National Report on

# Deep-Sea and Distant-Water Fishery Resources of Indian EEZ




सत्यमेव जयते

Centre for Marine Living Resources & Ecology
Ministry of Earth Sciences, Government of India

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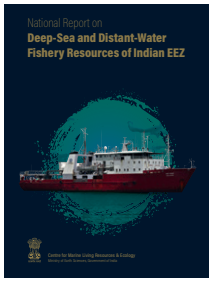
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This report presents a scientific assessment of deep-sea and distant-water fishery resources of the Indian Exclusive Economic Zone (EEZ). It synthesizes information from extensive surveys conducted by CMLRE onboard FORV *Sagar Sampada*, along with secondary data and relevant scientific literature. The report reviews the current status of deep-sea fishery research in India, identifies knowledge gaps, and outlines future needs, opportunities, and strategic pathways for resource exploration and development. It emphasizes the strengthening of sustainable management practices through science-based approaches, advanced monitoring tools, and improved observational frameworks, in support of national priorities in blue economy development and marine conservation.

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# Message


डॉ0 जितेन्द्र सिंह
राज्य मंत्री (स्वतंत्र प्रभार),
विज्ञान एवं प्रौद्योगिकी मंत्रालय;
राज्य मंत्री (स्वतंत्र प्रभार) पृथ्वी विज्ञान मंत्रालय;
राज्य मंत्री, प्रधान मंत्री कार्यालय;
राज्य मंत्री कार्मिक, लोक शिकायत एवं पेंशन मंत्रालय;
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राज्य मंत्री अंतरिक्ष विभाग
भारत सरकार

सत्यमेव जयते

**Dr. JITENDRA SINGH**
Minister of State (Independent Charge)
of the Ministry of Science and Technology;
Minister of State (Independent Charge)
of the Ministry of Earth Sciences;
Minister of State in the Prime Minister's Office;
Minister of State in the Ministry of Personnel,
Public Grievances and Pensions;
Minister of State in the Department of Atomic Energy; and
Minister of State in the Department of Space
Government of India




It gives me great pleasure to present this *National Report on Deep-Sea and Distant-water Fishery Resources of Indian EEZ*, a significant milestone in India's journey towards harnessing the full potential of our marine resources through science-driven, sustainable development.

As the world's second largest fish producing nation, India's fisheries sector plays a pivotal role in ensuring food security, providing livelihoods to over 28 million people, and contributing to national economic growth. However, as coastal fishery resources approach their exploitation limits, it becomes imperative to shift our focus to underutilized and uncharted frontiers, our deep-sea ecosystems.

This document is the result of extensive research undertaken by the Ministry of Earth Sciences (MoES) through the Centre for Marine Living Resources and Ecology (CMLRE) and the Fisheries Oceanographic Research Vessel (FORV) *Sagar Sampada*. It provides a comprehensive assessment of India's deep-sea fishery resources and not only highlights our nation's rich biodiversity in the depths of the Arabian Sea, Bay of Bengal, and Andaman waters, but also outlines a clear roadmap for sustainable exploration, conservation, and development.

Aligned with India's Vision 2047 and the Sustainable Development Goals (SDG), this document reflects our commitment to advancing the Blue Economy through responsible management of marine ecosystems. It emphasizes the need for technological innovation, infrastructure development, and inclusive policy-making to ensure that deep-sea fisheries are tapped in a way that balances ecological conservation with economic opportunity.

I commend the scientific community of CMLRE for their dedicated efforts in bringing this report to fruition. I am confident that it will serve as a vital resource for policymakers, researchers, and stakeholders working to secure a sustainable and prosperous future for India's marine sector.

**(Dr. Jitendra Singh)**
MBBS (Stanley, Chennai)
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# Foreword

सत्यमेव जयते

डॉ. एम. रविचंद्रन
Dr. M. Ravichandran

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भारत सरकार
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PRITHVI BHAWAN, LODHI ROAD, NEW DELHI-110003



I am pleased to present this *National Report on Deep-Sea and Distant-water Fishery Resources of Indian EEZ*, which marks a significant contribution to India's scientific and policy framework for sustainable marine resource management.

India's vast Exclusive Economic Zone (EEZ), spanning over 2.37 million square kilometers, harbours immense potential in its deep-sea realms, rich in biodiversity, ecosystem services, and economic value. As the demand for aquatic food continues to rise, driven by population growth and changing consumption patterns, the deep-sea represents a critical frontier for enhancing national food security, diversifying fisheries, and advancing the objectives of the Blue Economy.

This document, is an amalgamation of four decades of research by the FORV *Sagar Sampada* coordinated by the CMLRE, providing a detailed scientific assessment of deep-sea fishery resources in India. It offers insights into species distribution, resource abundance, fishing potential, ecological risks, and strategic opportunities. The comprehensive findings, including those on mesopelagic, demersal and distant ecosystems, are a testament to India's leadership in oceanographic research and ecosystem-based fisheries management.

At the Ministry of Earth Sciences (MoES), we remain committed to promoting sustainable ocean development through integrated scientific approaches, technological innovation, and collaborative governance. This report aligns with national priorities outlined in Vision 2047 and supports global commitments under the United Nations Sustainable Development Goals, particularly SDG 14.

I congratulate the scientific teams and researchers who have contributed to this publication. I am confident that this document will serve as a foundational reference for decision-makers, academic institutions, and researchers striving to secure a sustainable future for India's marine fisheries sector.

Dr. M. Ravichandran

# Preface



India's marine ecosystem, spanning an Exclusive Economic Zone of over 2.37 million square kilometres and adjoining high seas, represents the cornerstone of national prosperity, ecological security, and food sustainability. While coastal resources have long supported livelihoods, the vast deep-sea domain beyond 200 metres remains a frontier of opportunity. This document brings together four decades of scientific research from the Marine Living Resource Program (MLRP) implemented by CMLRE, largely enabled by FORV *Sagar Sampada*, to provide a forward-looking vision for unlocking the sustainable potential of India's deep-sea resources. These efforts have revealed the significance of mesopelagic and deep-sea systems, as critical drivers of ocean productivity and emerging avenues for future fisheries and blue economy growth.

At a time when coastal fisheries face increasing stress and national demand for fish is projected to rise substantially, India stands at a strategic inflection point. The transition towards responsible deep-sea resource utilization must be guided by robust science, technological innovation, and ecosystem-based management. This calls for a multi-pronged approach that balances economic aspirations with ecological stewardship, ensuring resilience of marine ecosystems while supporting livelihoods and national food security.

Central to this vision is the strengthening of India's scientific and technological capabilities. FORV *Sagar Sampada*, which has served the nation with distinction for over four decades, has laid a strong foundation for marine living research. Building on this legacy, the Ministry of Earth Sciences (MoES) is advancing plans to induct a next-generation research vessel equipped with state-of-the-art observational and analytical systems. This initiative will significantly enhance India's capacity to lead in ocean science and will contribute to achieving national priorities under Vision 2047, and also global commitments including Sustainable Development Goal 14 and the UN Decade of Ocean Science. This report is envisaged as a guiding framework to drive innovation, inform policy, and promote responsible stewardship of India's deep ocean resources for generations to come.

Dr. R. S. Maheskumar

# Acknowledgement

We acknowledge the vision and leadership of the former Secretaries, and Directors of the Ministry of Earth Sciences (MoES) and the Department of Ocean Development (DOD), as well as the guidance of the Research Advisory Committee (RAC), and Joint Scientific Technical Advisory Committee (JSTAC), in shaping the scientific direction and execution of the programmes presented in this report. We also place on record our appreciation to the former Heads of CMLRE for their leadership and contributions towards strengthening marine research in India.

This report is fundamentally built upon the sustained and coordinated efforts of the scientific community, including scientists, researchers, technicians, research scholars, and project scientists associated with the Marine Living Resources Program (MLRP), whose contributions to systematic data collection, sample processing, analysis, and interpretation constitute its core strength. We particularly recognize the significant role of the Grant-in-Aid (GIA) project teams from national research institutes and academic centres across the country, whose multi-institutional and interdisciplinary collaboration has substantially advanced the assessment and understanding of Marine Living Resources (MLR), while contributing to national scientific capacity and evidence-based decision-making.

We acknowledge the support of the Vessel Management Cell and associated agencies in enabling and sustaining survey operations. We also appreciate the captains and crew of FORV *Sagar Sampada* for their professionalism and support during research cruises, which were critical for data acquisition under diverse and challenging oceanic conditions.

We further acknowledge all individuals and stakeholders who have contributed, directly or indirectly, to the completion of this report.

# Abbreviations & Acronyms

| | |
|---|---|
| ABNJ | Areas Beyond National Jurisdiction |
| ADCP | Acoustic Doppler Current Profiler |
| AIS | Automatic Identification System |
| AI | Artificial Intelligence |
| AS | Arabian Sea |
| ATTC | Alleppey-Trivandrum Terrace Complex |
| AUV | Autonomous Underwater Vehicle |
| BBNJ | Biodiversity Beyond National Jurisdiction |
| BoB | Bay of Bengal |
| BOBPS | Bay of Bengal Process Studies |
| BRDs | Bycatch Reduction Devices |
| CAGR | Compound Annual Growth Rate |
| CBD | Convention on Biological Diversity |
| CCAMLR | Commission for the Conservation of Antarctic Marine Living Resources |
| CCSBT | Commission for Conservation of Southern Bluefin Tuna |
| CEAS | Central Eastern Arabian Sea |
| CIFNET | Central Institute of Fisheries Nautical and Engineering Training |
| CIFT | Central Institute of Fisheries Technology |
| CITES | Convention on International Trade in Endangered Species |
| CMFRI | Central Marine Fisheries Research Institute |
| CMFP | Comprehensive Marine Fishing Policy |
| CMLRE | Centre for Marine Living Resources and Ecology |
| CPUE | Catch Per Unit Effort |
| CPCs | Contracting Parties and Cooperating Non-Contracting Parties |
| CRV | Coastal Research Vessel |
| CRZ | Coastal Regulation Zone |
| CTD | Conductivity Temperature Depth |
| CV | Crustacean Version |
| DADF | Department of Animal Husbandry and Dairying |
| DHA | Docosahexaenoic Acid |
| DNA | Deoxyribonucleic acid |
| DOD | Department of Ocean Development |
| DOM | Deep Ocean Mission |
| DSDWF | Deep-Sea and Distant-Water Fishery |
| DSL | Deep Scattering Layer |
| DVM | Diel Vertical Migration |
| DWF | Distant-Water Fisheries |
| EAF | Ecosystem Approach to Fisheries |
| EANI | Eastern Andaman-Nicobar Islands |
| EAS | Eastern Arabian Sea |
| EBM | Ecosystem-Based Management |
| EBSA | Ecologically and Biologically Significant Area |
| eDNA | Environmental Deoxyribonucleic Acid |
| EEZ | Exclusive Economic Zone |
| EIO | Eastern Indian Ocean |
| EK-80 | Echosounder |
| EMM | Ecosystem Monitoring and Management |
| EPA | Eicosapentaenoic Acid |
| EXPO | Expo-model Fish Trawl |

| | |
|---|---|
| FADs | Fish Aggregating Devices |
| FAO | Food and Agriculture Organization |
| FIKEX | First Indian Krill Expedition |
| FFPO | Fish Farmer Producer Organizations |
| FIDF | Fisheries and Aquaculture Infrastructure Development Fund |
| $F_{MSY}$ | Fishing Mortality at Maximum Sustainable Yield |
| FORV | Fisheries and Oceanographic Research Vessel |
| FSI | Fishery Survey of India |
| FV | Fishing Vessel |
| GC-MS | Gas Chromatography- Mass Spectrometry |
| GDP | Gross Domestic Product |
| GIS | Geographic Information System |
| GLOBEC | Global Ocean Ecosystem Dynamics |
| GSI | Geological Survey of India |
| GVA | Gross Value Added |
| HABs | Harmful Algal Blooms |
| HCRs | Harvest Control Rules |
| HOT | High-Opening Trawl |
| HPC | High-Performance Computing Systems |
| HSDT | High Speed Demersal Trawl |
| ICAR | Indian Council of Agricultural Research |
| ICCAT | International Commission for the Conservation of Atlantic Tunas |
| IIOE | International Indian Ocean Expedition |
| IKMT | Isaacs-Kidd Midwater Trawl |
| INCOIS | Indian National Centre for Ocean Information Services |
| IndOBIS | Indian Ocean Biodiversity Information System |
| IODE | International Oceanographic Data and Information Exchange |
| IOSO | Indian Ocean Sector of the Southern Ocean |
| IoT | Internet of Things |
| IOTC | Indian Ocean Tuna Commission |
| IPCC | Intergovernmental Panel on Climate Change |
| ISSF | International Seafood Sustainability Foundation |
| ITI | Integrated Trawl Instrumentation |
| ITTC | Inter-American Tropical Tuna Commission |
| IUCN | International Union for Conservation of Nature |
| IUU | Illegal, Unreported, and Unregulated |
| JGOFS | Joint Global Ocean Flux Study |
| LBB | Length-Based Bayesian biomass estimation |
| LBSPR | Length-Based Spawning Potential Ratio |
| LCR | Laccadive-Chagos Ridge |
| LOA | Length Overall |
| MBES | Multibeam Echo Sounders |
| MCDA | Multi-Criteria Decision Analysis |
| ML | Machine Learning |
| MLR | Marine Living Resources |
| MLRP | Marine Living Resources Programme |
| MMME | Monitoring and Modelling of Marine Ecosystem |
| MoEFCC | Ministry of Environment, Forest and Climate Change |
| MoES | Ministry of Earth Sciences |
| MPAs | Marine Protected Areas |
| MPEDA | Marine Products Export Development Authority |
| MPN | Multi-Plankton Net |
| MRFP | MoES Research Fellowship Programme |
| MSY | Maximum Sustainable Yield |
| MUFA | Monounsaturated Fatty Acid |
| NBoB | Northern Bay of Bengal |
| NCESS | National Centre for Earth Science Studies |

| | |
|---|---|
| NCPOR | National Centre for Polar and Ocean Research |
| NEAS | North Eastern Arabian Sea |
| NFDB | National Fisheries Development Board |
| NIO | National Institute of Oceanography |
| NIOT | National Institute of Ocean Technology |
| nMDS | non-metric-Dimensional Scaling |
| NOAA | National Oceanic and Atmospheric Administration |
| NPOA | National Plan of Action |
| NWBoB | North West Bay of Bengal |
| OBIS | Ocean Biodiversity Information System |
| OMZ | Oxygen Minimum Zone |
| ORV | Oceanographic Research Vessel |
| OSPAR | Oslo and Paris Conventions for the protection of the marine environment of the North-East Atlantic |
| PCR | Polymerase Chain Reaction |
| PIB | Press Information Bureau |
| PMMSY | Pradhan Mantri Matsya Sampada Yojana |
| PP | Primary Production |
| PUFA | Polyunsaturated Fatty Acid |
| QFPCO | Qeshm Fish Process Company |
| REIS | Resource Exploration and Inventorization System |
| RFMOs | Regional Fisheries Management Organisations |
| RIMS | Royal Indian Marine Survey |
| ROVs | Remotely Operated Vehicles |
| RPAS | Remotely Piloted Aircraft Systems |
| RV | Research Vessel |
| SANI | South Andaman-Nicobar Islands |
| SCAR | Scientific Committee on Antarctic Research |
| SDG | Sustainable Development Goals |
| SDM | Species Distribution Modelling |
| SEAS | South Eastern Arabian Sea |
| SIOFA | Southern Indian Ocean Fisheries Agreement |
| SIMPER | Similarity Percentage |
| SIMRAD | Simonsen Radio |
| SP | Secondary Production |
| $SSB_{MSY}$ | Spawning Stock Biomass at Maximum Sustainable Yield |
| SWBoB | South West Bay of Bengal |
| SWQM | Sea Water Quality Monitoring |
| TAC | Total Allowable Catch |
| TEs | Transfer Efficiencies |
| ToT | Terrace off Trivandrum |
| TS | Target Strength |
| TUFFS | Tuna Fishery Forecast System |
| UN | United Nations |
| UNCLOS | United Nations Convention on the Law of the Sea |
| UNDP | United Nations Development Programme |
| UNGA | United Nations General Assembly |
| USD | United States Dollars |
| UUV | Unmanned Undersea Vehicles |
| VMEs | Vulnerable Marine Ecosystems |
| VMS | Vessel Monitoring Systems |
| VPA | Virtual Population Analysis |
| WANI | West Andaman-Nicobar Islands |
| WCPFC | Western and Central Pacific Fisheries Commission |
| WCS-India | Wildlife Conservation Society India |
| WEIO | Western Equatorial Indian Ocean |
| WG-EMM | Working Group on Ecosystem Monitoring and Management |
| WIO | Western Indian Ocean |
| XRD | X-Ray Diffraction |
| XRF | X-Ray Fluorescence |
| ZSI | Zoological Survey of India |

# Glossary

| | |
|---|---|
| Abundance | The total number of individuals of a species within a defined area or volume of water. |
| Acoustic Doppler Current Profiler (ADCP) | An instrument used to measure ocean current velocity profiles. |
| Acoustic Surveys | The use of sound wave equipment (such as echosounders) to assess fish abundance and distribution. |
| Acoustic Telemetry | A technique using sound and radio signals for tracking fish movements and behaviour. |
| Bathymetry | The measurement and mapping of ocean depth and the contours of the ocean floor. |
| Bathypelagic Zone | The ocean depth range roughly between 1000-4000 m, where no sunlight penetrates. |
| Benthic Zone | The ocean floor area, including sediments and organisms living on or within the seabed. |
| Biodiversity Hotspot | A marine area with exceptionally high species richness, endemism, and ecological significance. |
| Biodiversity Index | A measure used to assess the diversity of species in an ecosystem. |
| Biogeographic Zonation | Classification of oceanic areas based on species, habitats, and environmental conditions. |
| Bioluminescence | The ability of certain deep-sea organisms to produce light aids in communication, predation, or camouflage. |
| Biomass | The total weight of a species or group of organisms in a given area. |
| Bioprospecting | The exploration of biological material from deep-sea organisms for potential use in pharmaceuticals, nutraceuticals, and other industries. |
| Bioturbation | The reworking of sediments on the ocean floor is caused by burrowing organisms. |
| Blue Economy | Sustainable use of ocean resources for economic growth, improved livelihoods, and ocean health. |
| Bycatch | The capture of non-target species (fish, sharks, rays) during fishing operations. |
| Byproduct | A valuable species captured unintentionally that can be utilized, e.g., fish oil or fishmeal. |
| Catch Per Unit Effort (CPUE) | A measure of fishing efficiency calculated as the quantity of fish caught per standardized effort (e.g., per trawl or per hour). |
| Cephalopods | A class of marine molluscs, including squid, octopus, and cuttlefish, many of which are commercially valuable. |
| CMLRE (Centre for Marine Living Resources and Ecology) | An autonomous institute under the Ministry of Earth Sciences (MoES), Government of India, responsible for deep-sea marine biodiversity and fishery studies. |
| Coastal Regulation Zone (CRZ) | Regulations implemented by the Government of India to govern the use and protection of coastal areas. |

