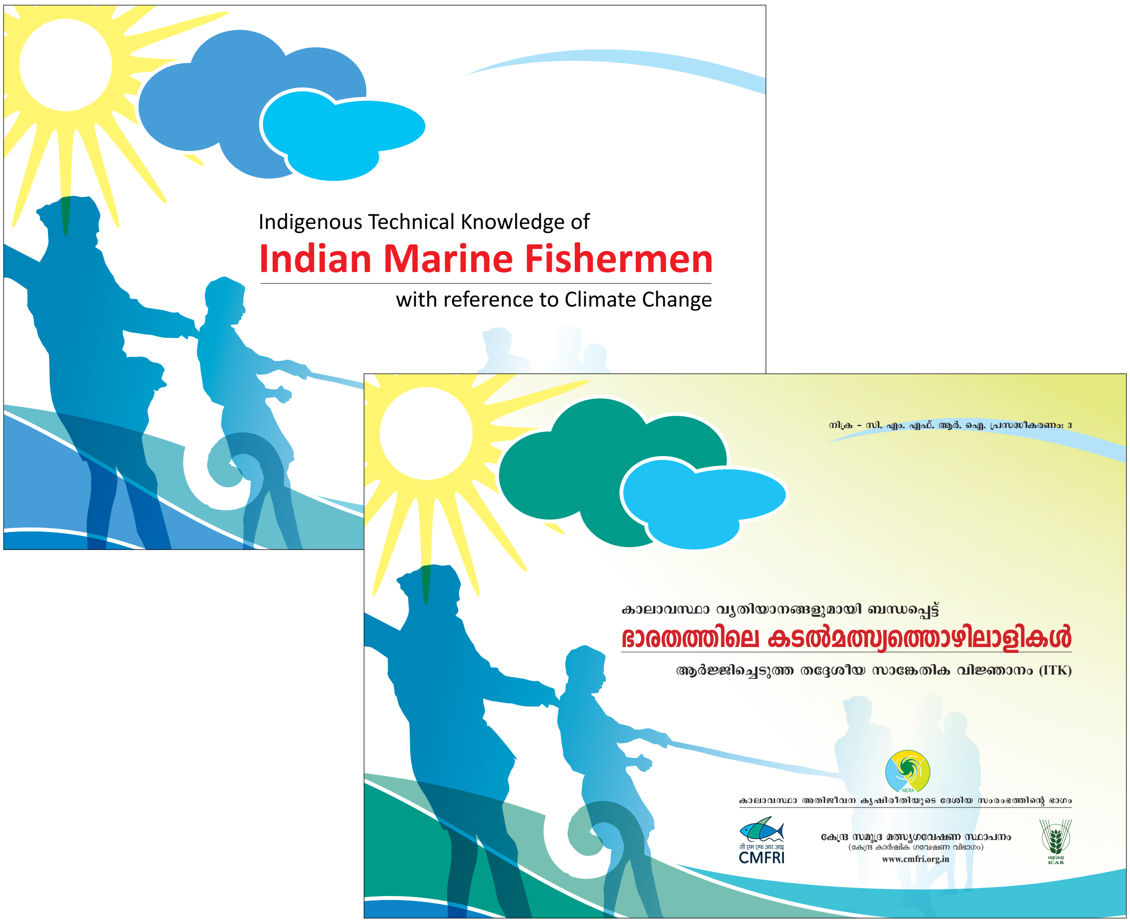
Enriching fisher's knowledge

ITK of fisher folk on climate change

Data pertaining to the Indigenous Technical Knowledge with respect to climate change were collected from 1500 fishermen, from nine coastal States of the country. Detailed questionnaires for collection of information on ITK were developed. The ITKs were documented with various parameters in climate change such as temperature, salinity, coastal up welling, rainfall pattern, wind speed, chlorophyll content of foliage etc. Free-wheeling interviews and ITK transects and triangulation techniques were conducted among the different stakeholder categories The ITKs were tabulated and analysed with respect to interpretations on climate change.

The resulting ITKs were presented at a write-shop held at the Mangalore Research Centre of CMFRI from 22-03-2012 to 24-03-2012. The ITKs collected from different coastal states were validated by a group of scientists, researchers and fisher folk. The selected and validated ITks were then documented as pictorial representations, compiled and published as a book in English and Malayalam.

NICRA ITK writeshop at Mangalore



NICRA ITK Publications

Thematic Apperception Test (TAT)

The TAT was conducted at Mandapam Regional Centre of ICAR-CMFRI to ascertain the level and intensity of achievement motivation through imaginative writing produced by the participants against a series of pictures shown to them. The standard procedure developed by McCleland (1958) was followed in scoring achievement motivation. The story written by each participant was assessed based on 11 indicators.

Table 24. Scoring of sub-categories in Thematic Apperception Test (TAT)

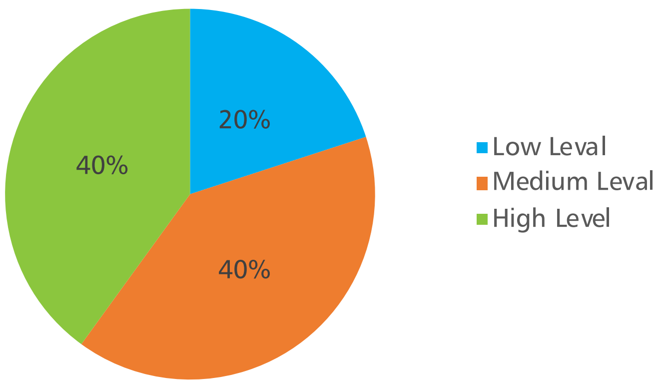
S.No	Sub-categories	Symbol	Score
	Need	N	+1
	Activity	Act + or Act – or Act ?	+1
	Goal anticipation Positive goal anticipation Negative goal anticipation	 Ga + Ga -	 +1 +1
	Obstacles or blocks Personal blocks Worldly blocks	 Bp Bw	 +1 +1
	Help	H	+1
	Feeling Positive feeling Negative feeling	 Fe + Fe -	 +1 +1
	Achievement theme	Th	+1
Stories with AI			+1

Maximum obtainable score in one story will be +11

Table 25. Criteria for categorizing the trainees into low, medium and high level of achievement motivation

S.No	Criteria	Category
1	If an individual scored less than '5' in TAT	Low Level of Achievement Motivation
2	If an individual scored between '5 to 7' in TAT	Medium Level of Achievement Motivation
3	If an individual scored above '7' in TAT	High Level of Achievement Motivation

The result clearly shows that the majority of trainees with medium to high level of achievement motivation participated in the training. Further, through follow-up activity, the trainees can improve their entrepreneurial behaviour.



Level of Achievement Motivation (N=40)

Evaluation of the training–To assess the Training Effectiveness Index (TEI)

Feedback was received from the trainees in an evaluation schedule. Based on the response from the evaluation schedule, Training Effectiveness Index (TEI) was worked out. The indicators used by Koshti, 2008, to study the effectiveness of training was modified and suitably developed for the present study. The indicators are:

- Relevance and utility of course content (Theory and Practical)
- Training organization
- Impact on knowledge and skill
- Overall usefulness of information
- Fulfillment of expectations
- Opinion about meeting room and facilities

Training effectiveness

Taking into account of all the above mentioned indicators of training effectiveness total score was worked out by adding scores of all aspects considered responsible for training effectiveness. Training Effectiveness Index (TEI) was worked out by using the formula given below:

$$TEI = \frac{\textit{Obtained scores on all dimensions of training effectiveness}}{\textit{Maximum obtainable score on all dimension of training effectiveness}}$$

Evaluation of the training – Reaction about the training

It was found that most of the trainees perceived that the marine ornamental fish culture training programme was highly effective. More than two-third of the trainees perceived that the training effectiveness of marine ornamental fish culture training programme was between 71 and 90%. The overall training effectiveness on marine ornamental fish culture perceived by the trainees was 82%.

Table 26. Overall distribution of trainees based on the Training Effectiveness Index (N=40)

S.No	Training Effectiveness Index	Frequency	%
1	61 to 70 %	4	10
2	71 to 80 %	14	35
3	81 to 90 %	14	35
4	91 to 100 %	8	20

Before the training programme most of the trainees expressed they had no idea to start a small-scale ornamental hatchery, whereas after the training more than half of the trainees expressed that they are intended to start small scale marine ornamental hatchery unit in the near future

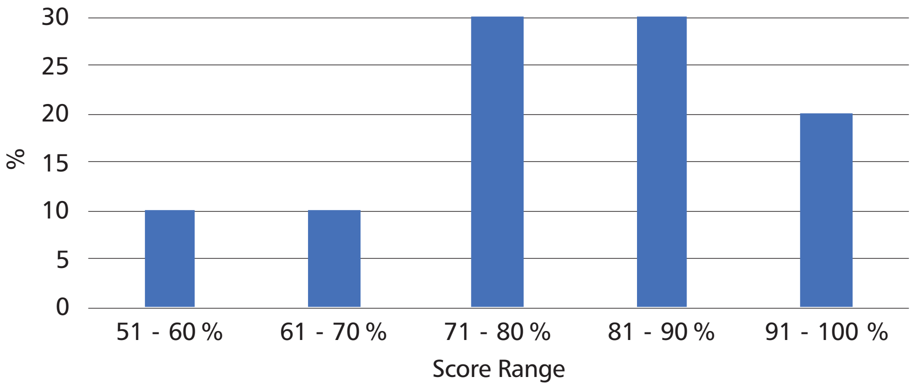
Table 27. Extent of use of practices learnt (N=40)

S.No	Reactions	Yes	
		No	%
1.	Start a small scale hatchery immediately	16	40
2.	Intend to start small scale hatchery in the future	20	50
3.	No plan to start	4	10

Learning – Increase in knowledge as a result of the training

A knowledge test was conducted before and at the end of training to ascertain their change in knowledge due to the training. Majority of trainees obtained only 10-15 % of score in the knowledge test conducted before training. Whereas, 80 % of trainees obtained above 70 % of score in the knowledge test conducted after the training. It is evident that the trainees gained adequate knowledge on marine ornamental seed production due to the training

(N=40)



Overall distribution of trainees based on their score in knowledge test

Developing 'Climate Smart Villages'