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| Continental Slope | The area between the continental shelf and the deep ocean floor ranges roughly from 200 m to 3000 m in depth. |
| Deep Scattering Layer (DSL) | A zone in the ocean where sound waves are scattered by dense aggregations of organisms (fish, shrimp, zooplankton), making it appear as a "layer" on sonar. |
| Deep-Sea Camera Systems | Specialized camera setups for capturing images and video from deep-sea environments. |
| Deep-Sea Elasmobranchs | Sharks, skates, and rays are found in deep-sea habitats. |
| Deep-Sea Shrimp | Shrimp species found in deeper ocean waters (usually >200 m), commercially exploited for their higher value. |
| Deep-Sea Fisheries | The capture of fish species living beyond 200 m depth, including mesopelagic, bathypelagic, and benthic species. |
| Drop Camera | Equipment that captures images of deep-sea habitats and species for research and monitoring. |
| EAF (Ecosystem Approach to Fisheries) | A fisheries management approach that considers the entire ecosystem, including species interactions and habitats. |
| Echosounder | Equipment that uses sound waves to measure fish abundance and underwater topography. |
| Ecosystem-Based Management (EBM) | An approach that considers the entire ecosystem when making resource management decisions. |
| Environmental Impact Assessment (EIA) | Assessment of potential impacts of development or fishing activities on marine habitats and species. |
| Epipelagic Zone | The uppermost ocean zone (0-200 m), also called the sunlight zone. |
| Exclusive Economic Zone (EEZ) | The area extending 200 nautical miles from a country's shoreline, granting rights to explore and use marine resources. |
| FAO (Food and Agriculture Organization) | A United Nations agency focusing on global food security and sustainable fisheries practices. |
| Fecundity | The reproductive capacity of a fish species, generally measured by the number of eggs a female can produce. |
| FORV *Sagar Sampada* | A dedicated Fishery Oceanographic Research Vessel used for deep-sea and oceanographic research owned by MoES, Govt. of India. |
| Gear Selectivity | The ability of a fishing gear (net or hook) to target certain species or sizes, minimizing the capture of unwanted species. |
| High Seas | Areas of the ocean beyond national jurisdiction (beyond EEZ), available for exploration and exploitation by any nation. |
| High-Opening Trawl (HOT) | A deep-sea trawl net designed with a higher mouth opening for capturing demersal and semi-pelagic species. |
| Integrated Coastal Zone Management (ICZM) | A holistic approach to managing coastal resources that integrates environmental, social, and economic priorities. |
| Integrated Trawl Instrumentation (ITI) | Instruments used in trawl nets to measure depth, opening, and positioning during fishing operations. |

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| IUU Fishing | Fishing conducted outside the rules of international or national regulations impacts fish stocks and ecosystems. |
| Leptocephali | The larval form of eels is an important component of deep-sea and pelagic ecosystems. |
| Longline Fishing | A method that uses a long line with baited hooks to target highly migratory species. |
| Mariculture | The farming of marine organisms such as fish, shellfish, and seaweed. |
| Marine Biodiversity monitoring | Research and survey methods focusing on marine species diversity, distribution, and abundance patterns. |
| Marine Debris Monitoring | Systematic monitoring and recording of marine debris and its impact on habitats and fisheries. |
| Marine Protected Areas (MPAs) | Specific ocean areas are set aside for the protection and conservation of marine biodiversity and habitats. |
| Marine Spatial Planning (MSP) | A process of organizing ocean spaces to balance ecological, economic, and social interests, including fisheries. |
| Maximum Sustainable Yield | The largest long-term average catch that can be taken from a stock without reducing its ability to replenish. |
| Mesopelagic Fishes | Fishes living within the “twilight zone” of the ocean (~200-1000 m depth), e.g., lanternfish and bristlemouths. |
| Mesopelagic Zone | The ocean depth range roughly between 200-1000 m, also called the “twilight zone” of the ocean. |
| Myctophids (Lanternfishes) | Small mesopelagic fishes are abundant in deepscattering layers, making up a significant portion of deep-sea biomass. |
| Oceanographic Surveys | Scientific investigations are conducted at sea to study ocean conditions, biodiversity, habitats, and fisheries resources. |
| Otter Board | A device attached to trawl nets that holds the net open horizontally while being dragged. |
| Overfishing | The depletion of fish stocks by excessive fishing beyond sustainable levels. |
| Pelagic Fish | Fish that inhabit the water column of the ocean, as opposed to the sea floor. |
| Post-Harvest Losses | The quantity or quality of fish lost due to mishandling, spoilage, or lack of coldchain infrastructure after capture. |
| Post Larval Dispersal | The distribution and movement of juvenile fish and invertebrates from spawning grounds to their adult habitats. |
| Recruitment | New, young fish or invertebrates are added to the adult population as they survive and mature. |
| Remotely Operated Vehicle (ROV) | A remote-controlled underwater robot used for deep-sea exploration and habitat studies. |
| Seamount Fisheries | Targeting fish and invertebrates that congregate around underwater mountains or ridges. |
| Seamount | An underwater mountain rising from the ocean floor that supports unique deep-sea habitats. |
| Side-Scan Sonar | Sonar technology is used to create images of the ocean floor and to identify habitats and fish aggregations. |
| Species Composition | The types and relative abundance of species in a particular area or habitat. |

| | |
|---|---|
| Species Distribution Modelling (SDM) | Computer-based predictive tools are used for understanding species distribution and habitat suitability. |
| Species Dominance | The abundance of a particular species relative to others within a habitat. |
| Species Richness | The total number of species present in a specific area or ecosystem. |
| Stock Assessment Models | Mathematical and statistical approaches for assessing fish stock health and dynamics for sustainable fisheries. |
| Standing Stock Biomass | The total weight of living organisms (or a species) present in a given area at a specific time. |
| Submersible Vehicles | Specialized manned or unmanned vessels used for deep-sea exploration and sampling. |
| Sustainable fisheries | The ability to maintain fish populations and marine ecosystems for future generations. |
| Swept Area | The area of the ocean floor covered by a trawl net during a fishing operation. |
| Tagging and Marking | Attaching tags to fish species to track their movements, behaviour, and population dynamics. |
| Trawl Net | A type of fishing net dragged through the water column or along the seabed to capture fish. |
| Trawling Impact | The effects of using trawl nets on the seafloor and associated habitats. |
| Upwelling | The process is where deep, nutrient-rich water rises to the surface, supporting productivity and rich fisheries. |
| Vertical Migration | The daily movement of organisms (such as mesopelagic fishes) between deep and shallow waters. |
| Vulnerable Marine Ecosystems (VMEs) | Sensitive deep-sea habitats (e.g., corals and sponges) are highly susceptible to damage from human activities and require special protection. |
| Vessel Monitoring System (VMS) | A satellite-based monitoring tool for tracking the movements and fishing activity of vessels. |
| Zooplankton | Tiny animal organisms drifting in the water column serve as a crucial food source for many fish species. |

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# कार्यकारी सारांश

राष्ट्रीय रिपोर्ट: भारत के ईईज़ेड (विशिष्ट आर्थिक क्षेत्र) के गहरे समुद्री एवं दूरस्थ जल मत्स्य संसाधन। यह राष्ट्रीय रिपोर्ट भारत के ईईज़ेड के अंतर्गत गहरे समुद्री एवं दूरस्थ जल मत्स्य संसाधनों का एक व्यापक, वैज्ञानिक एवं तथ्य-आधारित आकलन प्रस्तुत करती है। यह रिपोर्ट समुद्री जीवित संसाधन एवं पारिस्थितिकी केंद्र (CMLRE) द्वारा मत्स्य एवं समुद्रवैज्ञानिक अनुसंधान पोत सागर संपदा के माध्यम से चार दशकों से अधिक समय में किए गए बहुविषयक अनुसंधानों पर आधारित है। रिपोर्ट भारत की विशिष्ट आर्थिक क्षेत्र (EEZ) तथा राष्ट्रीय अधिकार क्षेत्र से बाहर के क्षेत्रों (ABNJ) में समुद्री जीवित संसाधनों (MLR) के सतत उपयोग, संरक्षण एवं प्रबंधन हेतु एक रणनीतिक रूपरेखा प्रदान करती है, जो राष्ट्रीय ब्लू इकोनॉमी प्राथमिकताओं तथा SDG 14 सहित वैश्विक प्रतिबद्धताओं के अनुरूप है।

भारत का समुद्री मत्स्य क्षेत्र सामाजिक एवं आर्थिक दृष्टि से अत्यंत महत्वपूर्ण है, जो लगभग 16–28 मिलियन लोगों की आजीविका का आधार है, राष्ट्रीय खाद्य सुरक्षा में योगदान देता है तथा देश के सकल घरेलू उत्पाद (GDP) में लगभग 1.1% का योगदान करता है। यद्यपि कुल मत्स्य उत्पादन 2023–24 में 18.4 मिलियन टन तक पहुँच चुका है, समुद्री कैप्चर मत्स्य उत्पादन पिछले कई वर्षों से 3.5–4 मिलियन टन प्रतिवर्ष के स्तर पर स्थिर है। तटीय संसाधनों का 50% से अधिक भाग पूर्णतः या अत्यधिक दोहन की स्थिति में पहुँच चुका है, जिससे मेसोपेलैजिक एवं गहरे समुद्री क्षेत्रों जैसे अल्प-उपयोगित संसाधनों की ओर विस्तार की आवश्यकता स्पष्ट होती है।

CMLRE, अपने Marine Living Resources Programme (MLRP) तथा मत्स्य एवं समुद्रवैज्ञानिक अनुसंधान पोत सागर संपदा' के माध्यम से, भारत के EEZ एवं ABNJ क्षेत्रों में समुद्री जैवविविधता, पारिस्थितिकीय प्रक्रियाओं एवं मत्स्य संसाधनों के वैज्ञानिक अध्ययन में महत्वपूर्ण भूमिका निभाता है। इसके अंतर्गत गहरे समुद्री पारिस्थितिक तंत्रों, मेसोपेलैजिक संसाधनों तथा हाइपोक्सिया एवं जलवायु परिवर्तन जैसे उभरते पर्यावरणीय खतरों पर विशेष ध्यान दिया गया है। संसाधन अन्वेषण, ध्वनिक एवं ट्रॉल आधारित आकलन, जैवविविधता दस्तावेजीकरण तथा पारिस्थितिकीय मॉडलिंग जैसे दीर्घकालिक अध्ययनों से गहरे समुद्री आवासों एवं संसाधनों के संबंध में महत्वपूर्ण जानकारी प्राप्त हुई है।

रिपोर्ट में दूरस्थ जल के मेसोपेलैजिक क्षेत्र को जैविक उत्पादकता के एक विशाल एवं अप्रयुक्त भंडार के रूप में चिन्हित किया गया है। यह क्षेत्र, जिसे Deep Scattering Layer (DSL) कहा जाता है, मुख्यतः मायक्टोफिड (लैंटर्न फिश) जैसी प्रजातियों से समृद्ध है, जो समुद्री खाद्य जाल एवं कार्बन चक्र में महत्वपूर्ण भूमिका निभाती हैं। पूर्वी अरब सागर में लगभग 15.8 मिलियन टन बायोमास के अनुमान इस क्षेत्र की अपार संभावनाओं को दर्शाते हैं। तथापि, इन संसाधनों के व्यावसायिक दोहन हेतु वैज्ञानिक, सावधानीपूर्ण एवं नवाचार-आधारित दृष्टिकोण आवश्यक है।

भारत के EEZ में गहरे समुद्री डिमर्सल मत्स्य संसाधन भी महत्वपूर्ण संभावनाएँ रखते हैं। हालांकि पारंपरिक मत्स्य गतिविधियाँ मुख्यतः तटीय क्षेत्रों तक सीमित रही हैं, अपतटीय गहरे समुद्री क्षेत्र अभी भी अपेक्षाकृत कम अन्वेषित हैं। वर्तमान आकलनों से यह स्पष्ट होता है कि पारंपरिक डिमर्सल संसाधनों के अतिरिक्त मेसोपेलैजिक मछलियाँ, महासागरीय स्क्विड एवं जेलीफिश जैसे गैर-पारंपरिक संसाधनों में भी पर्याप्त संभावनाएँ मौजूद हैं। गहरे समुद्री प्रजातियाँ सामान्यतः दीर्घायु एवं धीमी वृद्धि वाली होती हैं, इसलिए इनके अत्यधिक दोहन से पुनर्प्राप्ति अत्यंत कठिन हो सकती है।

रिपोर्ट में यह भी उल्लेखित है कि दक्षिण-पश्चिमी तट, अरब सागर एवं अंडमान क्षेत्र के कुछ भागों में डिमर्सल संसाधनों की उत्पादकता अपेक्षाकृत अधिक है, जबकि अन्य क्षेत्र कम उत्पादक हैं। गहरे समुद्री झींगा मत्स्य पालन अपेक्षाकृत विकसित है, परंतु अधिकांश अन्य संसाधन अभी भी तकनीकी, विपणन एवं ज्ञान संबंधी सीमाओं के कारण अल्प-उपयोगित बने हुए हैं। अतः इन संवेदनशील पारिस्थितिक तंत्रों के संरक्षण हेतु कठोर विनियमन, उन्नत निगरानी प्रणाली एवं पारिस्थितिकी-आधारित प्रबंधन दृष्टिकोण आवश्यक हैं।

दूरस्थ जल मत्स्य क्षेत्र में भारत की ट्यूना मत्स्य पालन में बढ़ती उपस्थिति देखी गई है, किंतु येलोफिन ट्यूना एवं बिलफिश जैसी प्रजातियों के अत्यधिक दोहन के संकेत भी प्राप्त हुए हैं। महासागरीय स्क्विड एक संभावनाशील वैकल्पिक संसाधन के रूप में उभरे हैं, जबकि शार्क प्रजातियों के संरक्षण हेतु तत्काल उपायों की आवश्यकता है। रिपोर्ट में त्रिवेंद्रम टेरेस, आंग्रिया बैंक, लक्षद्वीप तथा अंडमान एवं निकोबार क्षेत्रों को जैवविविधता हॉटस्पॉट के रूप में चिह्नित किया गया है, जिन्हें

Marine Protected Areas (MPAs) एवं अन्य संरक्षण उपायों के माध्यम से सुरक्षित किया जाना आवश्यक है।

रिपोर्ट में सतत विकास हेतु प्रमुख चुनौतियों की भी पहचान की गई है, जिनमें गहरे समुद्री अनुसंधान अवसंरचना की कमी, स्टॉक आकलन संबंधी डेटा अंतराल, तकनीकी सीमाएँ, उच्च बायकैच तथा 25–30% तक की पोस्ट-हार्वेस्ट हानि शामिल हैं। इसके अतिरिक्त, जलवायु परिवर्तन, महासागरीय ऊष्मीकरण, ऑक्सीजन न्यूनता क्षेत्र (OMZ) का विस्तार एवं समुद्री परिसंचरण में परिवर्तन जैसी समस्याएँ मत्स्य संसाधनों की अनिश्चितता को और बढ़ाती हैं।

इन चुनौतियों से निपटने हेतु रिपोर्ट में निम्नलिखित सिफारिशें प्रस्तुत की गई हैं:

a) उन्नत मत्स्य महासागरीय अनुसंधान पोत, ध्वनिक सर्वेक्षण, पारिस्थितिकी मॉडलिंग तथा eDNA, कृत्रिम बुद्धिमत्ता एवं मशीन लर्निंग जैसे आधुनिक उपकरणों के माध्यम से वैज्ञानिक क्षमता को सुदृढ़ करना।

b) गहरे समुद्री एवं मेसोपेलैजिक संसाधनों हेतु Ecosystem-Based Fisheries Management (EBFM) एवं सावधानीपूर्ण दोहन रणनीतियों को अपनाना।

c) निगरानी, नियंत्रण एवं सर्विलांस (MCS) प्रणाली तथा स्टॉक आकलन ढाँचे को मजबूत करना।

d) पोस्ट-हार्वेस्ट हानि कम करने हेतु कोल्ड-चेन एवं मूल्य संवर्धन अवसंरचना का विकास करना।

e) मत्स्य समुदायों की क्षमता निर्माण एवं समावेशी शासन को बढ़ावा देना।

f) प्रवासी एवं साझा संसाधनों के वैज्ञानिक प्रबंधन हेतु क्षेत्रीय एवं अंतरराष्ट्रीय सहयोग को सुदृढ़ करना।

g) पारिस्थितिकीय दृष्टि से संवेदनशील क्षेत्रों एवं Marine Protected Areas (MPAs) के संरक्षण उपायों को आगे बढ़ाना।

h) समुद्री संसाधनों के संरक्षण एवं सतत उपयोग के एकीकरण हेतु समुद्री स्थानिक नियोजन (Marine Spatial Planning - MSP) को सुदृढ़ बनाना, जिससे पारिस्थितिकी तंत्र की सहनशीलता सुनिश्चित करते हुए विज्ञान-आधारित, बहु-क्षेत्रीय महासागरीय शासन को सक्षम बनाया जा सके।

अंततः, यह रिपोर्ट स्पष्ट करती है कि भारत के मत्स्य क्षेत्र की भविष्य की वृद्धि तटीय जल क्षेत्रों से आगे गहरे समुद्र एवं दूरस्थ जल क्षेत्रों में निहित है। वैज्ञानिक नवाचार, उत्तरदायी संसाधन उपयोग एवं पारिस्थितिकी संरक्षण के संतुलित समन्वय के माध्यम से ही इन संसाधनों की दीर्घकालिक सततता एवं समुद्री पारिस्थितिक तंत्रों की स्थिरता सुनिश्चित की जा सकती है।

# Executive Summary

The *National Report on Deep-Sea and Distant-Water Fishery Resources of Indian EEZ* provides a comprehensive, science-based assessment of India's underexploited marine resources, drawing on over four decades of multidisciplinary research by the Centre for Marine Living Resources and Ecology (CMLRE) using the FORV *Sagar Sampada*. The report establishes a strategic framework for the sustainable utilization, conservation, and governance of marine living resources (MLR) within India's Exclusive Economic Zone (EEZ) including the deep-sea and distant-waters, aligned with national Blue Economy priorities and global commitments, including SDG 14.

India's marine fisheries sector is of critical socio-economic importance, supporting 16-28 million livelihoods, contributing to national food security, and accounting for approximately 1.1% of GDP. While total fish production has reached 18.4 million tonnes (2023-24), marine capture fisheries have plateaued at 3.5 to 4 million tonnes annually, with more than 50% of coastal resources already fully or overexploited. This underscores the urgent need to diversify into underutilized resources, particularly in the mesopelagic and deep-sea domains.