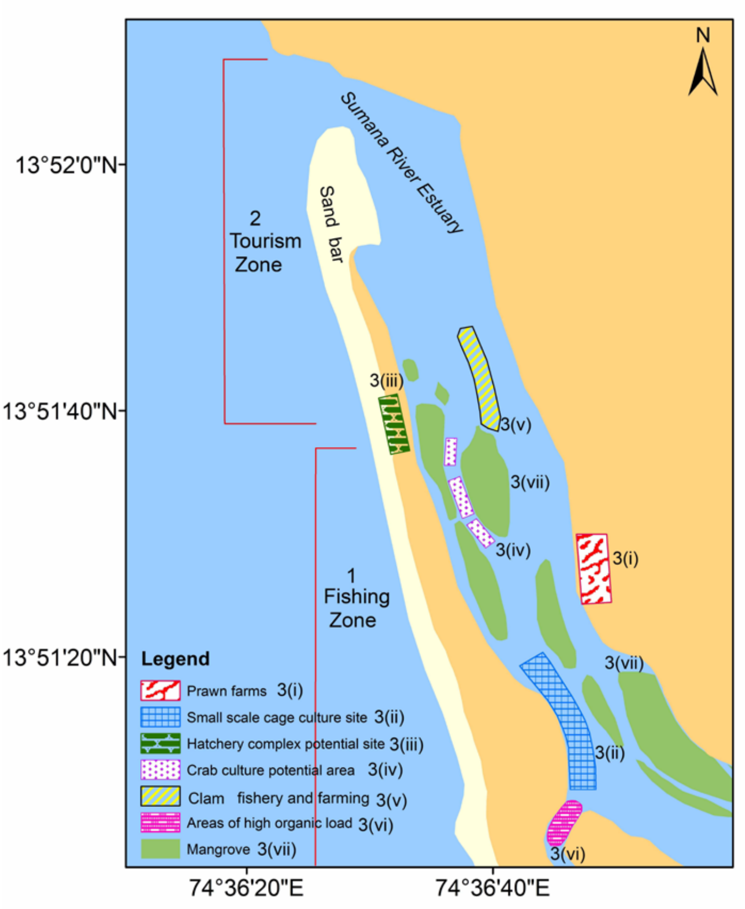
Climate Smart Village Development (CSV) in Karnataka

Selection of district and village: Based on the results of Integrated District Level Adaptation and Mitigation (IDLAM) studies, Udupi district was selected for developing CSV. Tharapathi Village in Byndoor is a progressive fishing village with fishing coastal hamlets Karkikali and Alvekodi. Alvekodi, one of the northern hamlets at the mouth of Suvarna River is a hamlet with active fishing and fish landing areas, long and clean beach extending to river mouth. Greenery is mainly formed by coconut plantations and rich assemblage of mangroves. Most of the coastal fishermen thrive on coastal fishing and estuarine fishing. In earlier years fishing was highly profitable venture and by 2000, Alvekodi rose to a status of one of the most progressive village with organized fishing sector adopting self-regulation to ensure overall development.

GIS-based Marine Spatial Planning: GIS based Marine Spatial Planning concept was introduced for the first time in India with making spatial zonation for different activities in coastal and marine area of the village in which the areas were marked for fishing, marine cage farming, estuarine aquaculture zones, tourism activities and also are designated for aquaculture compile for envisaging future multi species seed production/ rearing area. Economic use of mangroves as a supporting activity to give awareness of mangrove protection was also included in the MSP.

First demonstration of the customized cages with CMFRI design was demonstrated in northern part of Tharapathi village in which all fishermen of the village were given hands on training in cage fabrication, cage maintenance in all procedures till harvesting and marketing. The fishermen of the village showed extra ordinary skills in improving feasibility and production and the fish production per cage rose up to 1 ton/cage

Felicitation of coastal fishermen who adopted NICRA technologies



GIS-based Marine Spatial Planning for zonation of marine livelihood activities in Tharapathi village, Karnataka

Empowerment of estuarine fishermen to combat salinity accretion in estuaries, by giving training in marine fish culture

(6 x 2 x 2m) for one year, i.e., 3.2 t per cage in 20 months. This is among the highest production reported from seabass farming in India and the fishermen of the village deserve appreciation for their effort and achievement. Encouraged and empowered by the CMFRI customized cage demonstration, first cage made of Netlon was introduced in Alvekodi estuary by a group of fishermen and at present more than 100 cages of different dimensions are being managed by the fishermen in the estuaries.

The success story of the village has attracted media attention and all important print media and visual media including Doordarshan telecast the success story with great importance. In 2017 the fish production from the estuary was 20 t (from about 80 cages @ 250 kg).

To increase the production from the limited water body, the concept of Integrated Multi Trophic Aquaculture was introduced in the Village in which green mussels were grown along with fish culture cages and further to improve production seaweeds also introduces in the finfish cages as a future avenue to be looked up on to produce more income from a limited water body. To sustain the production from these customized cages without environmental and disease problems, the carrying capacity of the estuary was estimated with scientific methodology. The carrying capacity for the estuary was estimated to be 50 cages of 6 x 2m x 2m dimension with a stocking density of 12,000 seeds. Anticipated production from these cages will be 1 t. If managed well, the annual production from the estuary per year is estimated to be 50 t (20 t more than initial production) with substantial reduction in existing number of cages.

Scarcity of drinking water: Scarcity of drinking water is the major problem faced by the villagers, and rain harvest methodologies were introduced in a limited manner. officials from NABARD and MOEFCC were brought to the village for further plans for improving water scarcity issues in futuristic perspective.

Awareness generation on alternate vocations for coastal families: Low returns from the fishery are projected as major outfall of climate change and awareness regarding alternate vocation was an immediate requirement. The fisherwomen who were involved in daily routines of fish collection, fish carrying and also in fish sales had turned jobless and the income generated through fishing-related activities

Empowerment of estuarine fishermen to combat salinity accretion in estuaries, by giving training in IMTA had totally stopped. An awareness generation workshop was conducted, in which officials from agriculture, horticulture, livestock, and fisheries departments and KVK resource persons explained possible activities that could be taken up to increase the income from alternate sources so as to keep the fishermen from diverting towards unskilled sectors in urban areas by empowering them in alternate income generation possibilities. As an immediate follow-up of the workshop the coastal fishermen households having coconut plantations were formed into a Cooperative Society registered with the agriculture department and free fertilizer was provided to the Society under State government schemes.

Demonstrations of horticulture and supply of plant and fertilizers to enhance livelihood avenues in 'Climate Smart Village'

Demonstration of poultry rearing to enhance livelihood avenues in 'Climate Smart Village'

Successful fishermen adopted NICRA technologies

The workshop created lot of interest especially among women folk in the village. Immediate actions planned were horticulture development and poultry farming. Since the land area is limited, grow bag-based vegetable faming was planned and seeds of tomato, chilli and brinjal were grown to sapling stage in nurseries and farms of Department of Horticulture, Brahmavar and transported to Alvekodi. 20 grow bags each were distributed with saplings of these plants and also seeds planted for different gourd varieties. Under poultry farming initiatives, chicks of two fast growing varieties "Giriraja" and "Suvarna Dhara" grown by Department of Poultry Department of Karnataka were distributed to coastal fishermen @ 10 chicks each. Vegetable production from the village has increased substantially; poultry farming has also helped in improving income level.

Climate Smart Village Development (CSV) in Tamil Nadu

The Madras Regional Station of ICAR-of CMFRI at Chennai conducted detailed Integrated District-Level Adaptation and Mitigation (IDLAM) studies in the districts of Kancheepuram, Cuddalore and Thiruvallur under the NICRA project during the period 2012-2019 and identified the most vulnerable fishing villages in each district, based on criterion ranking. The biological vulnerability of different fishery resources was also worked out to identify the species most vulnerable/resilient to climate change along the southeast coast of India. Based on these findings, activities were taken up in Kovalam village of Kancheepuram district and later, in Nettukuppam village of Thiruvallur district, to build Climate Smart Villages (CSV).

Several activities were taken up to promote alternate livelihood adoption by the fish communities in the two villages, including open sea cage farming and artificial reef deployment with technical support from CMFRI and promotion of eco-tourism thro ugh sea sports like angling, surfing and diving, and beach clean-up programs with the support of the local Panchayat, NGOs and enterprising fisher youth. The village now stands as a model CSV, with successful participatory cage farming activities including sale of live cultured Asian sea bass and cobia and exemplary results from community managed artificial reefs. The village also attracts tourists and young beach sports enthusiasts, adding to the revenue of the local fisher youth.

A one-day interactive workshop was conducted for fishing villages in Kancheepuram district, at Kovalam Communiy Hall on 16th March 2017 in which 73 fishers from Kovalam, Kadalur chinnakuppam, Injambakkam, Chemmencherry, Palaya nadukuppam, Kanathur Reddikuppam, Oyyalikuppam, Mamallapuram, and Sulerikattukuppam participated. Officials of the Tamil Nadu State Fisheries Department, and also participated in the workshop.The progress of Kovalam village into a CSV was explained to the fishers from the other villages and Kovalam village was declared "Climate-smart". Six fishermen SHGs responsible for this development, were honoured – Association

Stakeholder meeting in progress in Kovalam

Declaration of Kovalam as a Climate Smart Village and presentation of awards

of Kovalam Progressive Fishermen, Kovalam Artificial Reef Management Committee, Covelong Point Surf School, Barefoot Scuba, Beach Wolves and Bay of Life.

A one-day interactive workshop was conducted for six identified fishing villages in Thiruvallur district–Ennorekuppam, Mughatauvarukuppam, Kathivakkam Periyakuppam, Nettukuppam, Thazhankuppam and Kattupalli, at Nettukuppam Communiy Hall on 9th March 2018, in which 72 fishermen participated. The fishermen were appraised about different adaptation and mitigation options for sustainable livelihood in the background of climate change event affecting the fishery resources.

Three fisher youth representatives – Mr. Sudarshan of the Association of Kovalam Progressive Fishermen, Mr Moorthi of Covelong Point Surf School and Mr Venkat of Barefoot Scuba presented detailed talks on the evolution of their SHGs and how they have been able to find a firm footing in alternate livelihood programs. Which paved the way for Kovalam village to become "Climate-smart".

Experience gained from promoting alternate livelihood options for coastal communities in the selected villages and feedback obtained from the stakeholders it is inferred that -

- Youth (15-18 years) have to be identified and given skill development training in specific livelihood promotion options like cage culture, sea sports and ecotourism, fish hatcheries etc.

- Separate trainings can be organized for each village based after identifying the best options that can be taken up for them.

Workshop inauguration by Thiru Velan, ADF (MF). Ponneri and talks by fisher representatives from Kovalam village on various alternate livelihood options

Participants of the workshop with CMFRI team

- Technical skill development by CMFRI can be coupled with financial support from State Fisheries Department, NFDB etc. to help the fisher youth start alternate livelihood projects.

Empowering stakeholders under "Scheduled Caste Sub-Plan (SCSP)"

The SCSP component of NICRA was started during 2018-19. SCSP funds are being utilised to provide aquaculture trainings, seaweed farming, cage culture support, supply of fish feeds and seeds to the identified beneficiaries through Kochi, Tuticorin, Mangalore, Mandapam and Visakhapatnam centres of ICAR - CMFRI. Some of the activities under SCSP during 2018-2020 are as follows: A total of 22 beneficiaries of Ernakulam district, Kerala has been proportionally supported with various inputs such as pearl spot fish seed, fish feed , Ice boxes, Cast nets, Solar panel unit for aquaculture, Portable water quality analysers and portable freezers that can be mounted on two wheelers. Four fishers of Puthukudi village, Thondi in Ramanathapuram district of Tamil Nadu were provided with 40 monoline units to undertake seaweed farming. An awareness and training programme on "Mariculture Technologies for Diversified Livelihood" was also given to the beneficiaries. Field accessories like customised gloves, shucking knives and socks were distributed to 55 women beneficiaries of Kottaikadu village in Chingleput district, Tamil Nadu to augument occupational health safety during their activity of oyster picking from nearby creeks. Demonstration of rack culture of green mussel has been initiated in Kadalundi estuary of Kerala for three groups of beneficiaries. The farmers were given hands-on training in rack

Supply of fishing implements to the beneficiaries of SCSP plan under NICRA

Beneficiaries of NICRA SCSP program, provided with field accessories for oyster shucking

construction and seeding of mussel ropes, as a mitigation measure to switch over to scientific method of rack culture, so as to negate the financial loss incurred due to the siltation of the conventional on-bottom culture method.

Ten families of Hoode, Udupi Taluk, Karnataka were demonstrated and empowered with collection of seeds from estuary using cast net and drag net during the low tide. Training and demonstration of cage fabrication, mooring, installation and maintenance were provided to selected family of the same village. In Kochi 3500 Nos of Pearl spot seed (7cm), 200kg of Pearl spot feed and chiller insulated iceboxes (30 liter) were distributed to total 10 beneficiaries of Edavanakadu, Nayarambalam and Puthuvypeen coastal villages. Further, 2 Nos of hard top chest freezers cum cooler were distributed to 2 identified beneficiaries of Edavanakadu and Puthuvypeen villages. Distribution of seaweed seeding material to fishermen for improvised monoline seaweed farming and distribution of cage to fishermen for conducting IMTA were done for 5 beneficiaries of Ayyanadaippu coastal village of Tuticorin. In Mangalore, 3000 Nos of fish seed were provided to 10 beneficiaries and further support was extended through fabrication, installation and mooring of cage frame to 2 beneficiaries. Seaweed farming monoline unit support was provided through inputs such as casuarina poles, ropes, seaweed seeds and other accessories to 6 Nos of beneficiaries of Mandapam, whereas awareness programs on Mariculture technologies for diversified livelihood options were provided to 50 beneficiaries. Three day training activities were carried out at Vishakhapattanam for 10 Nos of fishermen youth.

E-commerce

Role of E-commerce as a socio-economic resilience strategy against climate change for fishermen communities

Indian coasts have recently been witnessing increase in frequency of extreme climatic events such as Ockhi and Gaja cyclones, which caused unprecedented damages to coastal infrastructures, fishermen houses and fishing equipments, and also resulted in loss of life, thereby increasing the vulnerabilities of coastal communities. Loss of fishing days, meagre catches, low valued catch compositions and increased scouting time due to movement of fish stocks are evidenced impacts of climate change and stock fluctuations on the national marine fisheries sector, which in turn reflects on the socio-economics of fishermen community. The fishermen are not left with many other options for availing better price on their reduced catch, than to sell at the landing centers or fishing habours for low prices offered. Owing to climatic pressures and livelihood insecurities, the fishermen youth are being forced to seek exit path from fisheries sector, which is an undesirable scenario to the national fisheries economy.

The mariculture scenario of the nation is also under high stress due to changes in physico-chemical and microbial composition of the ecosystem, which in turn has detrimental effects on farm outcome. Irregular rainfall patterns and extreme events results in influx of flood and storm water into marine farms and consequently the species growth and maturity will be reduced along with increased susceptibilities to diseases and mortalities. The Kerala floods in 2018 resulted in huge economic loss to many fish farmers through washing away of cages and early harvests due to sudden salinity fluctuations of aqua farms. The harvest after overcoming these adversities deserves better price, but in reality the farmer is not yet earning the deserved profit tag, which stresses the livelihoods of fish farmers. In spite of high price for fishes in market, the profit is being reduced within the supply chain and the farmer is gaining only low margin.

Launch of E-commerce website and mobile app

While alternative livelihood practices or occupational changes away from the fishing sectors could present viable sustainable options, the challenge is to attain resilience of fishing and fish farming communities through establishing opportunities to retain them in the fisheries sector. Interventions in the supply chain, so as to gain more profit for the producer community is the strategy adopted and the E-Commerce technology has proved across several sectors to be an efficient solution to connect between the producers and consumers with beneficial implications on pricing and profits for both; besides it functions as a direct channel for marketing and sales for the producer communities. Accordingly, through NICRA the E-Commerce platform (www.marinefishsales.com) was developed and experimented as a socio-economic resilience option viz. opening up of new avenues for direct sales, strengthening of market linkages and improving livelihood securities.

Hon. Direct General, ICAR, Dr. Trilochan Mohapatra on 7th December 2018 at NAS, New Delhi launched and released the multivendor e-commerce website and associated mobile app developed through NICRA project of CMFRI.

Trainings on Fisheries E-Commerce familiarization

The launch of e-commerce portal and mobile app was followed by training programs to familiarize and validate the e-platform. The stakeholders for the training programs included fishermen communities, self-help groups, administrative and scientific communities.

On 16th December 2017, a training program was organized to familiarize the developed e-commerce website and mobile app among fish farmers, in which 28 participants (farmers, fishermen, SHGs and traders) underwent training. A farmers' meet was arranged on 21st March 2018 to discuss minimum base price for farm products. Training on 'Fish Processing and Packaging' was arranged on 17th April 2018 at KVK Narakkal, Kochi to familiarize the stakeholders with preparing the product for e-platform.

Training on fisheries E-Commerce implementation for the state of Himachal Pradesh

Upon launching of the e-commerce platform through the NICRA project, the Govt. of Himachal Pradesh expressed interest to implement a similar system in their state for inland fisheries, and accordingly, made necessary allocations in the state budget. Upon request from Director-cum-Warden, Directorate of Fisheries, Bilaspur, Himachal Pradesh for technical guidance from ICAR-CMFRI, Dr. P.U. Zacharia, Principal Investigator, NICRA project along with Dr. Rojith. G, Research Associate were deputed as resource persons. Training meeting was convened by the Director-

Training on E-commerce at Directorate of Fisheries, Himachal Pradesh cum-Warden at Directorate of Fisheries, Bilaspur along with other state fisheries officials, administrators and farmers on 5th February 2019. Technical information and implementation guidelines were provided by the resource persons. The training and interactive sessions were fruitful in furthering steps towards developing the e-platform for the state.

Field surveys carried out with 15 SHGs and 25 fishermen at Kalamukku and Chellanam fishing harbours of Kerala reveal motivation to associate with the e-venture, as it gains them direct marketing, additional sales and profit opportunities beyond their regular markets. A pilot scale run without any commercial level promotional activities was performed to assess the functionality of the e-platform with a few selected farmers and fishermen already engaged in fish sales. A total sale of Rs.1 lakh was done which validates the e-sale functionality, and the resilience indicator includes sale to new customers outside their regular geographical zones, indicating new market opportunities. Distributers have been engaged to facilitate distribution in case farmers do not have distribution facility. The website (www.marinefishsales.com) is accessible to the public to order fresh fish of their choice from the vendors who have registered their products on the website.

Scale-up of the e-commerce technology with adequate institutional support could enable vulnerable coastal self-help groups to advance through the supply chain and to make direct fish sales to consumers, thereby earning higher profit and livelihood securities. Nevertheless, lack of training, minimum assured order and financial bondages with money lenders are to be resolved prior to scaling up. Though e-commerce is gaining popularity in the fisheries sector, most of them are being operated by private entrepreneurs and the profit is being channelized to them than to the producer communities. Fisheries institutes supporting e-commerce technologies could facilitate and replicate resilience of fishermen or fish farmers thereby enabling to negate to a large extent the coastal livelihood insecurities, in the context of mounting climatic pressures.

Climate Club

Climate Clubs as a socio-economic and ecological resilient strategy

A Climate club was registered at ICAR-CMFRI under the Travancore Literary and Charitable Act in 2021. The Indian coasts with diverse microclimates as well as seasons, warrants region specific adaptation strategies and accordingly NICRA project of ICAR-CMFRI envisages first of its kind Climate Clubs network for enhancing coastal resilience and the registration process is being carried out in the name of 'CMFRI Climate Club Network'. Research institutions, Universities, Colleges, NGOs and coastal self-help-groups could be the key functional network partners. Climate Clubs could be the ideal instrument to bridge traditional and modern knowledge, so as to assimilate and disseminate region specific impacts and adaptation strategies. This transitional platform can impart climate change awareness, adapt mitigation measures, enhance coastal community preparedness and negate the climatic vulnerabilities in a better way. The intervention could bring the climate change stakeholders in a common platform across coastal states so as to widen the effective reach of the technology demonstrations such as open sea cage culture, IMTA, seaweed farming, climate resilient products, e-commerce and climate resilient village development. Prospective climate resilient technologies and climate smart practices could be promoted among the society through the club. The multi-tier interactions ensure community participations in conservation of coastal ecosystems such as wetlands and mangrove ecosystems. Climate clubs are envisaged to act as a regional transformational platform to enhance co-operation towards climate resilience efforts through incentives and stimulates. Identification of beneficiaries and vulnerable groups, in the context of climatic adversities could be effectively done towards support and sustenance. The Climate Club could play a key role in reporting the regional climatic adversities, impacts and vulnerabilities so that it could be assessed and intervened by scientific communities, administrative bodies or policy makers. Goals of Greenhouse Gas emission reduction and nationally determined contributions (NDCs) as per International climatic agreements could be better implemented, if semi-formal organization like clubs with balanced representation of coastal community and scientific stakeholder could be involved.