CMLRE, through its multidisciplinary projects under Marine Living Resources program (MLRP) and the research vessel FORV *Sagar Sampada*, plays a central role in advancing scientific understanding of marine biodiversity, ecosystem processes, and fishery resources within India's EEZ and Areas Beyond National Jurisdiction (ABNJ), with a particular focus on deep-sea ecosystems. Its long-term, integrated efforts spanning resource exploration, acoustic and trawl-based assessments, biodiversity documentation, and ecosystem modelling have generated critical knowledge on deep-sea habitats, mesopelagic resources, and emerging environmental challenges such as hypoxia and climate driven changes. Key initiatives, including the Deep-Sea and Distant-Water Fishery (DSDWF) programme, have identified new resource potentials, biodiversity hotspots, and ecologically sensitive areas, while supporting sustainable fisheries development and conservation planning. By leveraging advanced technologies, fostering national and international collaborations, and aligning with global frameworks such as CCAMLR, OBIS, and the BBNJ agreement, CMLRE provides a robust scientific foundation for evidence-based policy, contributing to India's blue economy, food security, and long-term ocean sustainability.

The report identifies the distant-water mesopelagic realm as a significant reservoir of untapped biological productivity. This domain, characterized by the Deep Scattering Layer (DSL), comprises diverse mesopelagic organisms dominated by myctophids (lanternfishes), which play a critical role in oceanic food webs and carbon cycling through diel vertical migration. Biomass estimates (15.8 million tonnes in the eastern Arabian Sea) indicate substantial resource potential, positioning mesopelagic fisheries as a strategic frontier for future expansion. However, given the ecological sensitivity of these systems, coupled with challenges related to rapid post-harvest degradation and existing technological limitations, any commercial exploitation must be guided by precautionary, science-based, and innovation-driven approaches.

India's deep-sea demersal fisheries within the EEZ represent a significant yet underutilized resource with strong potential to support food security, economic growth, and the blue economy. While marine fisheries have traditionally focused on coastal waters, deeper offshore regions remain relatively unexplored despite longstanding policy support and research efforts. CMLRE and the MLR, utilizing FORV *Sagar Sampada*, have generated valuable insights into deep-sea

biodiversity, distribution, and stock potential. Current assessments indicate modest conventional demersal resources alongside substantial non-conventional resources such as mesopelagic fishes, oceanic squids, and jellyfish, highlighting important opportunities for future development. Importantly, deep-sea demersal species are generally long-lived and slow-growing, making stock recovery particularly challenging once depleted, with potential consequences for ecosystem balance and overall benthic health.

In the demersal realm, resource distribution is spatially uneven, with higher productivity along the southwest coast and parts of the Arabian Sea and Andaman waters, while other regions remain less productive. Although deep-sea shrimp fisheries are relatively more developed, most resources, including diverse finfish and non-conventional species, remain underexploited due to technological, market, and knowledge constraints. Given the ecological sensitivity and vulnerability of deep-sea ecosystems, there is a critical need for stringent regulations, advanced monitoring systems, and ecosystem-based management approaches. Strengthening stock assessments, investing in technology, and ensuring continuous ecosystem monitoring are essential to evaluate impacts of climate change and fishing pressure, and to support sustainable utilization while safeguarding long-term ocean health.

In the distant-water domain, India has a growing presence in tuna fisheries; however, key stocks such as yellowfin tuna and billfishes show signs of overexploitation. Oceanic squids emerge as a promising alternative resource, while shark populations require urgent conservation measures due to declining trends. These findings highlight the need for strengthened regional cooperation and compliance with international fisheries governance frameworks.

The report also discusses the ecologically significant areas, including the Terrace of Trivandrum, Angria Bank, Lakshadweep, and the Andaman & Nicobar region, as biodiversity hotspots that support critical life-history functions. These areas are highly vulnerable to anthropogenic pressures and warrant prioritization for conservation through Marine Protected Areas (MPAs) and spatial management measures.

Key challenges to sustainable development in the sector include inadequate deep-sea and distant -water research infrastructure, data gaps in stock assessment, technological limitations in harvesting and processing, high bycatch, and substantial post-harvest losses (25-30%). Climate change impacts, such as ocean warming, altered circulation and production pattern, deoxygenation, and expansion of oxygen minimum zones, further exacerbate ecosystem vulnerability and fisheries uncertainty.

To address these challenges, the report recommends a multi-pronged policy approach;

a) Strengthening scientific capacity through advanced fisheries oceanographic research vessels, enhanced acoustic surveys, ecosystem modelling, and integration of emerging tools such as eDNA, artificial intelligence, and machine learning.
b) Adopting ecosystem-based fisheries management (EBFM) and precautionary harvest strategies for deep-sea and mesopelagic resources.
c) Expanding monitoring, control, and surveillance (MCS) systems and improving stock assessment frameworks.
d) Promoting value addition and infrastructure development, particularly cold-chain systems, to reduce post-harvest losses.
e) Enhancing fisher capacity-building and inclusive governance, ensuring equitable participation and livelihood security.
f) Strengthening regional and international cooperation for strengthening the scientific capacity and the management of highly migratory and shared stocks.
g) Advancing conservation measures, including the designation of ecologically sensitive regions and Marine Protected Areas (MPAs).
h) Strengthening Marine Spatial Planning (MSP) to integrate conservation and sustainable use of marine resources, enabling science-based, multi-sectoral ocean governance ensuring ecosystem resilience.

In conclusion, the report highlights that India's future fisheries growth lies beyond coastal waters. A balanced strategy that integrates scientific innovation, responsible exploitation, and ecosystem conservation will be essential to unlock the potential of deep-sea and distant-water resources while ensuring long-term sustainability and resilience of marine ecosystems.

# 1 Overview

The *National Report on Deep-Sea and Distant-Water Fishery Resources of Indian EEZ*, hereafter referred to as the National Report, summarizes the status of research work carried out by the Centre for Marine Living Resources and Ecology (CMLRE), Kochi, an attached office of the Ministry of Earth Sciences (MoES), Government of India. It summarizes the results of deep-sea exploratory surveys conducted onboard India's only Fishery Oceanographic Research Vessel (FORV) *Sagar Sampada*, owned by MoES and operated by CMLRE. Data and information on deep-sea demersal fishery resources, distant-water fishery resources, mesopelagic resources, and biodiversity hotspots in the Indian EEZ were gathered from more than 220 cruises of the vessel over the years (1996 to 2025).

## 1.1. Background

India, with a coastline stretching 11,098.81 km and an extensive Exclusive Economic Zone (EEZ) of 2.37 million square km, is strategically positioned to harness the vast potential of its marine fisheries, owing to its proximity to the highly productive waters of the Indian Ocean (Fig. 1.1). In addition to coastal and shelf fisheries, India's geographic position also provides significant scope for deep-sea and distant-water fisheries (Sinha et al., 2017), including operations in offshore and oceanic waters within the EEZ and in adjacent high seas, subject to appropriate regulatory frameworks. India has achieved a record in fish production over the past

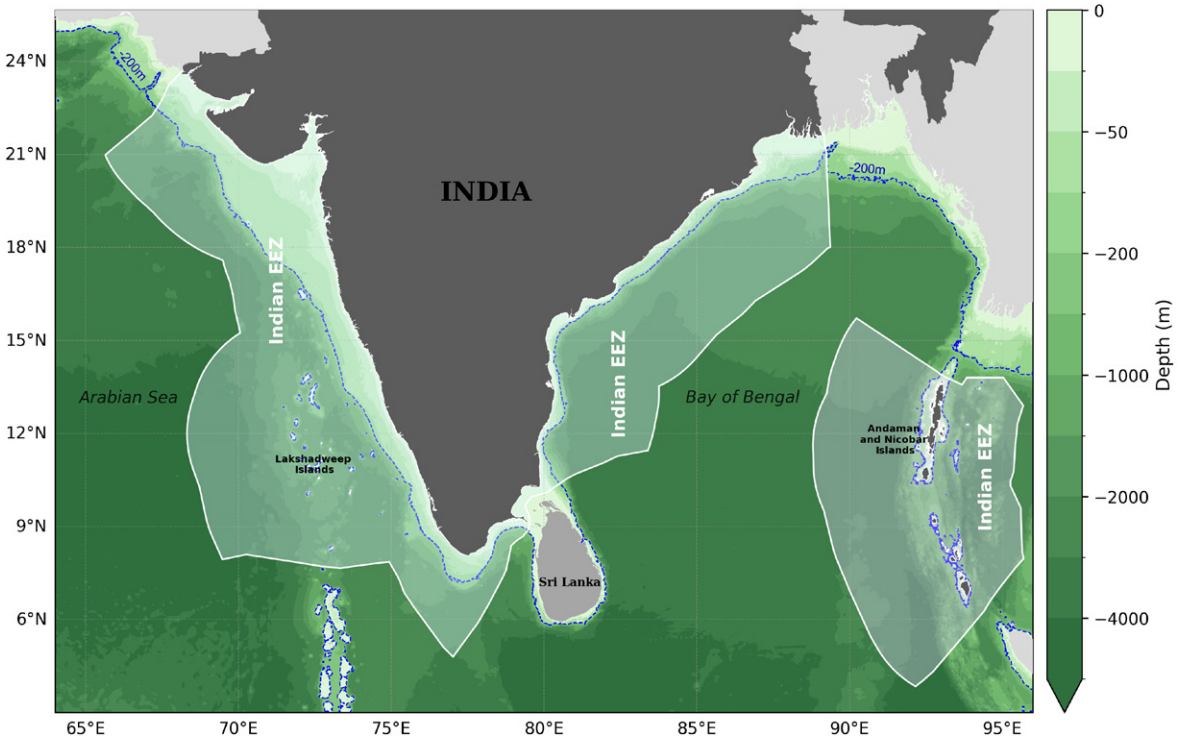



Fig. 1.1: Map showing the Indian EEZ

75 years, and the sector has gradually transformed into a commercial enterprise while maintaining its traditional, small-scale character. The combined annual fish production from capture and culture fisheries of India has increased from 9.579 mt (2013-14) to an all-time record of 18.4 mt (2023-24), *i.e.,* an increase of 8.82 mt (DoF, 2025) (Fig. 1.2).

India ranks second globally in total fish production (14.7 mt in 2020-21) and second in aquaculture. Marine capture fishery consistently contributes around 3.5-4 mt annually, against an estimated potential yield of 5.31 mt. In 2023, marine fish landings reached 3 mt, a marginal increase from the previous year. The Indian marine fishery sector supports 16-28 million livelihoods, including 4.9 million fishers (DoF, 2022). India's marine fishing fleet, as documented by the ReALCRaft national registry (2026), comprises approximately 2.35 lakh registered vessels. This fleet comprises roughly 64,302 mechanized vessels, which account for a disproportionately high share of total landings, with an average catch of 2,959 kg/trip. The traditional sector remains numerically dominant, with over 1.32 lakh motorized boats (averaging 174 kg/trip) and approximately 40,461-54,600 non-motorized crafts (averaging 41 kg/trip). These assets form the backbone of a sector that contributes 3.4-3.6 mt annually toward a potential of 5.31 mt, supporting the livelihoods of nearly 28 million people across the value chain (CMFRI, 2025).

The sector contributes 1.1% to national GDP and 7.26% to agricultural GVA (Gross Value Added). Around 70% of India's marine fishery potential is exploited, with 30% of stocks overfished. However, a 2022 assessment found that 91% of the 135 stocks are sustainably exploited, 8.2% overfished, and 0.7% recovering (Rajan Kumar et al., 2024). Many small-scale fishers face resource, credit, and infrastructure constraints. Overfishing, juvenile bycatch, and regulatory fragmentation persist. Climate change and plastic pollution pose new threats to biodiversity and fish productivity. In this context, deep-sea and distant-water fisheries represent important avenues to reduce fishing pressure on coastal stocks while diversifying and enhancing national fish production, provided that such expansion is grounded in robust science and precautionary management. To meet these demands, the Ministry of Earth Sciences (MoES), through the CMLRE, initiated deep-sea and distant-water fishery research in 1998. These efforts are being continued with appropriate upscaling in area coverage, grid resolution, and niche prioritization. The demersal fishery resources beyond the continental margin of the Indian coastline, including the Andaman and Nicobar Islands, the mesopelagic resources (200-1000 m column) in the oceanic waters of the eastern Arabian Sea (EAS), and the krill fishery in the Southern Ocean are explored in detail to understand the potential of the huge unexplored resources.

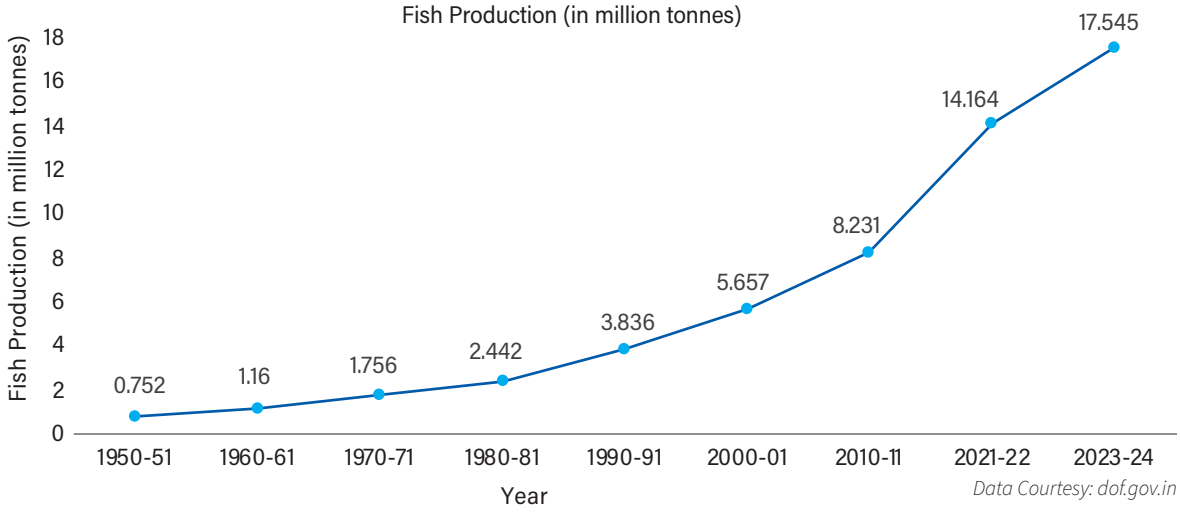



Fig. 1.2: Historical growth in India's fish production is notable, increasing from 0.1 mt in 1950-1951 to 18.4 mt, an 81% increase by 2023-2024.

The deep-sea, defined as depths beyond 200 m, is one of the least explored and ecologically sensitive regions of the world's oceans. This vast and enigmatic realm is characterized by extreme conditions, such as low light levels, high pressures, and nutrient-limited environments, which support a highly specialized and diverse array of marine life (Rogers, 2015). Deep-sea fisheries, which target finfish, crustaceans, and cephalopods, offer opportunities for economic growth, food security, and scientific advancement (FAO, 2008). Distant-water fisheries, operating in offshore and high-seas areas, similarly offer scope to supplement domestic supplies and strengthen India's role in regional and global seafood trade, but require careful governance to avoid overexploitation. Developing a sustainable deep-sea and distant-water fisheries sector aligns with India's strategic priorities, including optimizing the utilization of marine resources, fostering technological innovation, and strengthening the blue economy (Kumar et al., 2024).

## 1.2.Goal and application of the National Report

This report primarily focuses on fisheries beyond 200 m depth and in distant-waters, and also serves as a foundational document aimed at:

1. Evaluating the deep-sea and distant-water resources: Profiling the resources within India's EEZ, adjacent high seas, and distant-waters.

2. Assessing the current exploitation status: Evaluating the status of resource utilization and identifying economically viable species and fishing grounds for both deep-sea and distant-water fisheries.

3. Addressing challenges: Highlighting issues such as overexploitation, sustainability, bycatch, habitat degradation and technological challenges on resource exploitation.

4. Showcasing research contributions: Documenting the results of exploratory surveys of FORV *Sagar Sampada)* in assessing the biodiversity and deep-sea fisheries potential in the seas around India.

## 1.3.India's endeavour in deep-sea and distant-water fisheries research

India's journey into deep-sea fisheries exploration began in the late 20th century, spearheaded by the Fishery Survey of India (FSI), which was established in 1946. The FSI led efforts to assess fishery resources beyond the continental shelf, focusing on species composition, distribution, and biomass in deeper waters. In parallel, FSI also undertook exploratory distant-water surveys in offshore and oceanic areas to understand the potential of tuna, oceanic squids, and other highly migratory and mesopelagic resources (Sinha et al., 2017). A significant milestone was achieved in 1984 with the commissioning of the FORV *Sagar Sampada,* which was erstwhile managed by the Department of Ocean Development (DOD) to support research on Marine Living Resources in Indian waters. This institution laid the foundation for scientific surveys and the sustainable utilization of deep-sea resources. The research vessel was managed initially by the DOD's *Sagar Sampada* Cell and subsequently by the CMLRE. The vessel is 71.5 m in length, has an endurance of 45 days, and is equipped with state-of-the-art facilities for multidisciplinary oceanographic and fishery research. The exploratory surveys conducted by FORV *Sagar Sampada* generated baseline data on deep-sea ecosystems, including benthic fauna, demersal fishery, and mesopelagic communities. Fisheries data generated by various cruises provided quantitative and qualitative insights into the biology, distribution, and biomass of species. Additionally, potential estimates for assessing the country's deep-sea fisheries and identifying untapped resources are available (https://www.cmlre.gov.in).

## 1.4.Present fish production levels

### 1.4.1.Global fish production

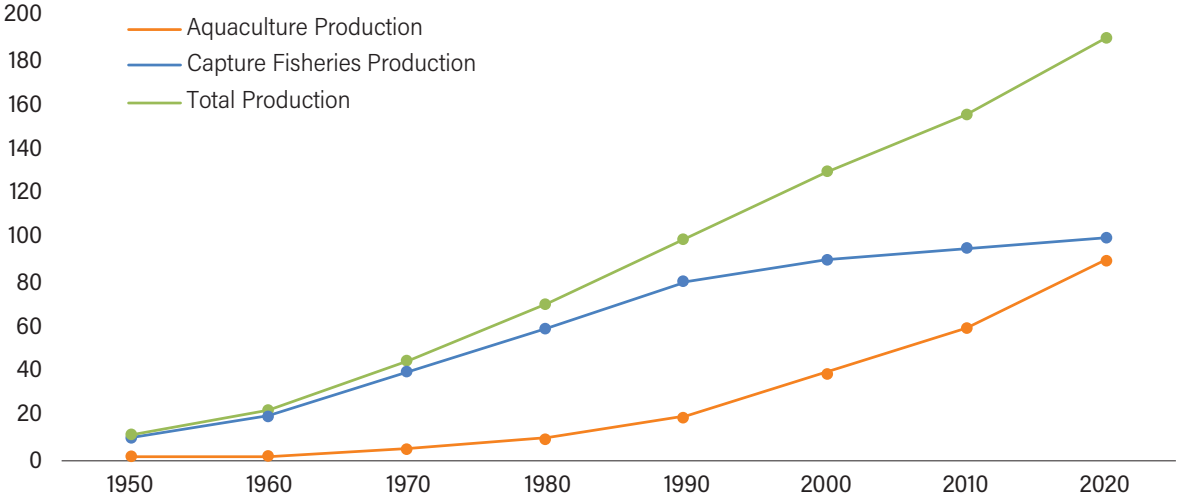
Global fisheries and aquaculture production reached 223.2 mt, of which 185.4 mt were aquatic animals

(Fig. 1.3). Asia dominated with 70% of aquatic animal production, followed by Europe and Latin America (9% each), Africa (7%), North America (3%), and Oceania (1%). China remained the top fish producer, contributing 36%, followed by India (8%), Indonesia (7%), Vietnam (5%), and Peru (3%). The total first-sale value of global fisheries and aquaculture was USD 472 billion, with fisheries valued at USD 159 billion (FAO, 2024). Global consumption of aquatic animal foods reached 162.5 mt in 2021, with per capita consumption rising from 9.1 kg in 1961 to 20.7 kg in 2022. Aquatic foods now account for 15% of global animal protein, playing a crucial role in supplying omega-3 fatty acids, essential minerals, and vitamins. By 2032, global per capita fish consumption is projected to increase to 21.3 kg, driven by factors such as urbanisation, changing dietary preferences, and enhanced distribution networks (FAO, 2024).