HRD programs

HRD Programs Conducted

S.No	Name of the Program	Stakeholders (Researchers/ Extension workers/ Farmers)	Duration & Date (dd/mm/yyyy)	No. of participants
	National PIT/ workshop on Techniques and methodologies in fishery biology of finfish and shellfish	Researchers, Scientists, Others	12-14 September 2011 Duration : 3	50
	National Workshop on Indigenous technical knowledge of fisherfolk on climate change	Farmers, Researchers, Scientists, Others	22- 24 March, 2012 Duration : 3	60
	National Workshop on Stock Vulnerability Assessment	Researchers, Scientists	08 -11 March, 2016 Duration : 4 days	22
	Integrated Multi-Tropic Aquaculture (IMTA)–A Climate change resilient approach	Farmers	Nov 16-17, 2016 Duration : 2	23
	Hands on Trainnning on Marine cage fabrication and installation techniques	Farmers, Researchers, Others	Feb.7-9, 2012 Duration : 2	27
	Methodologies for Fishery Biological studies, fishery data analysis, fishery resources assessment and record keeping	Researchers, Scientists	Feb.23-29, 2012 Duration : 7	
	Better management practices in lobster farming in sea cages		Feb.21- 13 March, 2012 Duration : 21	
	Awareness programme on Climate Change and Gujarat Fisheries		July.11, 2014 Duration : 1	
	Awareness programme on Climate Change and Gujarat Fisheries	Researchers, Scientists	Nov. 25, 2014 Duration : 1	
	Open Sea Cage Culture	Farmers, Others	07-03-2011 to 16-03-2011 Duration : 10	20
	Open Sea Cage Culture	Farmers, Others	05.01.2012 to 09.01.2012,27-02-2012 to 03-03-2012, 19-03-2012 to 24-03-2012,27.03.2012to 29.03.2012 Duration : 12	40

S.No	Name of the Program	Stakeholders (Researchers/ Extension workers/ Farmers)	Duration & Date (dd/mm/yyyy)	No. of participants
	Open Sea Cage farming of marine finfish and shellfish	Farmers, Others	26.7.12 to 28.7.12, 10.1.13 to 11.1.13, 15.1.13 to 19.1.13, 22.1.13 to 26.1.13, and 4.2.13 to 8.2.13 Duration : 18	84
	Open Sea Cage farming of marine finfish and shellfish	Farmers, Scientists	30.5.13 to 2.6.13, 17.6.13 to 21.6.13, 25.6.13 to 29.6.13, 8.7.13 to 12.7.13, 5.8.13 to 9.8.13,12.10.2013to 15.10.2013, 15.1.14 to 18.1.14, 25.2.14 to 1.3.14, 07.3.2014 to 08.03.2014 Duration : 30	144
	Open Sea Cage farming of marine finfish and shellfish	Farmers, Others	23.9.14 to 24.9.14, 9.10.2014 to 18.10.2014, 8.1.15 to 9.1.15 Duration : 13	7
	Open Sea Cage farming of marine finfish and shellfish	Farmers	01.12.2015 to 7.12.2015,17.12.2015 to 18.12.2015,17.12.2015 to 19.12.2015,19.12.2015 to 21.12.2015,1.01.2016 to 2.01.2016 Duration : 17	46
	Open Sea Cage farming of marine finfish and shellfish	Farmers	6.05.2016 to 07.05.2016,05.06.2016 Duration : 2	56
	Cage farming on finfish and shell fish	Farmers	23.03.2011 Duration : 1	10
	Cage farming on finfish and shell fish	Farmers	08.04.2011, 20.05.2011, 14.10.20 11,22.11.2011,13.01.2012,28.02 .2012 Duration : 6	65
	Cage farming on finfish and shell fish	Farmers	12.04.2012, 17.10.2012 Duration : 2	20
	Cage farming on finfish and shell fish	Farmers	23.05.2013, 18.10.2013,28.11.2013 ,24.12.2013,07.02.2014,20.03.2014 Duration : 7	50
	Brackish water cage farming of wild collected fish seeds (under CBA)	Farmers	24.04.2014,19.11.2014,26.12.2014, 16.10.2014,16.01.2015,12.05.2015 ,30.03.2015 Duration : 9	60
	Brackish water cage culture of Asian Seabass,Brackish water cage culture of Asian Seabass and snapper, seed collection of snappers under CBA, cage mooring, feeding protocols, biofouling, net exchange	Farmers	10.06.2015, 12.08.2015, 13.08.2015, 20.08.2015, 19.10.2015, 08.11.2015, 18.12.2015, 13.02.2016, 17.02.2016 Duration : 4	120
	Technology demonstration programs conducted for fishermen self help groups by Karwar RC of CMFRI	Farmers	18.10.2013,08.11.2013, 24.01.2013, 13.02.2013 Duration : 4	50
	Technology demonstration programs conducted for fishermen self help groups by Karwar RC of CMFRI	Farmers	17.04.2013, 26.04.2013, 24.01.2014, 30.01.2014 Duration : 2	40

S.No	Name of the Program	Stakeholders (Researchers/ Extension workers/ Farmers)	Duration & Date (dd/mm/yyyy)	No. of participants
	Technology demonstration programs conducted for fishermen SHGs by Karwar RC of CMFRI	Farmers	16.05.2014, 24.10.2014 Duration : 1	20
	Technology demonstration programs conducted for fishermen self help groups by Karwar RC of CMFRI	Farmers	19.12.2015 Duration : 1	12
	Open sea cage farming		17.07.2010 to 18.07.2010 Duration : 2	
	Popularisation of open sea cage culture		04.10.2012 to 05.10.2012	
	National consultation programme integrated development of uttara kannada district		01.01.2012	
	Stake holders meet-2012	Farmers, Researchers, Scientists, Others	18.06.2012 Duration : 1	17
	Stake holders meet-2014	Researchers, Scientists, Others	18.06.2014 Duration : 1	13
	Stake holders meet-2015	Farmers, Researchers, Scientists, Others	08.04.2015 Duration : 1	18
	Stake holders meet-2016	Farmers, Scientists	22.04.16 Duration : 1	18
	Entrepreneurship development training programm on Climate resilient aquaculture practices	Farmers	06.03.15-10.03.15 Duration : 5	14
	Fishermen Meet on Awareness Generation to climate change and its impacts on marine fisheries	Farmers	25-Mar-11 Duration : 1	100
	Advanced models in Fish Stock Assessment and Biodiversity Analysis	Researchers, Scientists	12-20 March 2012 Duration : 9	21
	Sea farming avenues and cage farming to cope with climate variability	Farmers		52
	Etroplus breeding and farming	Farmers		40
	High density freshwater fish culture in abandoned granite quarries	Farmers		85
	Breeding Techniques		16th March to 29th march 2012 Duration : 14 days	
	Open sea cage culture of finfishes	Farmers–27	12th march to 18th March 2012 Duration : 7 days	
	Identification of marine finfishes and shellfishes		19th March to 25th March 2013 Duration : 8 days	
	Recent advances in stock maintenance and mass culture of phytoplankton in mariculture		10th Dec to 15th Dec 2012 Duration : 6 days	

S.No	Name of the Program	Stakeholders (Researchers/ Extension workers/ Farmers)	Duration & Date (dd/mm/yyyy)	No. of participants
	Recent advances in stock maintenance and mass culture of rotifers and copepods in mariculture		7th Jan to 12th Jan 2013 Duration : 7 days	
	Monitoring structure & function of pelagic ecosystem at regional sectors: Relevance for fisheries		1th November to 06th December 2016 Duration : 21 days	

S.No	Name of the Program	No. of participants	Venue
1.a	E- commerce training (www.marinefishsales.com) 16th December 2017	28 farmers, fishermens, SHGs and traders	CMFRI, Kochi
b	Farmers meeting to fix minimum base price for Multivendor e-commerce,21st March,2018	farmers, fishermens, SHGs and traders	
c	Fish processing and Packaging for E-Marketing,17th April 2018	5 fish farmers, 4 research scholars	
2. a	Village level meetings to develop them in to Climate Smart Village on 8th February 2018	50 fishers from Chinnapalam village of Ramanathapuram district	Mandapam Regional Centre
b	Village level meetings to develop them in to Climate Smart Village on 9th February 2018	50 fishers from Vadakadu villages of Ramanathapuram district	
c	Marine Ornamental Fish Culture under National Innovations on 16th February 2018	40 fisherwomen from Chinnapalam village of Ramanathapuram district	
3.a	Fishers perception of vulnerability to climate change and its adaptation strategies for the coastal villages of Thoothukudi, 13th December 2017	52 fishermen from 15 villages	Tuticorin Research Centre
b	Field demonstration on Integrated Multi-trophic Aquaculture, 15th to 17th February 2018	25 trainees from 6 coastal villages were trained	Tuticorin Research Centre
4.	Training cum workshop on application of ARC GIS and QGIS in wetland mapping and analysis, 5th–9th February,2018	2 Research scholars	Mangalore Research Centre

Sl. No	Name of the Program	No. of participant
1	Awareness on climate change preparedness and alternate livelihood options at Singi Vala Kuchi, Thenkadarkarai, Vethalai on 17th September 2018	50
2	Training on Integrated Multi Trophic Aquaculture & Marine Ornamental Fish Culture during 27-28 September 2018	100

Sl. No	Name of the Program	No. of participant
3	Initiation of Seaweed culture–A Climate Resilient Farming Practice at Mullakadu coast of Thoothukudi District under the National Innovations on Climate Resilient Agriculture (NICRA) at the Tuticorin Research Centre of ICAR-Central Marine Fisheries Research Institute (CMFRI) on the occasion of National Fish Farmer's Day on 10th July 2018.	25
4	One day training program on "Seaweed farming: A Climate-Smart Farming Practice at Mullakadu village of Thoothukudi district on 11th December 2018. Fifteen fishermen participated.	15
5	Demonstration on Seaweed farming: A Climate Resilient Farming Practice at Tsunami Nagar of Thoothukudi coast on 14th August 2018.	15
6	One day 'Interactive meet of seaweed and sea cage farmers ' from Sippikulam, Keelavaipar, Tharavaikulam, Vellapatti, Fathima nagar, Inigo nagar, Tsunami nagar, Mullakadu coastal villages of Thoothukudi on 31st August 2018.	30
7	Established and maintained mangrove model farm for building resilience to climate change. In this connection an Awareness on the Model mangrove farm: building resilience to climate change" was conducted on 5th February 2019 at ICAR-TRC of CMFRI.	50
8	Training on fisheries E-Commerce implementation for the State fisheries officials and fish farmers for the state of Himachal Pradesh	25
	Total	310

Infrastructure & Equipment

Infrastructure developed under NICRA

Fishery Biology Lab: A fishery biology lab was set up at CMFRI headquarters under the NICRA project. The lab is facilitating climate change research on biological aspects of important fish species along the Indian coast. The lab is equipped with three large tables with attached sinks for ready dissection of fish samples. The lab is also equipped with a stereomicroscope and compound microscope for fecundity studies,

Fishery biology laboratory developed at ICAR-CMFRI, Kochi gut content analysis and other fishery biology tasks. The lab also contains 3 freezers for long term, low temperature storage of samples.