## 1.4.2.India's fish production levels

In India, fish production grew by 11.5% from 2005 to 2024, reaching 14.164 mmt. Domestic fish consumption also increased by 12%, with 83.65% of production directed toward human consumption. Per capita annual fish consumption surged from 4.9 kg to 8.89 kg (2005-2021), marking an 81.43% rise. The proportion of the population consuming fish weekly increased significantly, rising from 66% to 72.1%. Urban areas had a higher proportion of weekly fish consumers (42.7%) than rural areas (39.8%). In recent years, however, rural fish consumption has been growing more rapidly. Among Indian states, Tripura leads with 99.35% of its population consuming fish, followed by Tamil Nadu, Kerala, and Goa, which report more than 90% fish consumption, while Haryana has the lowest rate (20.55%). Kerala has the highest percentage of daily fish consumers (53.5%), while Assam and Tripura lead in weekly consumption (69% each) (Padiyar et al., 2024).

Fish consumption has increased across all income groups, with the highest growth observed in lower-income groups. In states with lower fish consumption, gender disparities exist, with men generally consuming more fish than women. By 2047-2048, per capita fish consumption is expected to reach 41.29 kg if the current growth rate of 4.05% continues (https://aquaasiapac.com). However, regional and socio-economic disparities need to be addressed to fully capitalize on the benefits of aquatic foods (Padiyar et al., 2024). To sustain current per capita consumption levels, global fish supply must grow from 142 mt in 2021 to 180 mt by 2030 (FAO, 2022). Domestic fish demand could rise to 68.1 mmt by this time, increasing the requirement of an additional 5 mmt by 2029-2030, 10.5 mmt by 2039-2040, and 14.6 mmt by 2047-2048, highlighting the growing role of fisheries and aquaculture in global food security, posing significant challenges in meeting future demands (Padiyar et al., 2024) (Fig. 1.4).




*Data Courtesy: FAO 2024*

Fig. 1.3: Global fisheries and aquaculture production

## 1.5. Supply chain considerations

The marine fisheries supply chain in India faces numerous challenges that significantly impact its efficiency and sustainability. These challenges include post-harvest losses, which are a major concern and are estimated at 25-30%, due to inadequate handling, storage, and transportation facilities, resulting in economic losses for fishers and generating waste. Limited access to technology for fishers often means a lack of access to modern fishing gear, navigation equipment, and communication devices, which can improve safety and efficiency. Fishers often face challenges accessing markets and obtaining fair prices for their catch due to the presence of middlemen and limited market access. Price fluctuations can also impact their livelihoods. Lack of skilled labour in various aspects of the supply chain, from fishing to processing and marketing, can hinder efficiency and quality (Aswathy & Abdussamad, 2013; Mohamed, 2022; Salim & Anuja, 2022).

The Government of India is investing in the upgradation of fishing harbours and fish landing centres through two key initiatives: the Pradhan Mantri Matsya Sampada Yojana (PMMSY) and the Sagarmala Programme. This investment aims to provide modern infrastructure, including cold storage facilities, ice plants, and auction halls. Encouraging the formation of fish cooperatives can empower fishers, improve market access, and enhance their bargaining power. Fish Farmer Producer Organizations (FFPOs) are being promoted to strengthen the value chain and ensure equitable access to resources and markets (https://pib.gov.in). Training programs are being conducted to enhance the skills of fishers, processors, and other supply chain stakeholders. Promoting sustainable fishing practices, such as reducing bycatch and using selective fishing gear, can help conserve fish stocks (Sreedhar, 2022). Investing in cold chain infrastructure, including refrigerated transport and storage facilities, can help reduce post-harvest losses. By addressing these challenges and implementing effective solutions, India can improve the efficiency and sustainability of its marine fisheries supply chain, benefiting fishers, consumers, and the environment (Sanyal et al., 2023).

Fisheries play a critical role in socio-economic development, supporting over 28 million people in India. Leveraging the blue economy can help mitigate the impacts of climate change while fostering sustainable growth. Key government initiatives, such as the National Fisheries Policy of India (2020), the Neel Kranti Mission (2015-2020), PMMSY, the Sagarmala programme, and the Fisheries and Aquaculture Infrastructure Development Fund (FIDF), provide vital technical and financial support. Advanced systems in aquaculture and mariculture, such as Re-circulatory

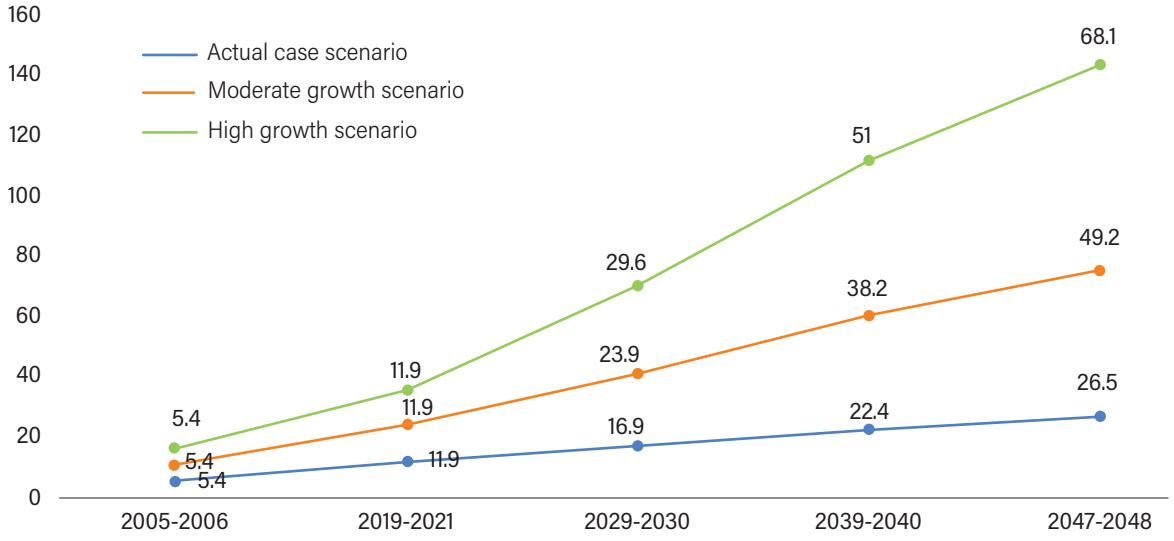



Fig. 1.4: The domestic fish consumption growth is computed based on the average growth rate of per capita fish consumption in India from 2005-2006 to 2019-2021 and the corresponding projected population for India by the UN (Padiyar et al., 2024).

Aquaculture System (RAS), biofloc technology, cage culture, paddy-cum-fish culture, and aquaponics, are highlighted as pathways to boost production sustainably (PwC, 2022; Gopalakrishnan et al., 2022).

The majority of fishery resources are harvested in coastal waters, with over 90% of the catch coming from depths of less than 50 m, resulting in increased fishing pressure on nearshore areas. This trend highlights the need to explore uncharted, high-potential regions, and many fishery managers advocate for expanding exploration into deeper waters and distant-water fishing grounds with enhanced capacity. However, while expectations for resource exploration remain high, implementing effective management strategies is crucial to ensure sustainable fishing practices. In India, deep-sea fishing has been an area of ongoing research, underpinned by the nation's commitment to strengthening fisheries research (Ranjith et al., 2021). Promoting community participation and integrating modern technologies are essential steps toward meeting future demands while balancing ecological conservation and economic growth. India's focus on its blue economy agenda, along with advancements in fisheries management and ecosystem conservation, positions the country as a global leader in sustainable fisheries, setting an example of responsible stewardship of marine resources, including those in the deep-sea and distant-water domains.

In this backdrop, the key objectives of this national report are:

- To comprehensively assess the current status of deep-sea and distant-water fisheries in India, with a focus on resource availability, species composition, and regional distribution within the Indian EEZ and its adjacent high seas.
- To identify critical knowledge gaps and research needs in the exploration, ecosystem understanding, and harnessing of India's deep-sea and distant-water fishery resources, particularly in the context of climate variability and technological limitations.
- To evaluate the key challenges associated with estimating the potential of deep-sea and distant-water fishery resources, including limitations in data, monitoring capabilities, and scientific methodologies.
- To recommend science-based, sustainable management and conservation strategies for deep-sea and distant-water fisheries, ensuring long-term ecological sustainability, livelihood security aligned with India's blue economy goals.

The report is organised into 8 sections to address the objectives outlined above. After providing a detailed overview in Section 1, Section 2 highlights the roles of CMLRE and FORV *Sagar Sampada* in strengthening India's deep-sea research knowledge base. Section 3 explains the current status and potential of the mesopelagic resources, and Section 4 outlines the current status of deep-sea demersal fishery resources, while Section 5 outlines the distant-water fishery resources. Section 6 is on biodiversity hotspots within Indian waters, followed by a compilation of challenges in Section 7, and the report concludes with a brief overview of the way forward in Section 8. Furthermore, the details about the study area, methodologies used for the surveys and biomass estimation (Annexure 1), the details about the research vessels of MoES and other national institutes involved in ocean research and advanced onboard infrastructure requirements for new FORVs (Annexure 2), the diversity indices of the mesopelagic and deep-sea resources (Annexures 3 & 4), checklists of species (Annexure 5a & 5b) and other scientific information are compiled in annexures.

# 2 Role of CMLRE and FORV *Sagar Sampada* in Deep-Sea Fishery Assessments

The mandate of CMLRE inter-alia is to focus on marine biodiversity, species distribution, and ecosystem processes in the Indian EEZ and Area Beyond National Jurisdiction (ABNJ) with emphasis on the largely less understood deep-sea ecosystems. This section examines the pivotal role of CMLRE and its flagship vessel, the FORV *Sagar Sampada*, in addressing national challenges and expanding knowledge of marine ecosystems, particularly deep-sea resources. Deep-sea ecosystems are characterized by their unique biodiversity, intricate ecological interactions, and immense resource potential, offering opportunities while posing challenges to scientific exploration and conservation efforts. CMLRE's strategic focus on these habitats has enabled the organization to generate critical insights into their structure, function, and resilience. Advanced research methodologies and state-of-the-art tools have been employed to address key scientific and operational questions, supporting the development of policies for exploring new resources, sustainable management, and conservation of resources and marine ecosystems.

## 2.1. FORV *Sagar Sampada*: A platform for Deep-sea ecological research

Commissioned in 1984, the FORV *Sagar Sampada* is a key facility for CMLRE's research activities (Fig. 2.1a &b). She is capable of conducting trawling operations up to and marginally beyond 1,000 m,




Fig. 2.1a: Archival image of FORV *Sagar Sampada*.




Fig. 2.1b: Present image of FORV *Sagar Sampada*.

allowing researchers to explore the rich marine biodiversity and deep-sea fisheries within India's EEZ and even beyond its borders. The vessel is equipped with cutting-edge fishery acoustic systems for precise underwater assessments, deep-sea sampling instruments for collecting samples from the ocean floor, and advanced analytical laboratories for detailed examinations of marine specimens. Additionally, she has sophisticated equipment that ensures accurate collection of atmospheric data, making her a truly versatile mobile research platform. Researchers onboard the FORV have conducted comprehensive trawl surveys, precisely collecting data crucial to understanding the distribution patterns and biomass of deep-sea and distant-water resources.

In response to the growing demand for fish and to alleviate the pressure on inshore fisheries, a multi-institutional project on "Mapping of Deep-Sea and Distant-Water Fishery Resources (DSDWF)" was initiated by the CMLRE in 1998. This project aimed to bridge the knowledge gap on deep-sea fishery resources, increasingly recognized as a vital component of India's blue economy. With an increasing human population and escalating demand for fish, exploring deep-sea and distant-water fisheries has become crucial. The DSDWF project prioritizes the identification, assessment, and sustainable harnessing of these resources, directly contributing to national food security, employment generation, and economic growth. Furthermore, the DSDWF project has made significant progress in identifying new trawling grounds in the Indian continental margins, including the Andaman and Nicobar Islands. Apart from this, particular attention was given to the early life stages of tuna, with a focus on the abundance and spatial distribution of eggs and larvae near reef systems as part of the Tuna Fishery Forecast System (TUFFS). The waters around Lakshadweep have been identified as important tuna nurseries, underscoring the need for targeted conservation measures in these regions.

Extensive surveys conducted in the deep and distant-waters of India have revealed a wealth of untapped fishery resources. These include economically valuable demersal stocks, mesopelagic fishes such as myctophids, and high-demand species of deep-sea shrimps and lobsters. A key objective of the project was to generate detailed, species-specific data on the availability and population dynamics of these resources. This included studies on species-specific growth parameters, spawning periodicity, and stock assessments, all of which are indispensable for formulating sustainable management strategies. Additionally, the project emphasized providing scientific advice on harvest and post-harvest technology, ensuring that fishing methods minimize ecological impacts while maximizing socio-economic benefits.

A detailed taxonomic and distributional account of deep-sea fishes specifically along the southwest coast of India was reported, based on collections made through systematic exploratory surveys by FORV *Sagar Sampada* under the Marine Living Resources Programme (MLRP). 152 deep-sea fish species, 123 genera, 70 families and 24 orders, based on specimens collected from depths of 200 m and above (Venu, 2009). Further, the taxonomy, diversity, distribution patterns, and biology of selected deep-sea demersal fishes were examined for the Indian continental margin, including the Andaman and Nicobar Islands (Hashim, 2012). The attempt reports 188 species from 136 genera, 80 families and 25 orders..

## 2.2. Unique habitats in the Indian EEZ: Mega faunal diversity and ecological significance of the Terrace off Trivandrum (ToT)

FORV *Sagar Sampada* surveys have identified distinct biodiversity hotspots, notably the Terrace off Trivandrum (ToT), located at depths of approximately 200 to 1,500 meters in the southeastern Arabian Sea (SEAS) (Fig. 2.2). This region supports unique deep-sea biodiversity, characterized by exceptional above-average faunal size, many of which are of significant ecological importance, highlighting the region's role in sustaining deep-sea ecosystem dynamics. The ToT megafauna reportedly includes 148 species across 122 genera and 86 families, spanning five phyla, including numerous rare and endemic species (Jacob, 2017). Notable rediscoveries include *Fenestraja mamillidens, Coryphaenoides woodmasoni,* and *Zoroaster alfredi*, many of which have not been reported since the historic Royal India Marine Ship (RIMS) *Investigator* expeditions over a century ago. The survey also yielded ten new species records for Indian waters and rediscovered the rare *Coryphaenoides hextii*, previously known from only two global specimens. A striking feature of ToT is the presence of gigantic megafauna, such as the giant squid (*Architeuthis cf. dux*), the largest known pycnogonid (*Colossendeis colossea*), and large cods (*Lepidion inosimae*), signifying that it serves as a core area for deep-sea giants.

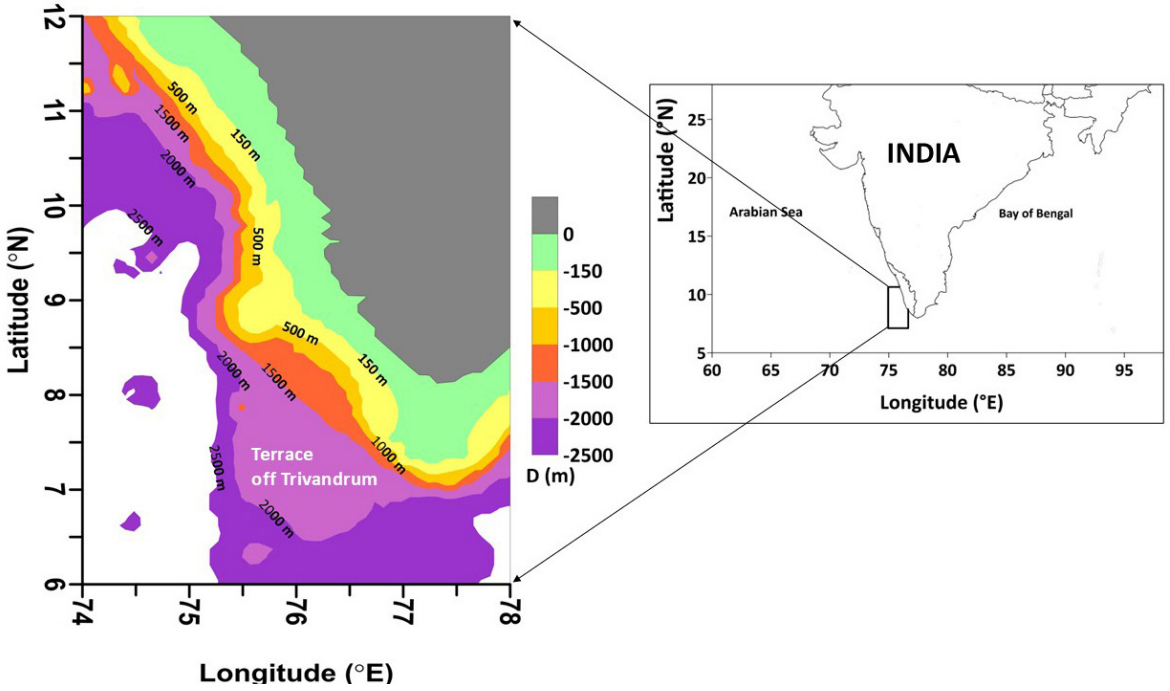



Fig. 2.2: Terrace off Trivandrum (ToT), a unique deep-sea habitat in the Indian EEZ.

## 2.3.*Dead zone* in the Bay of Bengal: Hidden threat to demersal fish ecosystems

A recent study, based on oceanographic and fisheries surveys conducted by FORV *Sagar Sampada*, has reported the occurrence of a seasonal *dead zone* on the north-western continental margin of the Bay of Bengal (BoB) (Hashim et al., 2025). This zone is characterized by severe hypoxia (low oxygen levels), leading to an almost complete absence of fish catches in the affected area. This *dead zone* is developed as a result of the existence of co-existing cold and warm core eddies, increased biological flux, water-column stratification, increased residence time, utilizing much of the oxygen in the bottom causing regional hypoxia (Fig. 2.3).

The implications are far-reaching, including the loss of biodiversity, the collapse of demersal fisheries, and alterations in trophic interactions. As one of the most productive and economically significant marine sectors of the Indian Ocean, the Bay of Bengal's vulnerability to dead zones poses a serious threat to regional food security and marine ecosystem health. Studies conducted by FORV *Sagar Sampada* highlight the urgent need for continuous monitoring, predictive modelling, and sustainable fisheries management to mitigate the long-term impacts of an expanding dead zone in the region.