Auto Analyzer: The Auto Analyzer was used in NICRA lab for automated chemical analysis of sea water samples. It is an automated titration device capable of assessing parameters such as ammonia, nitrate, nitrite, phosphate, silicate and total alkalinity from a total of 100 samples at a time. Using pre-prepared reagents, a large quantity of samples can be simultaneously tested for all the above parameters. The device also provides real time readouts of the data, allowing rapid and efficient testing with minimal repetitive labour from researchers. The device also allows for great scalability – as few as one to as many as 100 samples can be tested in batches, depending on requirements. The autoanalyzer utilizes continuous flow analysis–a continuous stream of material is divided by air bubbles into discrete segments in which chemical reactions occur. The continuous stream of liquid samples and reagents are combined and transported in tubing and mixing coils. The tubing passes the samples from one apparatus to the other with each apparatus performing different functions, such as distillation, dialysis, extraction, ion exchange, heating, incubation, and subsequent recording of a signal.

Auto analyzer

RBR CTD Logger: RBR CTD Logger is an oceanographic instrument used to determine Conductivity, Temperature and Depth. It has been used onboard in NICRA research vessel F.V Silver pompano during oceanographic samplings. Besides it has other sensors to monitor the water quality parameters of ocean cage culture sites such as fluorometer.. A fluorometer or fluorimeter is a device used to measure parameters of fluorescence–its intensity and wavelength distribution of emission spectrum after

RBR CTD Logger

excitation by a certain spectrum of light. These parameters are used to identify the presence and the amount of specific molecules in a medium. Modern fluorometers are capable of detecting fluorescent molecule concentrations as of extremely low concentrations. The fluorometer can be used for assessment of a variety of parameters. It can also be used to detect PAR (Photosynthetically Active Radiation) and is rated for a depth of 740m. The device also comes with a hard case for safe transport.

Current Meter (Current Profiler): Current Meter or Acoustic Doppler Current Profiler is used to measure the velocities of ocean currents over a depth range. The equipment is useful for hydrological profiling. It utilizes the Doppler Effect to acoustically determine the speed of currents. ADCPs contain piezoelectric transducers that transmit and receive sounds, and the travel time of the sound waves is utilized to give an estimate of the distance. Components of the ADCP include electronic amplifiers, receivers, a clock, temperature sensor and a pitch-roll sensor to determine the spatial orientation of the device in the water. A bottom-mounted ADCP can measure the speed and direction of currents at equal intervals at a wide range of depths, all the way to the water surface. It was deployed in NICRA research vessel and related data was obtained.

Spectrophotometer: Spectrophotometer finds application in marine sample analysis, protein estimation and related biological experiments. It is based on the principle of absorption of light by coloured solutions–a chemical substance absorbs light by measuring the intensity of light as a beam of light passes through sample solution. Spectrophotometry is also a non-destructive analysis technique – the sample being analysed is preserved. Spectrophotometry is an important technique used in many biochemical experiments that involve DNA, RNA, and protein isolation, enzyme kinetics and biochemical analyses. Since samples in these applications are not readily available in large quantities, they are especially suited to being analyzed in this non-destructive technique. It is a highly accurate instrument that is also very sensitive and therefore extremely precise, especially in determining color change.

FV Silver Pompano: Central Marine Fisheries Research Institute (CMFRI), Kochi procured a19.75 m fisheries research vessel F.V. Silver Pompano as part of the National Initiative on Climate Resilient Agriculture (NICRA) project by Indian Council of Agricultural Research (ICAR). The vessel is used for carrying out fisheries related research in the territorial waters. The vessel was manufactured by Goa Shipyard Ltd at a cost of about Rs. 4.75 crores.

The vessel is fitted with a 4 stroke Volvo Penta make 500 hp @1800 rpm marine engine. The main deck of the vessel contains cabin for scientists and crew, wet laboratory, weather station, galley, mess room and toilet. The hydraulically operated trawl which consist of 1000 m long, 12 mm diameter steel wire rope on each drum with a speed of 0 to 40m/minute which draws hydraulic power from main engine.

The vessel is used for experimental trawl fishing – both bottom and mid-water trawling using Issac-Kid Mid-water Trawl system and collection of oceanographic parameters and marine samples from the sea. The vessel is equipped with underway CTD sampler, Doppler current meter, instruments for chlorophyll measurements, zooplankton, TSS and sediment sampling. The vessels is equipped with a laboratory for preliminary

FV Silver Pompano

analysis and to fix the samples for further analysis. An automatic weather station to collect the atmospheric parameters like rainfall, humidity etc. The vessel is fitted with modern oceanographic equipment like underway CTD sampler, Doppler current profiler, Plankton net, sediment and benthic sampler etc.

Table 33. List of major and minor equipments procured under NICRA

Major Equipment (2015-16)

S.No.	Item	Procured at	Budget Allocated	Expenditure Incurred
1	Auto Analyzer	Hqrs., Kochi	25,00,000	25,09,534
2	Temperature Control System for culture experiments	No Procurement	6,00,000	Nil
3	Biofilters	No Procurement	10,00,000	Nil
4	Icthyoplankton net with flow meter and winch	No Procurement	6,00,000	Nil
5	Current Meter	Hqrs., Kochi	7,00,000	8,20,677
6	Current Meter	Veraval	7,00,000	8,03,000
7	Current Meter	Visakhapatnam	7,00,000	8,08,943
8	CTD Probe	Hqrs., Kochi	8,00,000	7,91,093
9	CTD Probe	Veraval	8,00,000	9,44,383
10	CTD Probe	Visakhapatnam	8,00,000	8,01,492
11	CTD Probe	Tuticorin	8,00,000	6,00,449
12	CTD Probe	Mumbai	8,00,000	8,94,625
13	CTD Probe	Mangalore	8,00,000	9,44,384
14	Current profiler	Tuticorin	6,00,000	8,21,699
15	Fish Feed Extruder Substitute to Laboratory mills and Homogenizers	Hqrs., Kochi	6,00,000	6,42,780
16	Spectrophotometer	Hqrs., Kochi	5,00,000	5,20,638
17	Microscope–Binocular with image analyzer	Hqrs., Kochi	12,00,000	5,50,000
18	Micrscope–Stereozoom with image analyzer	Hqrs., Kochi	10,00,000	6,21,000
19	Continuous plankton recorder	No Procurement	10,00,000	Nil
20	Trawl Monitoring System	No Procurement	6,00,000	Nil
21	Digital Balance–0-500 gm	Hqrs., Kochi	85,000	44,800
22	Automatic Weather Station	Hqrs., Kochi	8,00,000	4,71,833
23	Zoo plankton net	Hqrs., Kochi	2,00,000	3,16,280
24	Infrared CO2 Probe	No Procurement	35,000	Nil
25	Under Water Camera	Hqrs., Kochi	50,000	27,580
26	Desktop (5 Nos.)	Hqrs., Kochi	2,50,000	2,83,116
27	Desktop	Karwar	50,000	49,650
28	Desktop	Chennai	50,000	49,950

S.No.	Item	Procured at	Budget Allocated	Expenditure Incurred
29	Desktop	Mangalore	50,000	48,003
30	Data processing and documentation unit (4 Nos.)	Hqrs., Kochi	4,00,000	3,05,662
31	Data processing and documentation unit	Tuticorin	1,00,000	99,450
32	Data processing and documentation unit	Veraval	1,00,000	69,850
33	Data processing and documentation unit	Mumbai	1,00,000.00	98,700
34	Data processing and documentation unit	Visakhapatnam	1,00,000	99,900
35	Digital Video Camera	No Procurement	50,000	Nil
36	Digital Video Camera	Veraval	50,000	32,900
37	Digital Camera	Hqrs., Kochi	50,000	50,300
38	Digital Camera	Chennai	50,000	50,000
39	Printer–Colour	Hqrs., Kochi	30,000	34,503
Total Amount			197,00,000	152,07,174

Minor Equipment (2015-16)

S.No.	Item	Procured at	Budget Allocated	Expenditure Incurred
1	Fish cutting machine	No Procurement	1,50,000	Nil
2	Precision Electronic Balance	Hqrs., Kochi	1,00,000	83,250
3	BOD Incubator	Hqrs., Kochi	1,00,000	1,09,090
4	Van Veen Grab	Hqrs., Kochi	1,00,000	66,868
5	CO_2 Analyser/Sensor	No Procurement	50,000	Nil
6	Precision Electronic Balance	Veraval	1,00,000	98,094
7	CO_2 analyser/Sensor	No Procurement	50,000	Nil
8	Vertical Deep Freezer	Mumbai	1,50,000	1,85,625
9	Precision Electronic Balance	Mumbai	1,00,000	96,188
10	Fish cutting machine	Karwar	1,50,000	1,50,000
11	Vertical Deep Freezer	Karwar	1,50,000	1,49,000
12	Precision Electronic Balance 0.01 mg	Mangalore	1,00,000	79,807
13	Precision Electronic Balance	Chennai	1,00,000	97,125
14	Vertical Deep Freezer	Visakhapatnam	1,50,000	99,800
15	CO_2 Analyser/Sensor	No Procurement	50,000	Nil
Total			16,00,000	12,14,847

Major equipment (2016-17)

S.No.	Item (Priority wise)	Allocation at	Budget allotted	Expenditure Incurred/ Booked
	Microscope with all accessories	Mangalore	10,00,000.00	Retender
	UV-Visible Spectrophotometer	Mumbai	6,00,000.00	Retender
	FRP Boat with Out-board motor (25 HP)	Kochi	10,00,000.00	Retender
	Equipment for vessel (Details given below)		101,00,000.00	
	Fluorometer	Kochi	20,00,000.00	20,00,337.00
	NISKIN Water sampler (in place of Nansen Water sampler)	Kochi, Vizag, Calicut	4,00,000.00 + 3,00,000.00	Processing (Send to council) 12,72,040.00
	Water recirculation system for mariculture	Karwar	10,00,000.00	Retender
	PCO_2 Analyser	Kochi	10,00,000.00	10,00,000.00
	PIT Tagging equipment for mariculture	Mandapam	8,00,000.00	Retender
	Digital Global Positioning System	Kochi, Mangalore, Karwar, Mumbai, Veraval, Vizag, Tuticorin, Chennai	12,00,000.00	Retender
	High resolution pH meter	Kochi, Veraval, Vizag, Mandapam	4,00,000.00	3,40,155.00
	High precision electronic balance	Kochi, Tuticorin	5,00,000.00	4,14,421.00

Equipment for vessel (2016-17)