## 2.4.Survey of the submerged Angria Bank on the west coast of India

Angria Bank is an underwater offshore plateau situated roughly 105 km west of the Sindhudurg district and approximately 120 km from the mainland coast of Maharashtra. A collaborative 10-day multidisciplinary expedition onboard FORV *Sagar Sampada* was conducted in December 2019 by the CMLRE, Wildlife Conservation Society-India (WCS-India), the Mangrove Foundation, and other partner institutions to evaluate the ecological importance of this relatively unexplored region. During this mission, expert marine biologists and a team of certified SCUBA divers, including those from CMLRE, conducted 66 dives across 12 selected reef sites, surveying a total area of 3,500 $m^2$. Comprehensive surveys revealed a vibrant, undisturbed coral reef ecosystem comprising 29 coral genera and 39 species, with no signs of bleaching or degradation (Fig. 2.4). The expedition documented 123 fish species across key functional

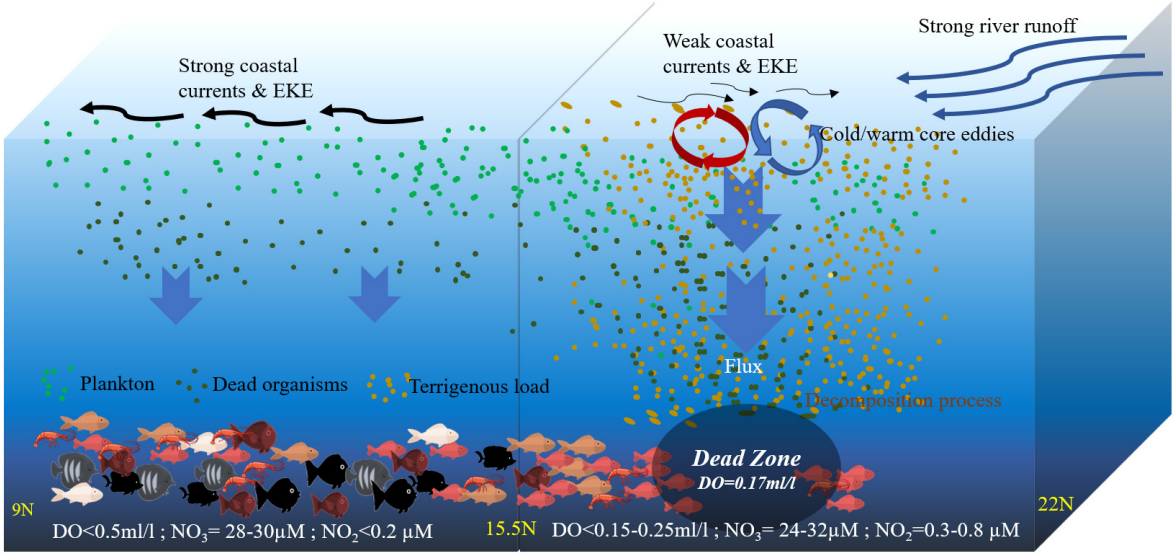



Fig. 2.3: The schematic representation on the *dead zone* in the western BoB

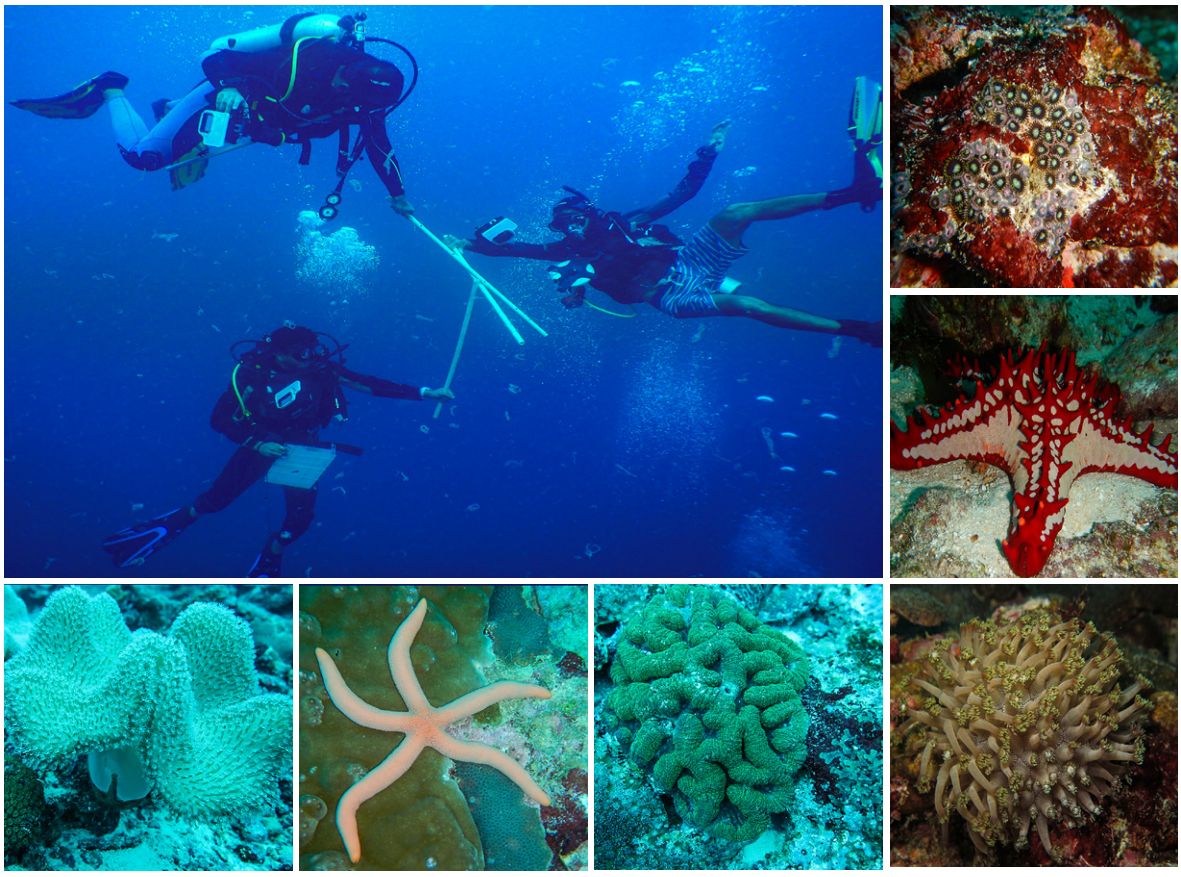


Fig. 2.4: CMLRE survey at Angria Bank showing underwater biodiversity and reef-associated fauna.

groups, along with 43 invertebrate species, including sea stars, nudibranchs, and comb jellies, indicating high biodiversity and a well-functioning trophic structure. SCUBA observations revealed the bank's topography, characterized by a shallow plateau at an average depth of 24 meters, with edges that drop steeply to depths of 70-300 m, creating structurally complex habitats. Notable predator activity and sightings of multiple dolphin species in surrounding waters suggest the area supports higher trophic levels, potentially sustained by upwelling zones along the bank's slopes.

## 2.5. Myctophid surveys

The FORV *Sagar Sampada* surveys conducted under DSDWF provided detailed assessments of mesopelagic resources, particularly Myctophids (Fig. 2.5) (see section 3), in the Indian EEZ and beyond. These studies enhance our understanding of their ecological roles as key intermediaries in marine food webs and highlight their potential for industrial and commercial use, such as in fishmeal production. Investigations on the Deep Scattering Layer (DSL) and associated mesopelagic fauna have revealed complex vertical migration patterns, community structure, and strong coupling with hydrographic features such as the Oxygen Minimum Zone (OMZ).



Fig. 2.5: Myctophids collected during mesopelagic trawling surveys onboard FORV *Sagar Sampada*.

## 2.6.First Indian Antarctic Krill Expedition (FIKEX)

Antarctic krill (*Euphausia superba*) is among the most ecologically important yet under-utilised marine living resources globally. As a keystone species in the Southern Ocean ecosystem, krill forms a critical trophic link between primary producers and higher predators, including fish, seabirds, seals, and whales. India has demonstrated its capability to operate in the Southern Ocean through the First Indian Antarctic Krill Expedition (FIKEX), conducted between December 1995 and March 1996 onboard FORV *Sagar Sampada* (Fig. 2.6). The expedition operated in Food and Agriculture Organization (FAO) Fishing Area 58 within the Indian Ocean sector of the Southern Ocean and employed a 49.5 m experimental midwater trawl supported by aimed trawling techniques and integrated trawl instrumentation. The valuable technical expertise and scientific support provided by the Sea Fisheries Institute (SFI), Gdynia, Poland, are gratefully acknowledged. Their contributions played a significant role in strengthening the scientific and operational success of the First Indian Antarctic Krill Expedition (FIKEX). An average catch rate of 379 kg/haul was achieved, resulting in a total biomass landing of 12,070 kg. Antarctic krill constituted 47.1% of the catch, while salps accounted for most of the remaining biomass. These results established the operational feasibility of Indian distant-water fishing activities in Antarctic waters and provided a valuable baseline for future engagements (Boopendranath et al., 2013). Commission for Conservation of Antarctic Marine Living Resources (CCAMLR) has prescribed catch limits of 4 mt for Statistical Area 48 in the Atlantic sector and 0.89 mt for Statistical Area 58 in the Indian Ocean sector, thereby allowing considerable scope for the expansion of scientifically regulated and sustainable krill fisheries (Boopendranath et al., 2012a).

## 2.7.Addressing climate change challenges

Global climate change imposes profound and escalating challenges to marine ecosystems, including vulnerable deep-sea habitats. Rising ocean temperatures, deoxygenation, and disruptions in current patterns have far-reaching consequences that can alter species distributions, behaviours, and ecological interactions. These impacts compromise the stability and resilience of marine environments,




Fig. 2.6: Images from the First Indian Krill Expedition (FIKEX) onboard FORV *Sagar Sampada*.

necessitating a strategic, science-driven response. The CMLRE has proactively integrated climate-focused research into its programs, leveraging long-term datasets collected through FORV *Sagar Sampada*. These datasets encompass critical environmental parameters, such as vertical profiles of ocean temperature, salinity, and dissolved oxygen, providing a robust foundation for evaluating the implications of global warming for marine biodiversity and fisheries.

The MLRP implemented through CMLRE emphasized ecosystem-based management strategies for marine resource conservation and sustainable utilization. Such strategies require a comprehensive understanding of the complex interactions among the atmospheric, biological, chemical, and physical components of marine ecosystems. The importance of capturing biophysical interactions cannot be underestimated, as these processes govern the ecological and economic viability of marine systems. Recognizing that living organisms within these systems respond dynamically to environmental changes, the Monitoring and Modelling of Marine Ecosystem (MMME) project prioritized the development of predictive models that integrate these factors. These models were instrumental in deciphering how atmospheric conditions such as monsoon cycles, temperature fluctuations, and ocean currents shape marine productivity and influence fishery patterns. By monitoring the responses of marine organisms to these environmental changes, researchers gain critical insights into population dynamics, reproductive cycles, and habitat preferences. This information is invaluable for fisheries and ecosystem management, as it enables the identification of spawning grounds, migratory routes, and vulnerable habitats that require conservation.

## 2.8.Conservation and biodiversity documentation

CMLRE is mandated to focus beyond fisheries, encompassing broader conservation objectives with an emphasis on protecting marine biodiversity. Deep-sea ecosystems, often regarded as the last frontier of marine exploration, comprise a vast and largely underexplored reservoir of biodiversity. Many species in the deep-sea ecosystems remain undocumented, necessitating targeted efforts to achieve insights into their ecological roles and potential applications in emerging fields such as biotechnology and medicine. Exploration programs conducted by the FORV *Sagar Sampada* have significantly contributed to this effort by documenting new species and enhancing our understanding of deep-sea biodiversity. A key component of CMLRE's conservation strategy is the identification and mapping of biodiversity hotspots and ecologically sensitive areas. The data and samples collected as part of the MLRP so far are being deposited and archived at the Data and Referral Center. The Referral Center, "*Bhavasagara*", in CMLRE, has been recognized by the National Biodiversity Board, Government of India, as the National Designated Repository, particularly for deep-sea organisms. It presently holds 3,548 voucher specimens of deep-sea fauna. Systematic studies covering various marine faunal groups revealed 48 species new to science and 94 species as new geographical records. These include taxa under different phyla such as Arthropoda, Annelida, Chordata, Cnidaria, Echinodermata, Mollusca, Nematoda, and Platyhelminthes. 76% of the new species were described from the SEAS and the Andaman Sea. These efforts provide the groundwork for establishing marine protected areas (MPAs), which are vital sanctuaries for vulnerable marine species and their habitats. In continuation of the DSDWF Program, the marine biodiversity research activities were brought under the umbrella of the "Resource Exploration and Inventorization System (REIS)" project implemented at CMLRE. This initiative aimed to systematically explore, document, and catalogue marine biodiversity within India's EEZ. One of the project's main objectives was to create a systematic inventory of species diversity and their spatial distribution. Further, it has been expanded as Fishery Resources and Habitat Assessment (FRHA) wherein the pelagic, mesopelagic, and demersal realms are being explored for habitat suitability and to assess the resources utilizing advanced techniques and methodologies.

Apart from the Data and Referral Center, CMLRE serves as a nodal agency for the Ocean Biogeographic Information System (OBIS) to integrate and collate information from sources that lie scattered among several agencies, institutions, and individuals within the Indian Ocean region through the Indian Ocean node of the OBIS platform (IndOBIS), www.indobis.in. It serves as a central repository for marine biodiversity data, promoting collaboration between domain experts and information technology specialists

within the Indian Ocean region. It is one of the more than 30 regional nodes of the OBIS. By facilitating the sharing and dissemination of biodiversity information, IndOBIS strengthens both national and international research initiatives. Moreover, the data generated through this initiative have been crucial in identifying vulnerable species and habitats, thereby informing the development of targeted conservation policies and management plans. IndOBIS supplies the global scientific community with various types of geo-referenced information on the biodiversity of Indian Ocean. So far 114,630 occurrence records of marine organisms reported from Indian Ocean have been hosted in the portal.

## 2.9.Sustained observations and understanding of the Indian marine ecosystems through MLRP

Understanding the biodiversity, biogeochemical interactions, and the food web dynamics in the northern Indian Ocean has developed a strong baseline through the International Indian Ocean Expedition (IIOE) during the late 50's and the Joint Global Ocean Flux Studies (JGOFS) and Bay of Bengal Process Studies (BOBPS) in the 90s. While these expeditions and studies were limited to a part of the northern Indian Ocean, the MLRP, which began in 1998, adopted an approach that systematically covered the entire Indian EEZ, both spatially and temporally. The multidisciplinary, multi-institutional programme was based on the FORV *Sagar Sampada*, and the projects under this programme were well structured to comprehensively address the Indian EEZ, aiming to explore the potential of deep-sea resources as an alternate avenue for future needs. From 2003 onwards, MLRP adopted a comprehensive ecosystem approach, integrating physical to biological components and emphasizing long-term monitoring and modelling of pelagic and deep-sea realms. The programme included, the Environment and productivity patterns, Harmful Algal Blooms (HABs), Benthic Productivity, DSDWF, Southern Ocean MLR, Hatchery Development of ornamental fishes and live baits etc. While the DSDWF focused on the demersal and mesopelagic trawls, biodiversity and fishery-related parameters, the environment and productivity studies explored and strengthened the understanding of the various ecosystem processes and their linkage with the biology and ultimately the fishery. The benthic studies and the benchmark information gathered for the continental margin (30-1000 m) of the Indian coastline, including the Andaman and Nicobar Islands, complement each other to explain the deep-sea demersal ecosystems and the possible seasonal variations driven by environmental variability and ecological interactions.

The 28-year-long observations in the Indian EEZ, mostly conducted onboard FORV *Sagar Sampada*, have resulted in a robust data and sample base, strengthening knowledge of MLR in Indian waters. This has achieved the delineation of different ecosystems in Indian waters. The spatio-temporal variations in ecosystem processes and responses, trophic linkages and efficiencies at different levels, and energy transfer between trophic levels are explained from primary to secondary and tertiary levels, including the benthos and demersal fishes. CMLRE, jointly with the Ministry of Fisheries, Animal Husbandry and Dairying, FSI, Marine Products Export Development Authority (MPEDA), and Central Marine Fisheries Research Institute (CMFRI), is a member of the expert committee tasked with revalidating India's resource potential. The data and understanding gathered through MLR have been effectively utilized to estimate marine resources using the trophodynamics approach.

## 2.10.Capacity building and technological innovation

Over the past decades, the CMLRE has evolved into a national hub for capacity building and technological innovation in marine research, generating critical baseline data on marine biodiversity, fisheries resources, and ecosystem processes. CMLRE has developed robust networks of national and international collaborations with universities, research institutions, and intergovernmental organizations. Through regular training programs, workshops, various academic programmes and onboard research expeditions, the Centre has significantly enhanced the scientific and technical

expertise and analytical capacity of Indian marine scientists. It's mission emphasizes human resource development in marine science and resource management, exemplified by its active support for doctoral researchers through the MoES Research Fellowship Programme (MRFP) and various universities, which enables students to pursue Ph.D. research across diverse areas.

Investments in technological innovation have further advanced CMLRE's research capabilities. The incorporation of remote sensing tools, including acoustics and optics, autonomous survey platforms, and molecular techniques such as DNA barcoding, environmental DNA (eDNA) analysis, and metagenomics, has revolutionized species identification and ecosystem monitoring. These technologies have expanded the spatial and temporal resolution of marine surveys, enabling exploration of previously inaccessible deep-sea regions and the generation of high-resolution ecological data. Such innovations are vital for addressing contemporary challenges, including assessing the ecological implications of deep-sea exploration, understanding the dynamics of mesopelagic communities, and supporting sustainable management of marine living resources in a changing climate.

## 2.11. CMLRE in the context of International Conventions/Treaties

CMLRE has strengthened India's scientific capabilities in alignment with global frameworks, including CCAMLR, OBIS, and the emerging Biodiversity Beyond National Jurisdiction (BBNJ) agreement (Fig. 2.7). India has been a permanent member of CCAMLR since 1986 and actively contributes to ecosystem-based conservation within the Antarctic Treaty System. India's CCAMLR activities are coordinated by the MoES through CMLRE, which provides scientific data, assessments, and policy-relevant inputs to CCAMLR processes. Through participation in OBIS, originally integrated into the International Oceanographic Data and Information Exchange (IODE) of UNESCO's Intergovernmental Oceanographic Commission (IOC) in 2009, India contributes open-access marine biodiversity data via IndOBIS.

A legally binding "High Seas Treaty", also known as the BBNJ Agreement, was adopted in June 2023 under the United Nations Convention on the Law of the




Fig. 2.7: CMLRE's participation in international marine science and ocean governance initiatives. a) CCAMLR b) OBIS c) BBNJ

Sea (UNCLOS). India officially signed the treaty at the United Nations General Assembly on 25th September, 2024. In September 2025, the global status of the BBNJ Agreement reached a critical turning point as it surpassed the required 60 ratifications, setting the stage for the treaty to enter into force on 17th January 2026. Throughout 2025, India has been aligning its domestic scientific and legal frameworks in preparation for ratification, with support from CMLRE.