	Water Sampler with rosette for 12 bottles + CTD + Display panel	Kochi	30,00,000	Processing (Send to council- 29,20,688.00)
	Multiparameter Kit	Kochi, Mangalore, Karwar, Mumbai, Veraval, Vizag, Tuticorin, Chennai	27,00,000	Processing
	Trinocular Microscope	Veraval	4,00,000	1,80,000.00
	NISKIN water Sampler	Tuticorin, Veraval, Mumbai, Karwar, Chennai, Mangalore	3,00,000	Processing (Send to council)
	Bongo Net	Kochi	5,00,000	5,33,326.00
	GPS Plotter	Kochi	5,00,000	Retender
	Primer Software	Kochi, Tuticorin Veraval, Mumbai Chennai, Vizag	4,00,000	1,71,864.00
	Trawl net with accessories	Kochi, Vizag	4,00,000	3,00,000.00
	Water filter unit with flask, Vacuum pump and filter holder	Kochi	4,00,000	Retender
	Turbidity Meter	Kochi	1,00,000	99,975.00

	Deep Freezer	Kochi	2,00,000	94,000.00
	Ice flaker	Kochi	2,00,000	1,88,275.00
	Hot air oven	Kochi	1,50,000	39,900.00
	Laser Measuring Board	Kochi	2,00,000	-
	Sediment corer	Kochi	1,00,000	99,970.00
	Van Veen Grab	Kochi	1,00,000	99,949.00
	Digital Balance	Kochi Tuticorin	2,00,000	99,844.00
	Muffle Furnace	Kochi	2,00,000	1,99,599.00
	Refrigerator	Kochi	50,000	49,800.00
Total			200,00,000.00	

Minor Equipment (2016-17)

S.No.	Items	Procured at	Budget Allotted	Expenditure incurred/Booked
	Compound Microscope with photographic attachment	Kochi Calicut	8,00,000	Processing (send to council)
	Stereo Microscope with Photographic attachment	Karwar Chennai	6,00,000	Retender
	Portable water quality analyser for mariculture	Kochi	3,00,000	Processing
	Air pump – UV-Protein Skimmer	Kochi	1,00,000	94,463.00
Total			18,00,000.00	

Minor Equipment (2017-18)

S.No	Name of the Equipment	Procured at	Budget alloted	Expenditure incurred/ Booked
1.	Bottom Sampler acc to Van veen stainless steel,	Kochi	1,00,000	99949
2.	Sediment corer incl. Transparent plexi glass core tube	Kochi	1,00,000	99970
Total			2,00,000	Rs. 1,99,919 /-

IT Equipment (2017-18)

S.No	Name of the Equipment	Procured at	Budget alloted	Expenditure incurred/ Booked
1.	Canon Digital Multifunction Printer	Kochi	48,900/-	48,900/-
2.	Desktop Acer Computer	Kochi	4,49,900/-	4,49,900/-
3.	GSM 1 GPRS Modem X Connect with database	Kochi	2,17,386/-	2,17,386/-
4.	I-SAT Phone	Kochi	1,23,601/-	1,23,601/-
Total			8,39,787/-	Rs. 8,39,787/-

Equipment (2018-19)

S.No.	Name of the Equipment	Status of procurement	Budget Allocated	Actual Cost
1.	HP Laserjet P1100 Series	Complete	11, 000	10, 464
2.	6KV UPS	Complete	75, 000	74, 800
3.	Erma Refractometer	Complete	2, 500	2, 520
4.	Digital Thermometer	Complete	1, 500	1, 416
5.	-20°C Vertical Deep Freezer	Complete	60, 000	59, 997
6.	Laboratory Refrigerator 1100l	Complete	1, 50, 000	1, 50, 969
7.	CyberScan pH monitor	Complete	25, 000	24, 948
8.	Magnetic Stirrer	Complete	25, 000	24, 980
9.	Garmin Etrex Handheld GPS Unit	Complete	24, 000	23, 500
10.	Microwave Oven (32l)	Complete	24, 000	23, 800
11.	IFB Split AC 1 tonne	Complete	40, 000	38, 260
Total			7,78,000	4,12,154

Outcome & Accolades

Awards & recognitions

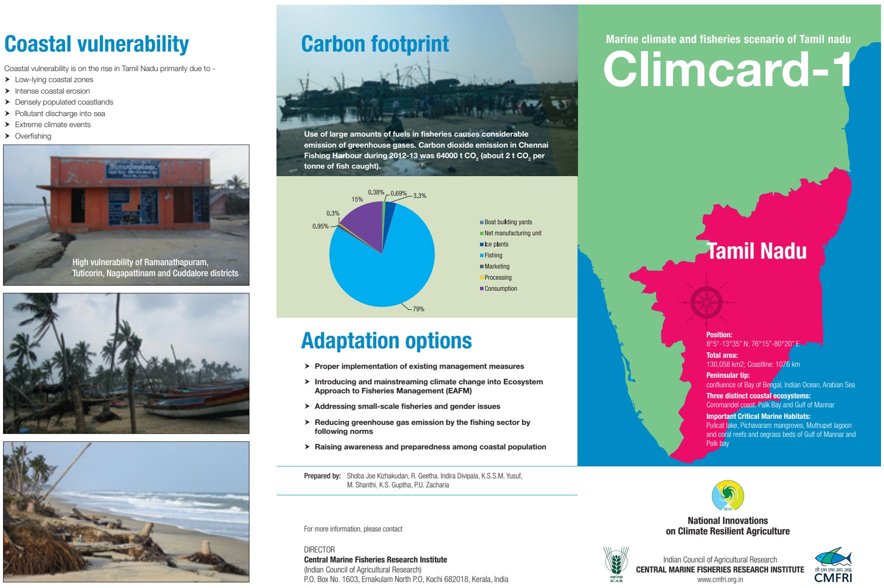
Special recognition awards

- Dr. P.U. Zacharia, Principal Investigator NICRA, CMFRI, Kochi received the award for best performing NICRA institution from Dr. S. Ayyappan, Secretary DARE & DG, ICAR at NICRA 4th Annual workshop held during August 2015 at CMFRI Headquarters, Kochi.
- Young pokkali farmer Shri Saigal A.R received national recognition from Dr.S. Ayyappan, Secretary DARE & DG, ICAR on May 2013 for his innovative experiment of integrating cage culture of finfish with traditional Pokkali-shrimp farming.

ICAR-CMFRI receiveing the award for best performing NICRA institution in 2015.

Best paper presentation awards

- Best paper (Oral) award: Sujitha Thomas and Dineshbabu A. P. 2013. GIS based resource mapping of fishery resources to reduce CO2 emission by multiday trawlers. In International symposium on Greening Fisheries held at Kochi from 21-23 May 2013.
- Best paper (Oral) award: Shyam S Salim., V. Kripa., Zacharia, P.U. and T.V. Ambrose. 2013. Coastal fisheries perception on climate change causes and effects: a PARS methodology approach. Presented and won best paper (Oral) award under technical session on Blue-Societal initiatives for a better tomorrow in fisheries in the International Symposium on Greening Fisheries-Towards Green Technologies in Fisheries. SOFTI and CIFT, Cochin May-21-23.
- Best paper (Poster) award: Vikas, P. A., Shinoj, Subramannian., John, Bose and Zacharia, P.U. 2015. Sustainable intensification of food production from Pokkali farming system through Cage farming. Presented at 5th International Symposium on Cage Aquaculture in Asia (CAA5).
- Best paper (Oral) award : Zacharia P.U., Rekha J. Nair, Somy Kuriakose., Jaysankar, J., Dinesbabu, A.P., Sujitha, Thomas., S.J. Kizhakudan., T.M. Najmudeen., Anulekshmi, Chellapan and Mohamed Koya, K. 2013. Distributional shift of pelagics, Indian Oil sardine and Indian Mackerel towards northern Indian Ocean-a climate change induced scenario? Abstract no.T01OP14 International conference on ecosystem conservation, climate cage and sustainable development, 3-5 October 2013, Thiruvananthapuram, pp.26-27.
- Best paper (Oral) award: Najmudeen T.M, Mary Febna A.A, Rojith G, Zacharia P.U (2019). "Characterization of biochar from water hyacinth *Eichhornia crassipes* and its effects on the growth of fish and paddy in intergrated culture systems" In Book of Abstracts, ICAR-Central Institute of Brackishwater Aquaculture (CIBA) & Society of Coastal Aquaculture and Fisheries (SCAFi), January 23-25,2019,Chennai, p.229
- Best paper (Poster) award: Shamiya Hasan, Haritha J, Rojith G, Ros Kooren, Rinu Madhu, Sayooj P, Grinson George, Zacharia P.U (2019). Conservation of Aquatic weed *Eichhornia crassipes* into climate change resilient products and its implications on climate resilience. In Book of Abstracts, ICAR-Central Institute of Brackishwater Aquaculture (CIBA) & Society of Coastal Aquaculture and Fisheries (SCAFi), January 23-25, 2019, Chennai, p.234
- Best paper (Oral) award: RojithGirindran, PU Zacharia, Sharon Benny, Sajna V Hussain, Liya V Benjamin, Roshen G Ninan, Dhanya Joseph, Akash Somashekharan and Grinson George (2019). "Climate change and role of E-commerce as a socio-economic resilient strategy for fisherman communities" in International conference on Aquatic resource and blue economy, Kerala university of fisheries and ocean studies (KUFOS), November 28-30, 2019.
- Best paper (Oral) award: Dineshbabu, A. P., Sujitha Thomas, Rajesh, K. M., Swathi Lekshmi, P. S., Prathibha Rohit, Shailaja Salian, Purbali Saha, and Zacharia, P.U. 2019. Constitution of an integrative approach for scaling up adaptation options to combatclimate change through climate-smart village (CSV) concept: A case study from Karnataka. In: World Brackishwater aquaculture conference (BRAQCON 2019
- Best paper (Poster) award: Sujitha Thomas, Dineshbabu, A. P., Rajesh K. M., Prathibha Rohit, Nataraja, G. D., Yogesh Kumar, Shailaja Salian and Purbali Saha 2019. Assessment of environmental statusof the coastal aquaculture locale in Karnataka-A precursor for carrying capacity study. In: World Brackishwater aquaculture conference (BRAQCON 2019).