## 2.12.Blue Economy and the deep-sea fisheries

The Blue Economy in the Indian context refers to the sustainable development of ocean resources for economic growth, improved livelihoods, and ecosystem health. India possesses significant marine resource potential. The marine sectors, including fisheries, shipping, offshore energy, tourism, and marine biotechnology & bioprospecting, are estimated to contribute nearly 4% to India's GDP, with substantial scope for expansion. India is currently the second-largest fish producer globally, with total fish production exceeding 17 mt (2022-23), and the fisheries sector supports around 30 million livelihoods directly and indirectly. Marine product exports reached approximately Rs. 60,523 crore (USD ~7.4 billion) in FY 2023-24, underlining the foreign exchange significance in this sector. The policy direction for harnessing ocean resources sustainably has been articulated by NITI Aayog in its strategy document on India's Blue Economy, which emphasizes deep-sea and offshore fisheries as a frontier area for growth, diversification, and reduced pressure on coastal stocks.

Deep-sea fisheries operating beyond the traditional 12 nm territorial waters and into India's EEZ represent an underexploited resource domain. The potential yield from India's EEZ is estimated at around 13.47 mt (revalidation report 2026- CMLRE), including oceanic and mesopelagic resources, of which a considerable portion remains untapped due to technological, infrastructural, and regulatory constraints. Expansion into deep-sea fisheries is viewed as a strategic intervention to decongest overfished nearshore waters, enhance the harvest of high-value species (such as tuna and oceanic squids), and strengthen food and nutritional security. The Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, through schemes such as the PMMSY, has prioritized modernizing the fishing fleet, developing deep-sea fishing vessels, improving onboard handling and cold-chain infrastructure, and enhancing landing and harbour facilities. Simultaneously, regulatory reforms for EEZ fishing and digital licensing systems are being introduced to promote transparency and sustainability.

However, deep-sea fisheries are capital intensive and require advanced fish-finding technologies, vessel monitoring systems, skilled manpower, and ecosystem-based fisheries management frameworks. There are also ecological considerations, particularly in relation to vulnerable deep-sea habitats and bycatch management. Sustainable expansion must therefore be guided by robust stock assessments, real-time monitoring, precautionary harvest control rules, and integration of oceanographic intelligence. In this context, strengthening the knowledge base, implementing science-based management strategies, conducting regular acoustic and exploratory surveys, and improving data-sharing mechanisms are critical. The blue economy approach thus demands a balance between economic expansion and conservation, ensuring that offshore resource utilization does not compromise biodiversity and the rights of small-scale fishers.

From a policy perspective, deep-sea fisheries offer India an opportunity to increase marine exports, generate employment in vessel construction and processing sectors, and position itself as a responsible maritime power in the Indian Ocean region. At the same time, aligning development with global sustainability frameworks such as FAO's Code of Conduct for Responsible Fisheries and SDG 14 is essential. A phased strategy combining strong regulatory frameworks, infrastructure investment, capacity building, and scientific research will be central to realizing the blue economy vision. This should also include the designing of inclusive interventions that safeguard artisanal fishers by promoting microcredit mechanisms, cooperative formation, and institutional support, thereby enabling their equitable participation alongside larger commercial enterprises. Properly governed, deep-sea fisheries can serve as a transformative pillar within India's broader blue economy framework, contributing to economic resilience, food security, and ocean sustainability.

# 3 Mesopelagic Resources

The open oceans and deep-seas (> 200 m depth) cover the majority of the Earth's surface area and habitat volume. Within these, the vast deep-pelagic habitat between the sunlit layers (upper 200 m) and the seafloor is the largest and least-understood environment on our planet (Webb et al., 2010). This habitat contains the mesopelagic zone (200-1000 m depth). Here, the sun's reach falters; the light dims until it is insufficient to sustain photosynthesis, marking the boundary between the world of the sun and the eternal dark of the abyss. Organisms inhabiting this environment exhibit remarkable adaptations to low light, cold temperatures, and increasing pressure. Zooplankton, micro nekton, and mesopelagic fishes dominate this ecosystem, many possessing enlarged eyes capable of detecting faint light, while others produce their own illumination through bioluminescence using specialized organs called photophores. Some species also possess elongated jaws, sharp fangs, or large mouths that enable efficient prey capture in this dim environment.

One of the most remarkable phenomena in this zone is the Deep Scattering Layer (DSL), a massive biological aggregation of organisms first discovered through naval sonar observations in the late 1940s. Submarine operators detected acoustic echoes that appeared to originate from a false seabed which was referred to as the "phantom bottom" (Fig. 3.1a). The observed difference, appeared stable during the day but migrated upward during the night, creating confusion and subsequent investigations using trawl nets, sonar observations and submarine studies revealed that these echoes were produced by dense biological communities of fishes, crustaceans and zooplankton capable of reflecting acoustic signals (Duvall & Christensen, 1946; Eyring et al., 1948; Raitt, 1948; Marshall, 1951). These aggregations form the

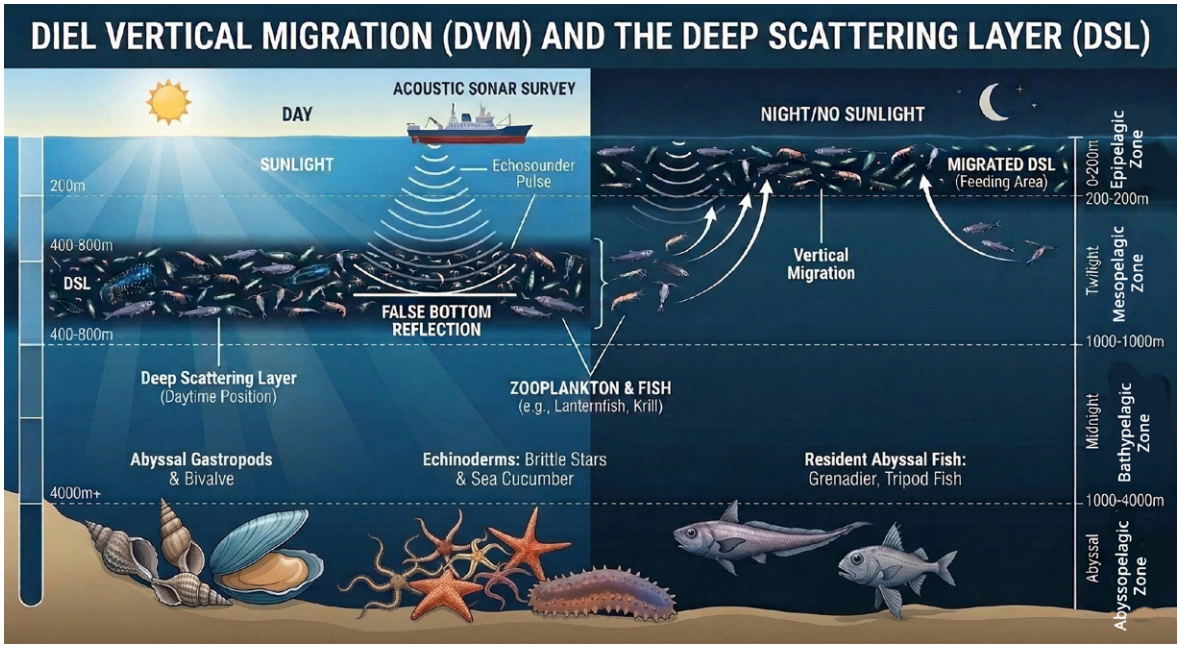



Fig. 3.1a: DSL and DVM in the Mesopelagic zone

DSL, which occurs throughout the world's oceans. It may extend hundreds of meters vertically and tens to hundreds of kilometres horizontally (Tont, 1975). The DSL is strongly associated with one of the largest daily animal migrations on earth. In most oceanic regions, the DSL occurs between 300 and 500 m depth, although its position varies depending on environmental conditions and time of day (Benoit-Bird, 2016). During daylight hours, organisms remain in deeper waters and ascend to the surface to feed on plankton, a daily cycle that continues without interruption. This movement plays a crucial role in oceanic food webs and contributes to the biological carbon pump through the downward transport of organic matter to deeper waters. Earlier assessments estimated about 1,000 mt of mesopelagic fish biomass (Gjosaeter & Kawaguchi, 1980; Lam & Pauly, 2005). Recent global estimates suggest that the mesopelagic zone may contain up to 10 billion metric tonnes of fish biomass, nearly ten times the current global annual fish catch (Irigoien et al., 2014).

Despite its global ecological importance, the DSL in the Indian Ocean remains comparatively understudied. Early acoustic observations in the western Arabian Sea (WAS) reported DSL signals at depths of about 300 to 400 m and a deeper layer around 900 to 1100 m (Kinzer, 1969). Later surveys by RV *Varuna* recorded DSL layers between 300 to 450 m and 750 to 950 m in the Lakshadweep Sea (Silas, 1972). Although several studies have investigated mesopelagic ecosystems in different regions of the world, often focusing on the dominant mesopelagic fishes such as myctophids. Some research has been conducted in the WAS about myctophids during the IIOE (1959-1965) and subsequent work by FAO in 1981 (Gjosaeter 1981a & b). But a systematic investigation of the DSL in Indian waters remains relatively limited. Recognizing the importance of this ecosystem for marine productivity and potential resource assessment, comprehensive studies of the DSL within the EEZ have been undertaken through dedicated oceanographic programmes by CMLRE, onboard FORV *Sagar Sampada*. The exploratory surveys started during 1989-1990 and continuing through multiple phases of the MLR between 1998 and 2025. These investigations integrate fisheries acoustics, trawl sampling and biological observations to understand the ecological functioning of mesopelagic communities within the Indian EEZ (Fig. 3.1b). The central objective of these studies is to determine the species composition associated with the DSL, evaluate its potential as a non-conventional fishery resource, and understand its role as a crucial trophic link between the pelagic and mesopelagic ecosystems. The present section is therefore designed to highlight the



Fig. 3.1b. Mesopelagic fish catches from trawling operations conducted by FORV *Sagar Sampada*.

occurrence, spatial distribution, abundance, migration characteristics, and biological composition of the DSL and its associated fisheries in Indian waters, thereby advancing our understanding of one of the largest and least explored biological phenomena. The information about the mesopelagic zooplankton community (3a), fishes (3b), ecological indices (3c), diel vertical migration (DVM) (3d), feeding and reproductive strategies of myctophids (3e), biochemical composition of selected myctophids from the AS (3f), and composition of DSL shrimps (3g) is compiled in Annexure 3.

## 3.1. DSL in the Indian EEZ

The DSL in the Indian EEZ exhibited varied characteristics and species distributions, with distinct observations across geographic and bathymetric zones during day and night, as well as across regions. It occurs as single or multilayered structures with varying intensities. Layer thickness ranges from 5-290 m. During daytime, the principal layer is typically observed at 200-540 m (Menon & Prabha Devi, 1990) and 750-950 m (Silas, 1972). At dusk, organisms ascend toward the surface, forming dense nocturnal aggregations at 20-80 m as part of diel vertical migration (DVM) from depths exceeding 300 m (Fig. 3.2).

Studies from the WAS have reported the speed of diel vertical migration associated with the DSL. The migration speed of zooplankton layers ranged from 2-8 cm/sec, while that of fishes ranged from 3-13 cm/sec (Luo et al., 2000). Similar observations were obtained from studies conducted in the Indian EEZ

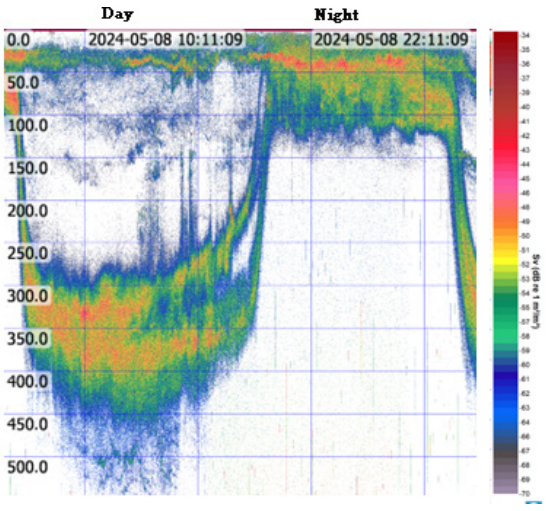



Fig. 3.2: Echogram showing DSL layer and the diel vertical migration

onboard FORV *Sagar Sampada*, where the migration speed of zooplankton layers was estimated at 2-8 cm/sec (Menon, 2000; Jadhav & Smitha, 2025), and fish migration speeds ranged between 3-10 cm/sec (Mathew & Natarajan, 1990).

The DSL was observed at comparatively higher bathymetric levels in oceanic waters than in shelf regions. While the layer exhibited an almost continuous horizontal distribution, its vertical position and concentration varied seasonally and geographically, and were also influenced by bathymetric conditions. The strong vertical gradients in temperature, dissolved oxygen, and nutrients regulate the distribution, vertical migration, and community structure of DSL organisms, underscoring their ecological importance and sensitivity to changes in oceanographic conditions.

On the west coast of India, the average DSL biomass was 8.17 ml/1000 $m^3$ at night and 6 ml/1000 $m^3$ during the day. On the east coast, the average biomass was 7.65 ml/1000 $m^3$ at night and 3.4 ml/1000 $m^3$ during the day. High DSL biomass values were recorded at specific stations along both the west and east coasts of India. On the west coast, high daytime biomass was observed off Karnataka and Ratnagiri, while high night-time biomass occurred off Vizhinjam and Mangalore. On the east coast, high daytime biomass was recorded off Vishakhapatnam and off Chennai (300-350 m depth), whereas high night-time biomass was observed at off Vishakhapatnam, the central BoB (CBoB), and north-western BoB (NWBoB) at depths of 30-50 m (Fig. 3.3, 3.4).

The southwest coast recorded the highest DSL biomass (54.8 ml/1000 $m^3$ during daytime), followed by the northwest coast (21.1 ml/1000 $m^3$), whereas comparatively lower values were observed in the Bay of Bengal (BoB) and the Equatorial Indian Ocean (3.0-4.4 ml/1000 $m^3$), with higher night-time catches at mid-depths (50-200 m) reflecting the influence of DVM (Table 3.1). Seasonal trends show peak biomass and fish abundance in the post-monsoon period, suggesting ecological partitioning and behavioural adaptations.

Micronekton (nekton <20 cm) constitutes 62% of the DSL biomass, and macro zooplankton comprised 38% in the Indian EEZ. The average biomass and composition of DSL resources in the Indian EEZ is shown in Fig 3.5, 3.6. Among the macro-

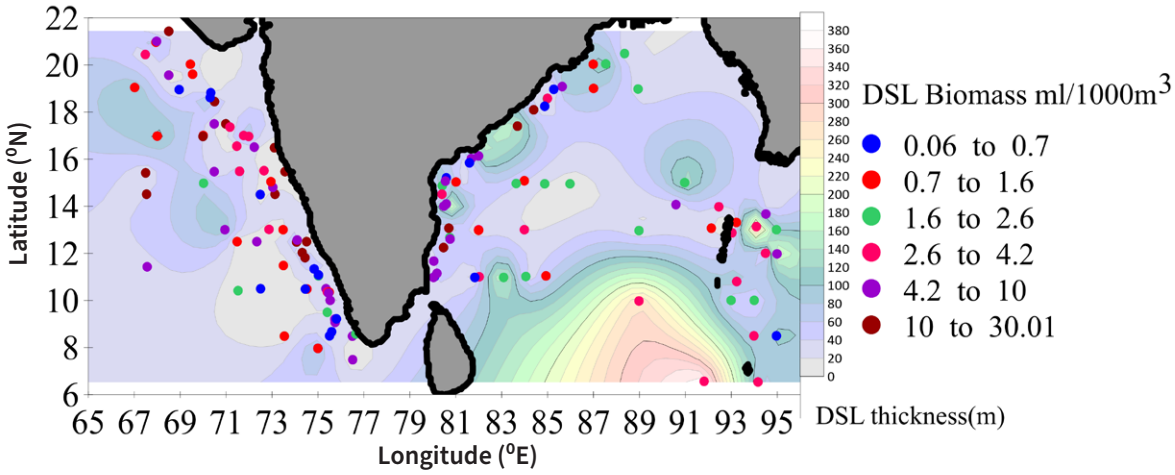



Fig. 3.3: Regional variation in DSL biomass (ml/1000 $m^3$) in the Indian EEZ during Day

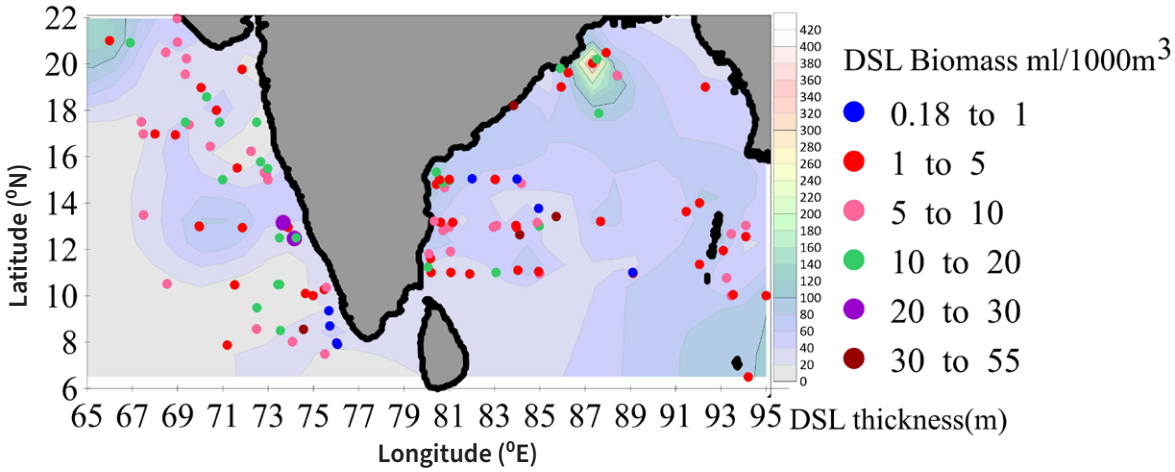



Fig. 3.4: Regional variation in DSL biomass (ml/1000 $m^3$) in the Indian EEZ during Night

Table 3.1: Regional variation in DSL biomass (ml/1000 $m^3$) along the Indian EEZ and EIO

| Region | Subregion / Area | Night (ml/1000 $m^3$) | Day (ml/1000 $m^3$) | Remarks |
|---|---|---|---|---|
| Southwest Coast | Cape Comorin to Goa | 22.5 | 54.8 | Most productive region |
| | Karwar area | 22.5 | 54.8 | High biomass region |
| | Off Cochin & Lakshadweep waters | 25.2 | 6.2 | High night-time biomass on the southwest coast |
| Northwest Coast | Off-Maharashtra & Gujarat | 21.1 | 19.5 | High daytime biomass |
| Southeast Coast | | 8.3 | 6.2 | Biomass is lower than on the southwest coast |
| Northern Bay of Bengal | | 4.4 | 3.2 | Lowest biomass region |
| Andaman Sea | | 8.3 | 3.6 | Enhanced biomass compared to the Bay of Bengal |
| Equatorial Indian Ocean | | 4.3 | 3.0 | Relatively low biomass |

zooplankton, Euphausiids are the dominant group (16-65% of zooplankton biomass), followed by salps (9-56%), amphipods (<3%), and larval forms of crabs, cephalopods, and fish. The DSL micronekton is dominated by fishes (93%) belonging to the families Myctophidae (lanternfish), Phosichthyidae (oceanic light fish), Stomiidae, Bregmacerotidae, Sternoptychidae, and Gonostomatidae, other nektons like leptocephali (larval stages of eels), cephalopods, shrimps, and crabs. Considering the dominance of myctophids, Phosichthyidae, leptocephali, shrimps and cephalopods, and their potential relevance, these are explained in detail, bringing out the species composition, distribution and abundance in the Arabian Sea (AS) with special emphasis on myctophids (Fig. 3.6).

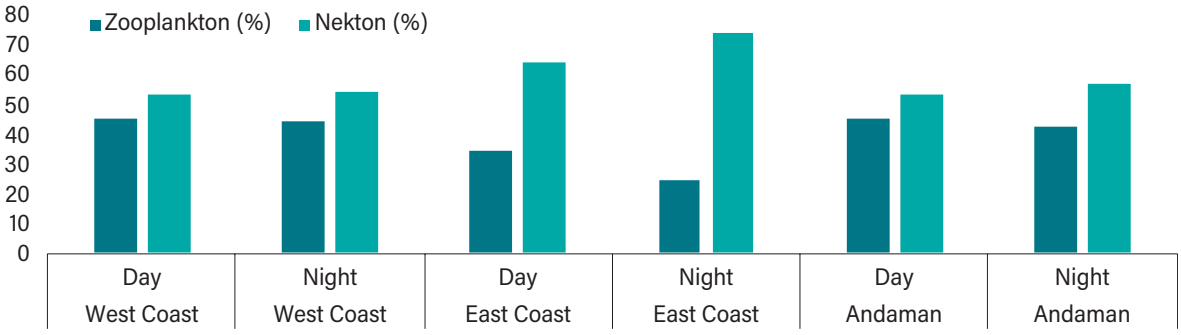



Fig. 3.5: Average biomass of Zooplankton and Nekton in the DSL of Indian EEZ (Day vs Night)

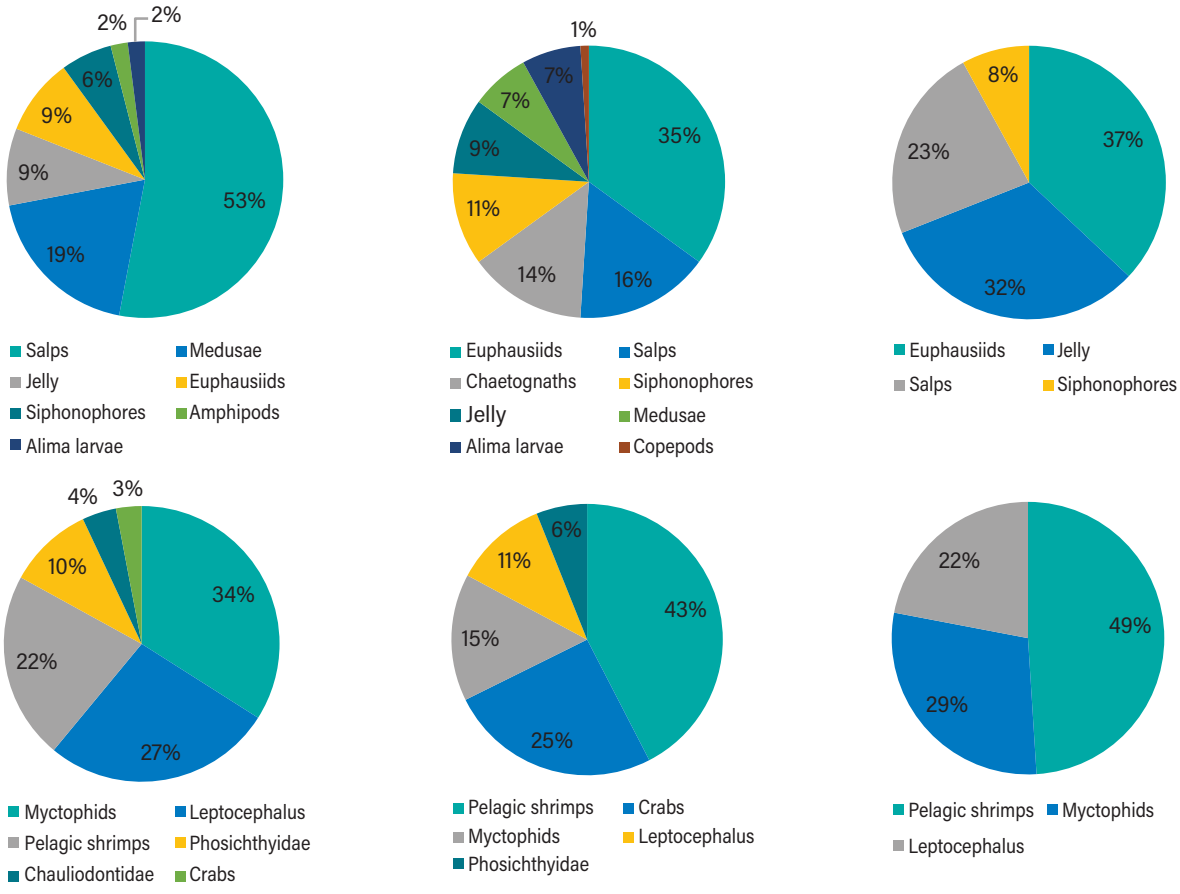



Fig. 3.6: Major groups of zooplankton and nektons contributing to total biomass in the West Coast, East Coast, and Andaman waters. (2A, 2D- west coast, 2B, 2E- East Coast, 2C, 2F- Andaman waters).

# 3.2.Myctophids

Myctophids, also known as lanternfishes, are the major inhabitants of the DSL within the Indian EEZ, accounting for 28-31% of the total mesopelagic population. Myctophids, are typically 3-30 cm long, have blunt heads, large eyes, laterally compressed bodies with small silvery scales, and distinctive rows of bioluminescent photophores on the head and body, making them distinguished (Fig. 3.7). Globally, myctophidae comprise of 253 species belonging to 34 genera (Fricke et al., 2026), while in the western Indian Ocean (WIO) it is recorded with 159 species belonging to 28 genera (Meera et al., 2023). The complete surveyed area onboard FORV *Sagar Sampada* is given in Fig. 3.8.

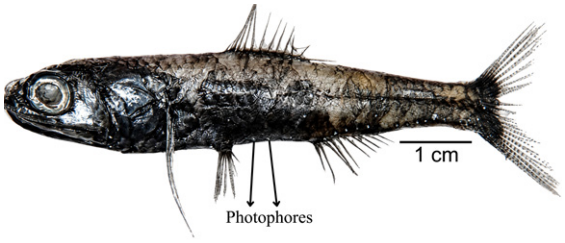



Fig. 3.7: Image of a myctophid fish showing a photophore

The reports from the WIO include six new records, *Bolinichthys nikolayi*, *Diaphus similis, D. theta*, *Lampadena urophaos, Lampanyctus crocodilus* and *L. macdonaldi*. The FORV *Sagar Sampada* surveys (2012–17) indicate a total of 16 species in NEAS dominated by 11 species that accounts for 99%

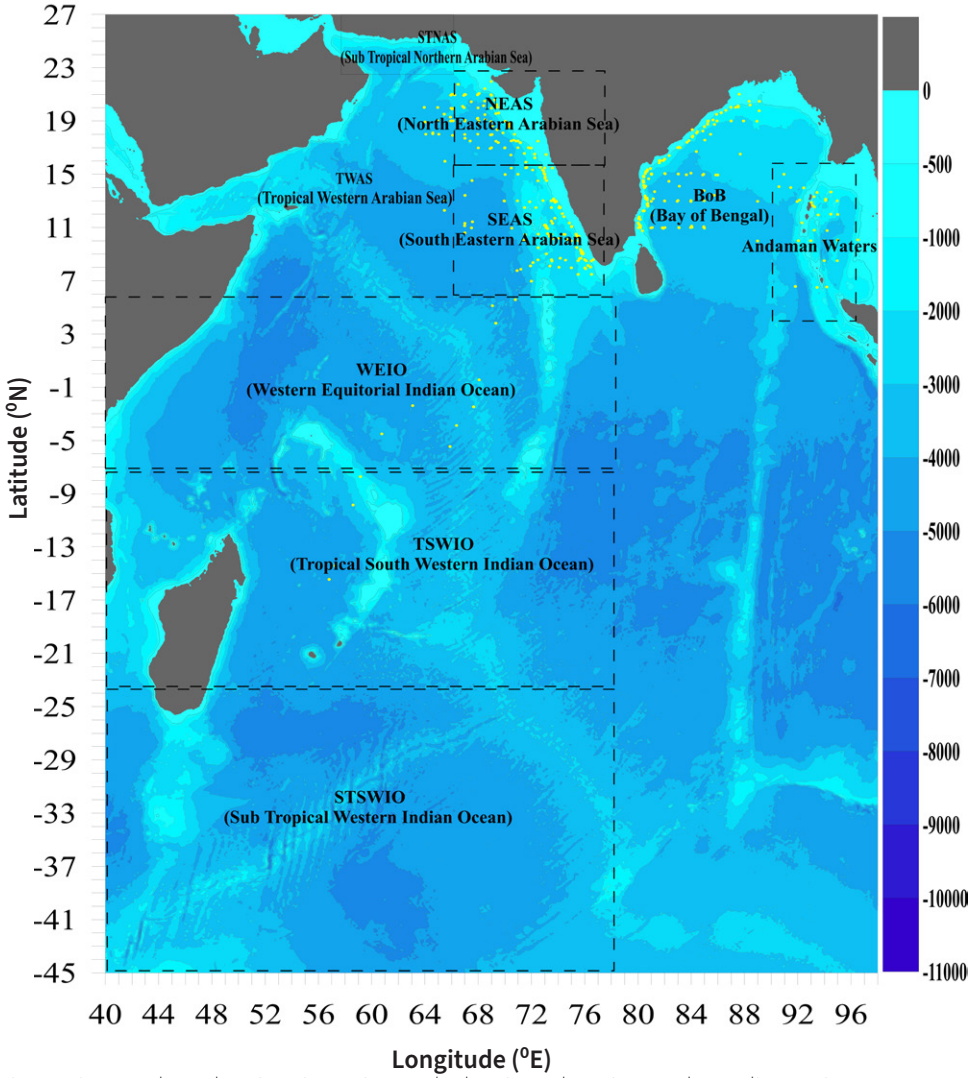



Fig. 3.8: Surveyed area by FORV *Sagar Sampada* showing sub-regions and sampling stations.




*Bolinichthys nikolayi*




*Lampadena urophaos*




*Diaphus similis*




*Lampanyctus crocodilus*




*Diaphus theta*




*Lampanyctus macdonaldi*

of the myctophid biomass. Of these 11 species, 7 *Diaphus* spp. account for 40% of the biomass, 2 *Benthosema* spp. for 31%, one *Bolinicthys* spp. for 21% and one species of *Ceratoscopelus* for 7%. In contrast, SEAS is recorded with 45 species, which is dominated by 29 species, among which *Diaphus* spp. contributes 40%, *Benthosema* spp. 31%, *Bolinichthys* spp. 21% and *Ceratoscopelus* spp. 7% to the total biomass of the region (Fig. 3.9). The spatial variation in the species distribution between NEAS and SEAS, highlight the need to address the two areas separately to discuss the stock of these resources (Fig. 3.10). The key findings of CMLRE on myctophid diversity, regional assemblages, feeding and reproductive biology, biomass estimates, and the environmental drivers that regulate these attributes are summarized in Fig. 3.11.

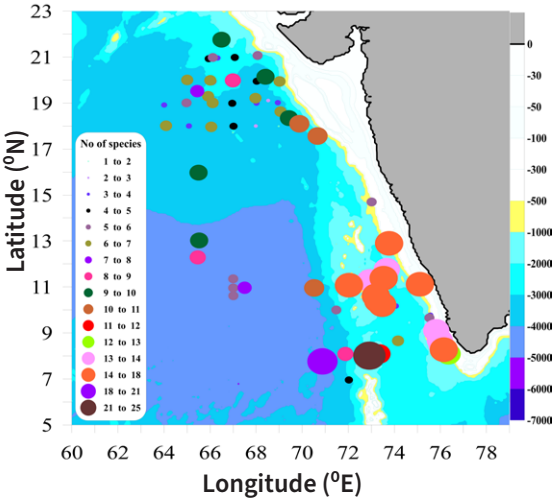



Fig. 3.10: Spatial patterns in species richness across the Northeastern AS

## 3.2.1.Standing stocks of Myctophids

The AS harbours rich myctophid biomass between 60 and 150 mt (Gjosaeter, 1981a). Subsequent quantitative assessments indicate that the AS supports approximately 100 mt of *Benthosema pterotum* alone (GLOBEC, 1993), the largest virgin fish stock in the region and one that is underexplored. Further studies between 2012 and 2017 estimated the total myctophid biomass in

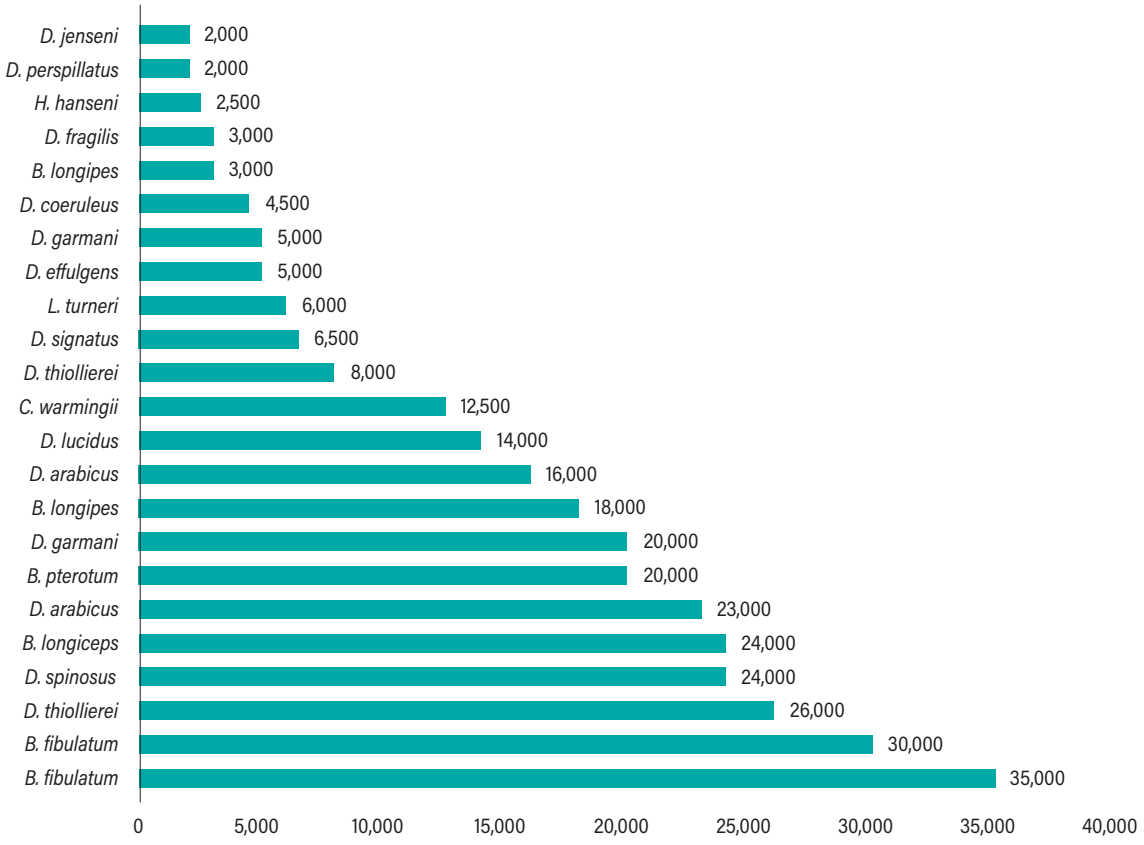



Fig. 3.9: Biomass of dominant myctophid species across NEAS, SEAS, and WEIO

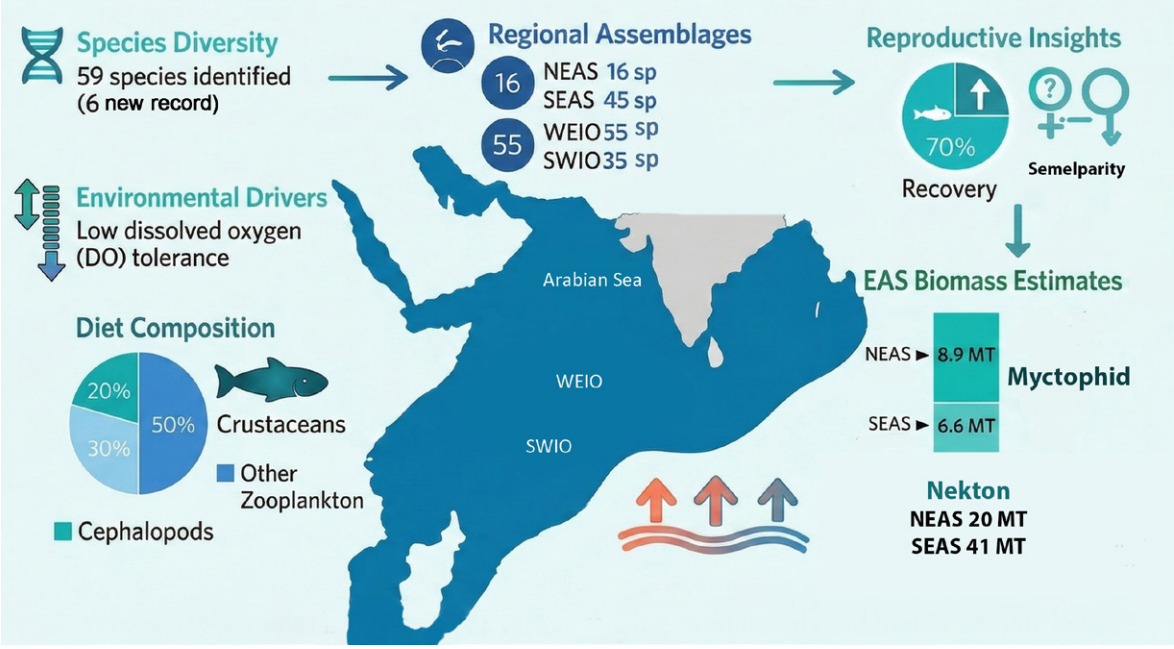



Fig. 3.11: Environmental drivers regulating the species diversity, feeding and reproductive biology, regional assemblages, and biomass of Myctophids in the WIO.

the eastern Arabian Sea (EAS) as 17.9 mt, based on the swept-area method, comprising 9.21 mt from the NEAS and 8.69 mt from the SEAS (Meera, 2018). A recent evaluation of the myctophid biomass, incorporating updated data and gridded biomass analysis, refined the estimate to 15.5 mt in the EAS, with higher biomass in the NEAS (8.93 mt) than in the SEAS (6.6 mt), while diversity showed the opposite trend"(Meera et al., under comm.) (Table 3.2)..