Coastal vulnerability
Coastal vulnerability is on the rise in Tamil Nadu primarily due to -
- Low-lying coastal zones
- Intense coastal erosion
- Densely populated coastlands
- Pollutant discharge into sea
- Extreme climate events
- Overfishing
High vulnerability of Ramanathapuram, Tuticorin, Nagapattinam and Cuddalore districts
Carbon footprint
Use of large amounts of fuels in fisheries causes considerable emission of greenhouse gases. Carbon dioxide emission in Chennai Fishing Harbour during 2012-13 was 64000 t CO_2 (about 2 t CO_2 per tonne of fish caught).
Boat building yards
Net manufacturing unit
Ice plants
Fishing
Marketing
Processing
Consumption
Adaptation options
- Proper implementation of existing management measures
- Introducing and mainstreaming climate change into Ecosystem Approach to Fisheries Management (EAFM)
- Addressing small-scale fisheries and gender issues
- Reducing greenhouse gas emission by the fishing sector by following norms
- Raising awareness and preparedness among coastal population
Prepared by: Shoba Joe Kizhakudan, R. Geetha, Indira Divipala, K.S.S.M. Yusuf, M. Shanthi, K.S. Guptha, P.U. Zacharia
For more information, please contact
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Central Marine Fisheries Research Institute
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P.O. Box No. 1603, Ernakulam North P.O, Kochi 682018, Kerala, India
Marine climate and fisheries scenario of Tamil nadu
Climcard-1
Tamil Nadu
National Innovations on Climate Resilient Agriculture
Indian Council of Agricultural Research
CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
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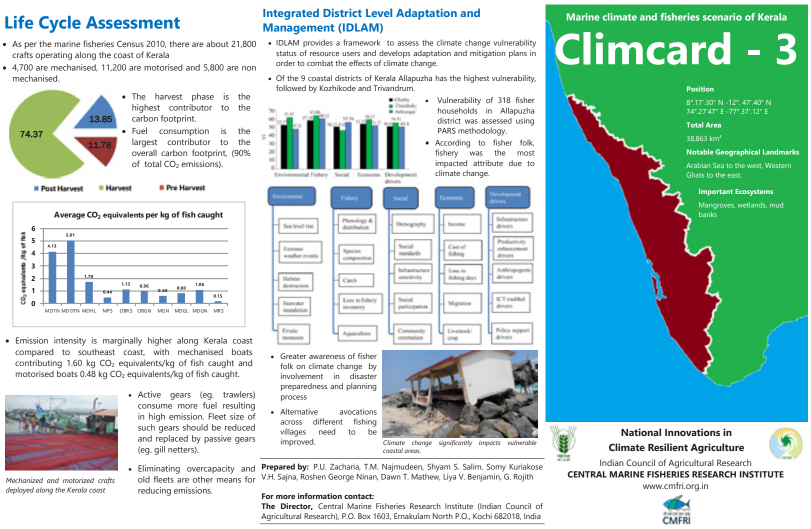
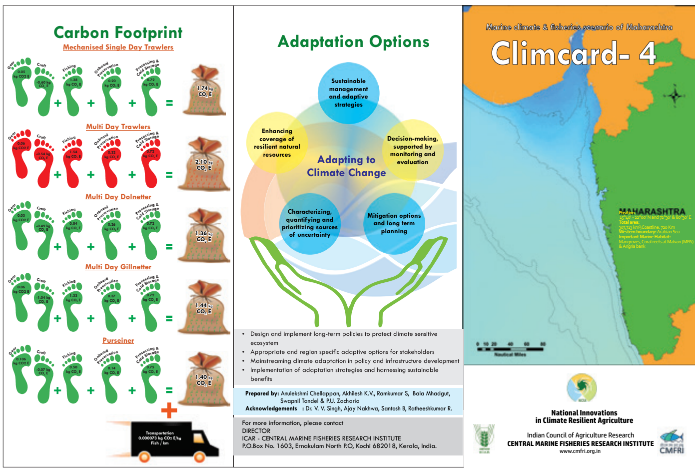

Life Cycle Assessment
- As per the marine fisheries Census 2010, there are about 21,800 crafts operating along the coast of Kerala
- 4,700 are mechanised, 11,200 are motorised and 5,800 are non mechanised.
- The harvest phase is the highest contributor to the carbon footprint.
- Fuel consumption is the largest contributor to the overall carbon footprint, (90% of total CO_2 emissions).
Post Harvest
Harvest
Pre Harvest
Average CO_2 equivalents per kg of fish caught
- Emission intensity is marginally higher along Kerala coast compared to southeast coast, with mechanised boats contributing 1.60 kg CO_2 equivalents/kg of fish caught and motorised boats 0.48 kg CO_2 equivalents/kg of fish caught.
- Active gears (eg. trawlers) consume more fuel resulting in high emission. Fleet size of such gears should be reduced and replaced by passive gears (eg. gill netters).
- Eliminating overcapacity and old fleets are other means for reducing emissions.
Mechanized and motorized crafts deployed along the Kerala coast
Integrated District Level Adaptation and Management (IDLAM)
- IDLAM provides a framework to assess the climate change vulnerability status of resource users and develops adaptation and mitigation plans in order to combat the effects of climate change.
- Of the 9 coastal districts of Kerala Allapuzha has the highest vulnerability, followed by Kozhikode and Trivandrum.
- Vulnerability of 318 fisher households in Allapuzha district was assessed using PARS methodology.
- According to fisher folk, fishery was the most impacted attribute due to climate change.
- Greater awareness of fisher folk on climate change by involvement in disaster preparedness and planning process
- Alternative avocations across different fishing villages need to be improved.
Climate change significantly impacts vulnerable coastal areas.
Prepared by: P.U. Zacharia, T.M. Najmudeen, Shyam S. Salim, Somy Kuriakose V.H. Sajna, Roshen George Ninan, Dawn T. Mathew, Liya V. Benjamin, G. Rojith
For more information contact:
The Director, Central Marine Fisheries Research Institute (Indian Council of Agricultural Research), P.O. Box 1603, Ernakulam North P.O., Kochi 682018, India
Marine climate and fisheries scenario of Kerala
Climcard - 3
Position
Total Area
38,863 km²
Notable Geographical Landmarks
Arabian Sea to the west, Western Ghats to the east.
Important Ecosystems
Mangroves, wetlands, mud banks
National Innovations in Climate Resilient Agriculture
Indian Council of Agricultural Research
CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
www.cmfri.org.in
CMFRI


Volume 1, Issue 1, July 2015
National Innovations on Climate Resilient Agriculture [NICRA]
ClimFish
NICRA Newsletter, CMFRI, Kochi
Inside this issue:
About NICRA
Principal Investigator's Desk
ICAR - CENTRAL MARINE FISHERIES RESEARCH INSTITUTE, KOCHI


Carbon Footprint
Mechanised Single Day Trawlers
Multi Day Trawlers
Multi Day Dolnetter
Multi Day Gillnetter
Purseiner
Adaptation Options
Sustainable management and adaptive strategies
Enhancing coverage of resilient natural resources
Decision-making, supported by monitoring and evaluation
Adapting to Climate Change
Characterizing, quantifying and prioritizing sources of uncertainty
Mitigation options and long term planning
- Design and implement long-term policies to protect climate sensitive ecosystem
- Appropriate and region specific adaptive options for stakeholders
- Mainstreaming climate adaptation in policy and infrastructure development
- Implementation of adaptation strategies and harnessing sustainable benefits
For more information, please contact
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ICAR - CENTRAL MARINE FISHERIES RESEARCH INSTITUTE
P.O.Box No. 1603, Ernakulam North P.O, Kochi 682018, Kerala, India.
Marine climate & fisheries scenario of Maharashtra
Climcard- 4
MAHARASHTRA
National Innovations in Climate Resilient Agriculture
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Publications

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Alphonsa Joseph	Young Proffesional-II	Kochi
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Arya. S. Sankar	Young Proffesional-II	Mumbai

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Way forward

The focus of research under NICRA project during the period 2021-2025 is directed towards climate resilience in the fishing sector by reaching out to the stakeholders, particularly the coastal fishing communities, to empower them with awareness of different impacts of climate change and provide them with options to overcome the impacts that could lead to disturbances in their livelihood security and disrupt their sources of income. With a view to achieving these goals, five major theme-based work programmes have been formed, with set objectives and targets.

Work programme 1 (WP1)

Projection on marine fisheries (WP 1.1) & mariculture production (WP 1.2)

WP 1.1 Projection on marine fisheries production: Fisheries Bioclimate Envelope Model for India

Purpose: To project marine fish catch in the Indian seas under IPCC climate change scenarios in the 21st century through 'Earth System Model (CMIP6)' and 'Fisheries Bioclimate Envelope Model for India' (modified from Dynamic Bioenvelope Climate Model (Cheung et al., 2018), for select SSP scenarios. The models would be developed taking into consideration IPCC AR6 on Physical Sciences (2021) and MoEF-IITM Report on CC in India (2020).

The projections will be based on spatial distribution-dispersal-biomass at species-level using CMFRI catch data and a few proxies. The catch potential (both in the past and future) will be estimated by simulating exploitation of the resource at an ideal MSY level, taking into consideration the change in ecosystem productivity over time (and in the future as driven by climate change), taking the estimated maximum catch potential to be a proxy of MSY of the resource.

Data required from CMFRI database:

- FRAD data to analyse change in the trend in fishing operating different craft-gear types over 30 years at 0.5^{o} x 0.5^{o} lat-long grid in the Indian EEZ;
- Fishing area* (to be calculated from fishing direction and distance from the harbor);
- Change in the size of boats (as proxy to calculate engine hp);

- Manpower in each type of fishing operation;
- Scouting time (absence from harbor minus actual fishing hours);
- Diesel consumption.

All of the above will be related with species catch and composition.

Data required from ESM and Biological models:

- Bioclimatic conditions (seawater temp., pH, O_2, advection currents, NPP over past 30 years (t) and future (t+1) in each grid from Earth System Models (ESM);
- Current spatial distribution and biomass of commercially exploited species in the grid (habitat preference, species thermal suitability);
- Projection on species distribution in grid;
- Changes in biomass at each time step in each grid (consider growth, spawning and larval dispersal using empirical equations and sub-models);
- Maximum Catch Potential (using F at the level required to achieve MSY).

WP 1.2 Projection on mariculture production

Purpose: To project mariculture production in India under IPCC climate change scenarios in the 21st century, with emphasis on -

- Current species, systems and areas of mariculture (marine fish, crustaceans, bivalves, seaweeds);
- Issues (such as loss of assets and crops due to extreme events, economics of operation, fish meal availability, etc);
- Addition of potential species and areas in the next 10 years.

The model will seek to quantify the ecological niche of each species for the present-day period (1991–2010) and calculate their habitat-species suitability index (HSI) for each 0.5° lat x 0.5° long grid, apply spatial filters (Oyinlola et al., 2018), informed by physical, environmental and socio-economic constraints of mariculture location, to generate potentially suitable species and areas for mariculture, apply Species Distribution Model (SDM) to project future habitat suitability index (HSI) and quantify the potential suitable marine area for mariculture under climate change, estimate the amount of fish meal required (Oyinlola et al., 2021), apply price forecasting (Cheung et al., 2021) and develop and apply Generalised Additive Model (GAM) by using above data to project mariculture potential (Oyinlola et al., 2021).

Work programme 2 (WP2)

Risk Assessment and adoption of weather forecast

Purpose: To suggest measures to reduce impact of extreme events on fishing communities and farmers.

The work programme envisages risk assessment for clusters of coastal districts in each maritime state following Exposure, Sensitivity, Adaptation capacity and Mitigation criteria, grouping all 66 districts or sampling districts under three clusters for large states and two clusters for smaller states (representative villages in each cluster may be surveyed for projection to each cluster). The study will assess trend in economic cost of loss and damages in fisheries and mariculture in the last 10 years, assets damage due to SLR, erosion & cyclones, infrastructure damage due to cyclones, loss of days of operation and economic loss, loss of life due to cyclones and current level of adaptation measures followed by the communities and governments (to be collected from field surveys, interviews and government records).

The assessment will also take into account the perceptions and beliefs of fishers and farmers on climate change and extreme events, the precision of weather forecast and dissemination efficiency, adoption rate of weather forecasts and expectations of fishers from forecasts, and will also address the issues of improving adoption rate, improving insurance penetration as an opportunity and identifying opportunities for risk reduction on near-term and long-term basis.

Work programme 3 (WP3)

Behaviour of Value Chain

Purpose: To identify opportunities and barriers in changing climate; to understand and develop future models of value chains

WP 3 will seek to define the current state and changing trend in fish value chains by assessing transfer of biomass and value from one node to the next, identifying inefficiencies (loss in quality and quantity) during on-board and on-shore handling, storage and transport, LCA across the chain, how the chain behaves due to disruption in supply: cyclones; off season, ban season, (capture fisheries); heavy monsoon, high temp (affecting aquaculture), identifying opportunities to enhance supply and profitability, and assessing the impact of market factors (infrastructure like storage facilities) on the price and profit. The study will seek to project future scenarios and adaptation options and suggest improved and best-practiced value chains.

Work programme 4 (WP4)

Mitigation potential of mangroves and coastal wetlands and cost-effectiveness of restoration

Purpose: To assess the role of blue carbon in coastal habitats.

WP4 will focus on extending the ongoing work on assessing blue carbon potential of mangroves, seagrasses and salt marshes to a larger scale with the purpose of projection for the entire coastal area in the country, covering different species below ground, above ground and soil, differentiating between natural and planted flora. Data from wetland surveys carried out in the past years under NICRA will be incorporated into blue carbon potential estimates and the blue carbon potential for carbon credit opportunities will be explored. The study will also seek to estimate the cost of restoration of selected ecosystems. Another component of study will be ocean acidification, its extent and impacts.

Work programme 5 (WP5)

Response of capture and mariculture species

Purpose: To collect data for input of projection models; and to find out the impact of 'deadly trio' water temperature, oxygen and acidification, and quantifying sensitivities.

This work programme will generate data on response of capture species for biological model of Fisheries Bioclimate Envelope Model (WP 1) and relevant data for mariculture projection model (WP 1.2). Data will pertain to -

- Laboratory experiments on aquaculture organisms, preferably larvae, fry and fingerlings of fish, shrimps and bivalves, and seaweeds exposed to combination of different temperature, oxygen concentration, pH and feeding densities;
- Biological response (survival, feeding, growth, shell calcification, etc) to a combination of maximum 0.5 unit reduction in pH (by bubbling pure CO_2 in seawater and manipulating different CO_2 treatments) + maximum 3.0° C rise in water temperature (of the habitat pH and temperature) + reduction in O_2 concentration + feeding densities;
- Potential abundance estimates on the taxonomic groups.

Work programme 6 (WP6)

Potential for adaptive management of fisheries (WP 6.1) and mariculture (WP 6.2) to climate change

Purpose: Preparation of detailed report on potential adaptation and mitigation for consideration of policy makers and managers

This work programme envisages the following outputs -

- Compendium of pan-India and local measures currently followed with case studies;
- Identifying pan-India and local management measures and practices that have the potential (best practices) to reduce the impact and risks in the next 20 – 30 years for fish resources, fisheries and fishing communities;
- Projection on cost of adaptation and mitigation;
- Suggestions to integrate the measures into management instruments.

Forthcoming publications

- Carbon Footprint of Indian Marine Fisheries.
- Vulnerability and adaptation to climate change in the coastal districts of Tamil Nadu, India.
- Reproductive performance of *Nemipterus japonicus* – a comparative assessment between Arabian sea and Bay of Bengal coasts of India across similar latitude and longitude ranges.
- Brochure on climate change adaptation and alternate livelihoods for coastal fishing communities.
- Policy brief on climate change mitigation and adaptation challenges for coastal Tamil Nadu.
- Dynamics of plankton and larvae of finfish and shellfish off Visakhapatnam.
- Estimation of potential yield for golden anchovies along the Gujarat coast in relation to changing climatic variables.
- Towards sustainable Bombay duck fishery along the northwest coast of India in a changing environmental regime.
- Temporospatial and vertical variability of dissolved oxygen in the coastal waters of north-eastern Arabian Sea (NEAS): a satellite remote sensing approach.
- GIS-based resource mapping of fishery resources to reduce carbon footprint – a case study from Karnataka.
- Spatiotemporal mapping of marine resources and correlation with the environment.
- Gene expression profile of selected tissues of *Panulirus homarus* generated through transcriptome sequencing: a genomic resource for exploring vulnerability to climate change.
- Prey-predator Biomass Dynamics Model with environmental effects for assessing fish stocks in a multi-species multi-gear tropical fishery.
- Assessing fishery and gear vulnerability to climate change in the multi-species and multi-gear marine fisheries of India.
- Mitogenomes of *Scomberomorus* spp. reveal niche specialization linked with abiotic factors.
- Impact of temperature on growth, associated bacterial populations and the histomorphological changes in the organs of silver pompano (*Trachinotus blochii*) fingerlings.

- Assessment of seaweed farming area, biomass production and carbon sequestration potential of farmed seaweed in Tamil Nadu.
- Satellite derived oceanographic parameter for predicting habitat suitability of Indian mackerel in northwest coast of India.
- Assessment of mangrove above-ground biomass and blue carbon stock along Tamil Nadu's southern coast using multispectral satellite images.
- Potential understanding of link between climate change and harmful algal blooms along the Gulf of Mannar.
- Effect of water temperature on growth, blood biochemistry, digestive, metabolic enzymology and antioxidant defences of snubnose pompano juveniles.
- Effect of different water temperatures and phosphate levels on growth and nutritive profile of marine microalgae, *Isochrysis galbana.*
- Comparison of carbon sequestration potential of natural and planted mangrove stands of Kolavipalam estuarine wetland of Kerala.

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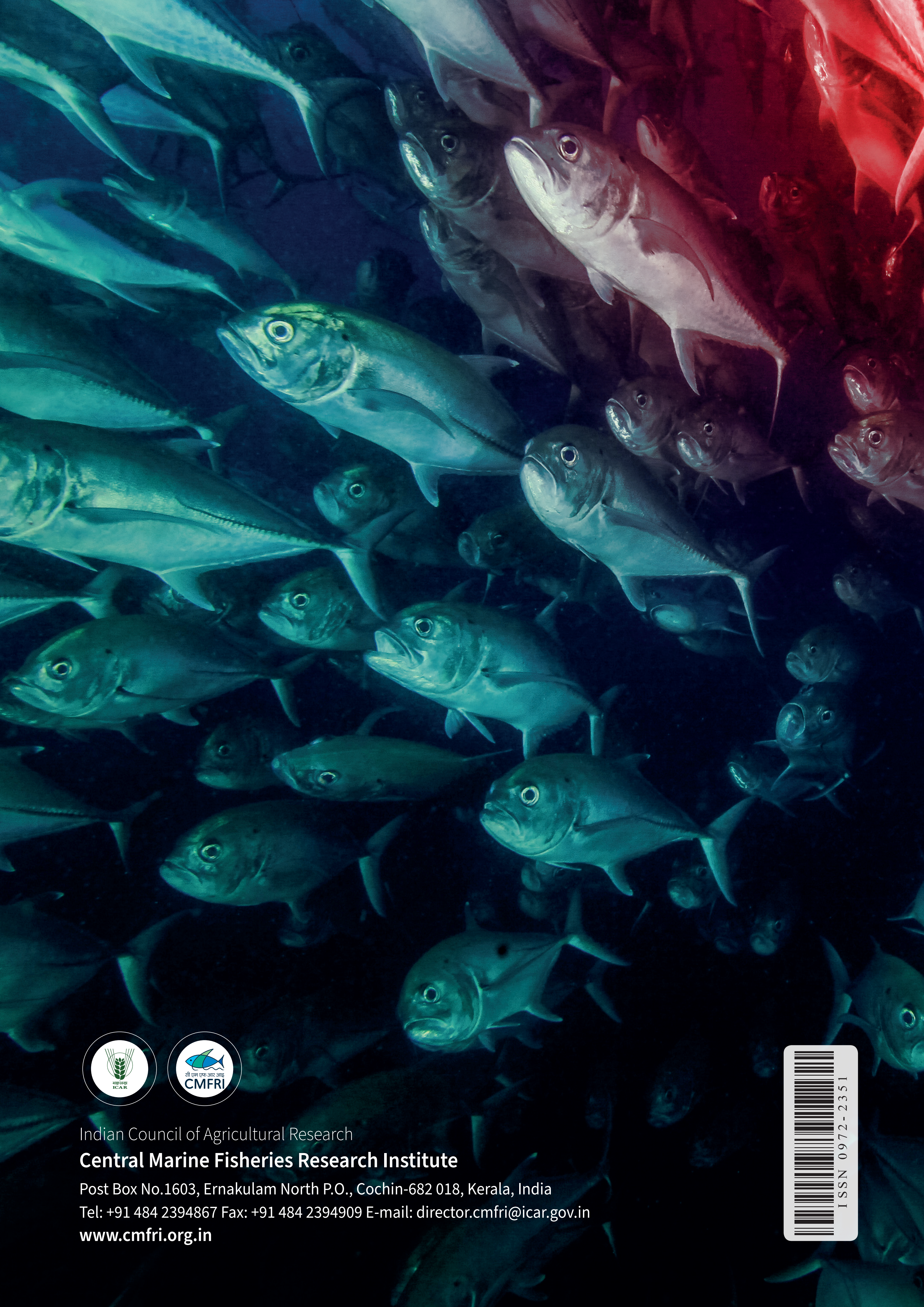
Notes



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