The spatial distribution of myctophid biomass across the NEAS and adjacent regions reveals highly variable and ecologically structured patterns, with biomass ranging from less than 1 kg/km$^2$ to over 100,000 kg/km$^2$. In SEAS, the highest biomass (106,490 kg/km$^2$) occurs near off Kollam along the southwest coast of India. High biomass (15,000-17,500 kg/km$^2$) between 68°-73°E and 11°-18°N, coinciding with the intermediate productivity areas, indicates its interlinkage with ecosystem dynamics. Moderate biomass (5,000-14,000 kg/km$^2$) is observed near 73-74°E and 10-15°N around the Lakshadweep region, and at 65-66°E across 15-21°N. The longitudinal trend shows higher biomass in the NEAS (72-76°E), while moderate levels in the central sector (65-69°E), followed by SEAS (Fig. 3.12).

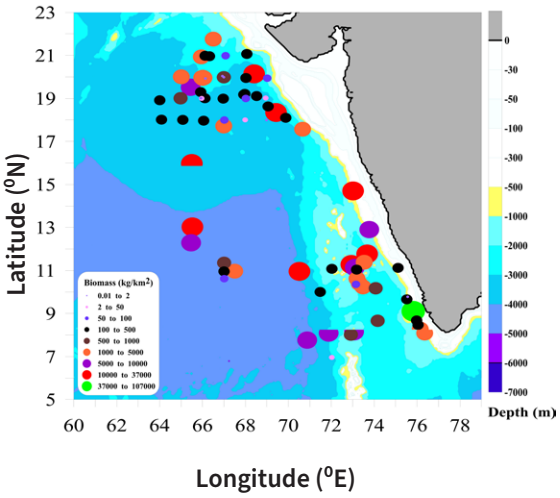



Fig. 3.12: Spatial distributions of Myctophid standing stock in the AS

## 3.2.2. Myctophid fishery-exploitation and utilization

Fishing trials in the Gulf of Oman during 1989-1990 provide concrete evidence that lanternfishes were actively pursued through targeted operations in

Table 3.2: Myctophid Biomass Estimates from Different Regions and Methodologies adopted

| Region / Study Area | Estimated Biomass | Method / Notes | Reference(s) |
|---|---|---|---|
| Global (trawl-based) | 550-600 mt | Based on trawl survey extrapolations | Gjosaeter & Kawaguchi, 1980; Valinassab et al., 2007 |
| Global (acoustic) | 10,000 mt (10 billion tonnes) | Acoustic survey data | Irigoien et al., 2014 |
| Southern Ocean | 70- 200 mt | Part of total mesopelagic biomass (212-396 mt); myctophid-dominated | Kozlov, 1995; Pakhomov et al., 1996 |
| Arabian Sea (AS) | 100 mt | General estimate | Gjosaeter, 1984; GLOBEC, 1993 |
| Arabian Sea (acoustic) | 60-150 mt | Dedicated acoustic surveys | Gjosaeter, 1981a |
| Gulf of Oman (FAO range) | 1.7-20 mt | Conservative estimate reported by FAO, trawl based | FAO (1997) |
| Eastern part of Gulf of Oman | 2.3 mt | Regional acoustic/trawl synthesis | Gjosaeter, 1984; Valinassab, 2005; Valinassab et al., 2007 |
| Eastern AS (EAS) | 15.58 mt | Trawl-based CMLRE surveys (2012- 2017, 2024) | Meera et al., 2018 |

waters connected to the broader AS region (Ziaee & Shilat, 1998). In Iranian waters of the Oman Sea, myctophids have been explicitly targeted for commercial purposes, with *Benthosema pterotum* receiving particular attention. Acoustic assessments supported by trial fishing with pelagic trawls establish both the intent and the technical feasibility of harvesting lanternfish, *B. pterotum*, as the central species in Iran (Valinassab et al., 2007).

The most consistent evidence indicates that myctophids occur as bycatch, largely associated with deep-sea shrimp trawling (Pillai, 2009; Sebastine et al., 2013; Fernandez et al., 2015). Landings along the southwest coast of India (south of Kochi) include records of *Dasyscopelus obtusirostris, Diaphus garmani, D. thiollierei, D. watasei* and *Myctophum fissunovi*, supporting a species-resolved view of lanternfishes in shrimp-trawl bycatch (Pillai, 2009). The bycatch and discard assessments from the southwest coast further indicate that myctophids can account for a substantial share of the bycatch (32-35%) (Fernandez et al., 2015). The capture of a responsible targeted myctophid fishery in India requires explicit design for gear selectivity, monitoring, and management, rather than relying on shrimp-trawl bycatch dynamics (Sebastine et al., 2013; Fernandez et al., 2015).

There are reports of a few myctophid species being exploited commercially, for human consumption such as *Electrona carlsbergi* in Antarctic waters and *Lampanyctodes hectoris* off the coast of South Africa (Dubrovskaya & Makarov, 1969; Melnikova, 1973). Between 1977 and 1992, commercial exploitation was also carried out in the Southwest Indian Ocean and the Southern Atlantic for *Diaphus coeruleus* and *Gymnoscopelus nicholski*, respectively, with reported catches up to 51,680 tonnes in 1992 (Sebastine et al., 2013; Pauly et al., 2021). Post-harvest utilisation of myctophids has progressed considerably over the past two decades, with several national and international studies demonstrating their potential for product development, high-value lipids, and nutraceutical applications despite their small size. As part of the MLR programme, detailed biochemical and nutritional evaluation was carried out for six myctophid species (*Diaphus watasei, D. luetkeni,*




*Benthosema pterotum*




*Dasyscopelus obtusirostris*




*Diaphus garmani*




*Diaphus thiollierei*




*Diaphus watasei*

*D. effulgens, D. hudsoni, Dasyscopelus obtusirostris,* and *Benthosema fibulatum*), including proximate composition, protein fractions, amino-acid profiles, fatty-acid composition, and mineral and trace element analysis. The results indicate that these species are nutritionally rich, with appreciable protein levels, high proportions of essential amino acids, and significant polyunsaturated fatty acids

(PUFA) such as DHA and EPA, highlighting their potential as valuable non-conventional marine resources.

## 3.2.3. Biochemical composition of Myctophids

Several studies have analysed the biochemical properties of myctophids, revealing their nutritional value and industrial potential. Noguchi (2004) conducted a comprehensive study of the biochemical composition of ten lanternfish species from the Pacific Ocean near northern Japan during the summer. The moisture content of these species ranged from 57.5% to 79.2%, protein content from 11.3% to 15.7%, lipid content from 4.9% to 28.5%, and ash content from 1.8% to 3.1%. The study also reported wide variability in wax ester content, approximately upto 94.6% of lipids, which served as the basis for categorizing lanternfish into three groups: species with low lipid and low wax content (*Diaphus gigas*, *Diaphus theta*, and *Lampanyctus jordani*), species with high lipid and low wax content (*Ceratoscopelus warmingii*, *Lampadena luminosa*, and *Symbolophorus californiensis*), and species with both high lipid and high wax content (*Stenobrachius leucopsarus* and *Lampanyctus regalis*). Lea et al. (2002a, b) examined the fatty acid profiles of Southern Ocean lanternfish, finding high levels of monounsaturated fatty acids (MUFAs), comprising 33.8%-53.5% of the total fatty acids, alongside PUFA levels of 17.5%-36.6%. The calorific values ranged from 6.1 to 13.3 kJ/g, highlighting their role as an energy-rich prey source.

Similarly, Seo et al. (1996) studied 20 species from the western sub-arctic and tropical Pacific, categorizing them into triglyceride-rich, wax ester-rich, and phospholipid-rich species. Triglyceride-rich species and wax ester-rich species were more abundant in the sub-arctic Pacific, while phospholipid-rich species predominated in tropical waters. Studies by Gopakumar et al. (1983) on *Benthosema pterotum* from the Gulf of Oman and the Gulf of Aden identified significant amino acids, including glutamic acid, aspartic acid, lysine, and leucine, in the edible portions. This composition underlines their nutritional potential, while the lipid-rich tissues of myctophids provide an energy-dense food source for marine predators (Pearcy, 1964; Neighbors & Nafpaktitis, 1982). The lipid and fatty acid content in myctophids is influenced by diet, habitat, and vertical migration patterns. Saito & Murata (1998) observed that triglyceride-depositing species exhibited significant seasonal and size-related variations in lipid quantities, whereas monoene content was associated with copepod-rich diets. Wax esters, which are often dominant in myctophid lipids, play a crucial role in buoyancy regulation and energy storage (Nevenzel et al., 1969).

A study on *Diaphus watasei* and *Dasyscopelus obtusirostris* from the AS revealed that their moisture content varied from 63.19% to 71.32%, with *D. watasei* having a higher fat content (15.13%) compared to *D. obtusirostris* (3.54%) (Rajamoorthy et al., 2013a). Protein content was also significant, with *D. watasei* containing 21.40% and *D. obtusirostris* 22.64%, along with essential amino acids such as glutamic acid, lysine, and leucine (Rajamoorthy et al., 2013b). Another study compared two myctophid species, *Diaphus effulgens* and *Diaphus hudsoni*, with commonly consumed Indian food fishes, such as *Sardinella longiceps*, *Mugil cephalus*, and *Rastrelliger kanagurta*. It was found that myctophids had comparable protein content (14.45%-16.54%) and higher levels of n-3 PUFA (Fernandez et al., 2014). The protein content in myctophids was slightly lower than in *M. cephalus* (19.7%) and *R. kanagurta* (19.02%), their fat content (up to 15.13%) was higher than that of lean fish species (Fernandez et al., 2014). Essential mineral content (sodium, potassium, calcium) in myctophids was comparable to other marine fish species, making them nutritionally valuable (Fernandez et al., 2014). The amino acid profile of myctophids revealed a balanced proportion of essential and non-essential amino acids, with glutamic acid being the most abundant, followed by leucine, histidine, and valine (Rajamoorthy et al., 2013b). The presence of omega-3 fatty acids in significant amounts makes myctophids a potential resource for developing fish oil-based supplements (Rajamoorthy et al., 2013a). Sebastine et al. (2013) analyzed the biochemical composition of *Diaphus watasei*, reporting 15.62% protein, 11.71% fat, and 28% dry matter in its edible portion. The study found a high proportion of monounstaurated fatty acid (MUFA) (36.7%), followed by saturated (33.3%) and PUFA (25.5%). Notably, Docosahexaenoic Acid (DHA, 9.33%) and eicosapentaenoic acid (EPA, 3.83%) were

predominant among the omega-3 fatty acids, making *D. watasei* a valuable source of essential fatty acids. These findings indicate the nutritional significance of myctophids and their potential utilization in food and nutraceutical industries (Fig. 3.13).

Internationally, large-scale post-harvest utilisation models, particularly from Iran's Qeshm Fisheries Processing Company (QFPCO, 2012) and Japanese reduction fisheries, have shown that myctophids can be processed into high-grade fish meal for aquaculture feeds, providing a cost-effective alternative to traditional fish meal (Kawaguchi & Aioi, 1972; Gjosaeter & Kawaguchi, 1980). The myctophids are converted into protein concentrates (60-70% crude protein) and defatted meal suitable for poultry and shrimp feeds, with stability enhanced through antioxidant treatment and controlled drying. Trials in India have demonstrated that myctophid meal supports excellent growth in shrimp (*Penaeus indicus*) and marine fish larvae owing to its balanced amino acid profile and high digestibility (Boopendranath et al., 2012b).

The presence of specialised pigments and biochemical compounds in lanternfishes (Myctophidae), including visual pigments associated with bioluminescence detection, indicates potential for value-added utilisation for industrial and nutraceutical applications (Turner et al., 2009; Douglas et al., 2015; Shaviklo, 2020). Their value-added avenues include fermented fish sauces, enzymatic hydrolysates, protein isolates, and peptide-rich extracts, all of which are promising sources for pharmaceutical and food-grade ingredients (Kristinsson & Rasco, 2000; Sathivel et al., 2002; Rajamoorthy et al., 2013b). Myctophid hydrolysates exhibit significant bioactive properties, including antioxidant and antihypertensive activities, making them promising candidates for incorporation into functional food formulations.

Pilot-scale studies have also demonstrated that whole myctophid fish can be effectively stabilised using low-temperature drying, freeze-drying, and irradiation, enabling their utilisation in pet food products and as organic fertilisers (Boopendranath et al., 2012b). In addition, the skin and scales of myctophids contain collagen and gelatine with




Fig. 3.13: Products developed from Myctophids

physicochemical properties suitable for biomedical applications, such as gels, wound dressings, and tissue-engineering scaffolds. While these properties have been well documented in marine fish generally (Nagai & Suzuki, 2000; Ahmad & Benjakul, 2011; Vidya et al., 2015), their commercial and biomedical potential from myctophid resources remains largely unexplored in the Indian context. The status and scope of myctophid-based product development are summarized in Fig. 3.14 below.

The CMLRE-MLR initiative, through sustained surveys and biological characterisation (Menon, 2002; Karuppasamy et al., 2006a; Boopendranath et al, 2012b; Meera, 2018), has laid the scientific foundation for establishing India's first dedicated mesopelagic processing sector. Together, these advances demonstrate that myctophids can be transformed into a high-value, multi-product resource, supporting nutraceuticals, aquafeeds, pharmaceuticals, cosmetics, and agricultural inputs, thereby offering India a realistic pathway to diversify beyond conventional fishery resources in a scientifically and economically sustainable manner.

## 3.3.Mesopelagic

## Resources other than Myctophids

Beyond myctophids, the mesopelagic community encompassed a diverse assemblage of taxa, including mesopelagic fishes such as lightfishes (Phosichthyidae), leptocephali (eel larvae), cephalopods, crabs, and shrimps, highlighting the complex trophic architecture of the DSL.

### 3.3.1.Lightfishes (Phosichthyidae)

Lightfishes, a significant family in the DSL, are commonly found in large concentrations in various oceanic regions. They are usually very small, rarely exceeding 10 cm, and contribute substantially to the biomass of the DSL, playing a vital role in marine food webs (Menon et al., 1996; Vimala, 2002). Among the lightfishes, *Vinciguerria nimbaria* is the most abundant species, constituting 95% of the total catch (Fig. 3.15). Other species, such as *V. attenuata* and *V. poweriae*, were also observed, though in smaller numbers. *V. nimbaria* is known to have a relatively short lifespan, typically around one year (Menon et al., 1996).

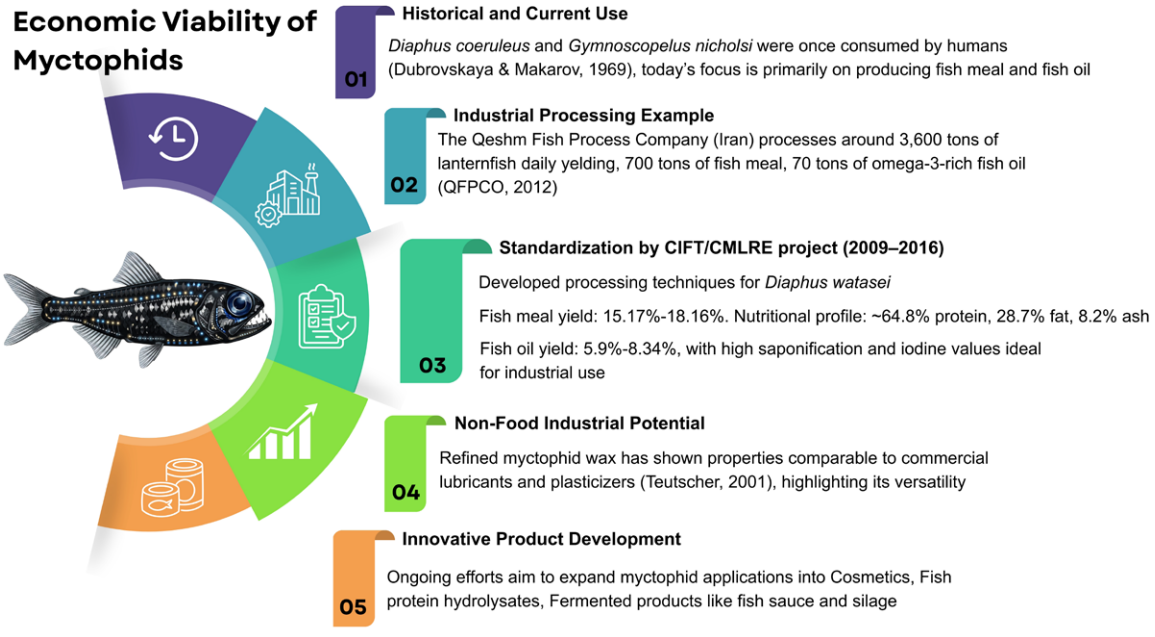



Fig. 3.14: Status and scope of myctophid-based product development




Fig. 3.15: Image of *Vinciguerria nimbaria*

This family was encountered across the Indian EEZ, along the west coast. The catch per haul reached up to ≈1144 nos./haul at night and ≈186 nos./haul during the day. On the east coast, abundance was comparatively low, and reached ≈44 nos./haul during the day and≈ 464 nos./haul at night. Along the Andaman coast, the abundance reached ≈90 nos./haul during the day and ≈149 nos./haul at night. They were found at depths ranging from 10 m to 350 m along the west coast and 10 m to 450 m along the east coast. Along the west coast, the highest catch reached ≈298 gm/km$^2$ off the Saurashtra-Mumbai sector. The Kerala-Karnataka-Goa sector showed mostly low to moderate catches (5-50 gm/km$^2$), with pockets near Lakshadweep reaching 45-60 gm/km$^2$. On the east coast, biomass was generally low (0.1-20 gm/km$^2$) but peaked at ≈227 gm/km$^2$. In the Andaman-Nicobar waters, catches were mostly below 13 gm/km$^2$ (Fig. 3.16).

## 3.3.2.Leptocephali

Leptocephali, the larval stage of eels, represent an important component of the mesopelagic ichthyoplankton community (Fig. 3.17). Their occurrence has been extensively documented along the Indian EEZ through systematic surveys conducted onboard FORV *Sagar Sampada*. They were identified from six families of Anguilliformes, Congridae, Synaphobranchidae, Nettastomatidae, Ophichthyidae, Muraenidae, and Nemichthyidae. Biomass estimates revealed strong sectoral variability, reaching up to ≈397 gm/km$^2$ in AS, and Bay of Bengal (BoB), biomass reached up to ≈170 gm/km$^2$, with notable concentrations off Odisha

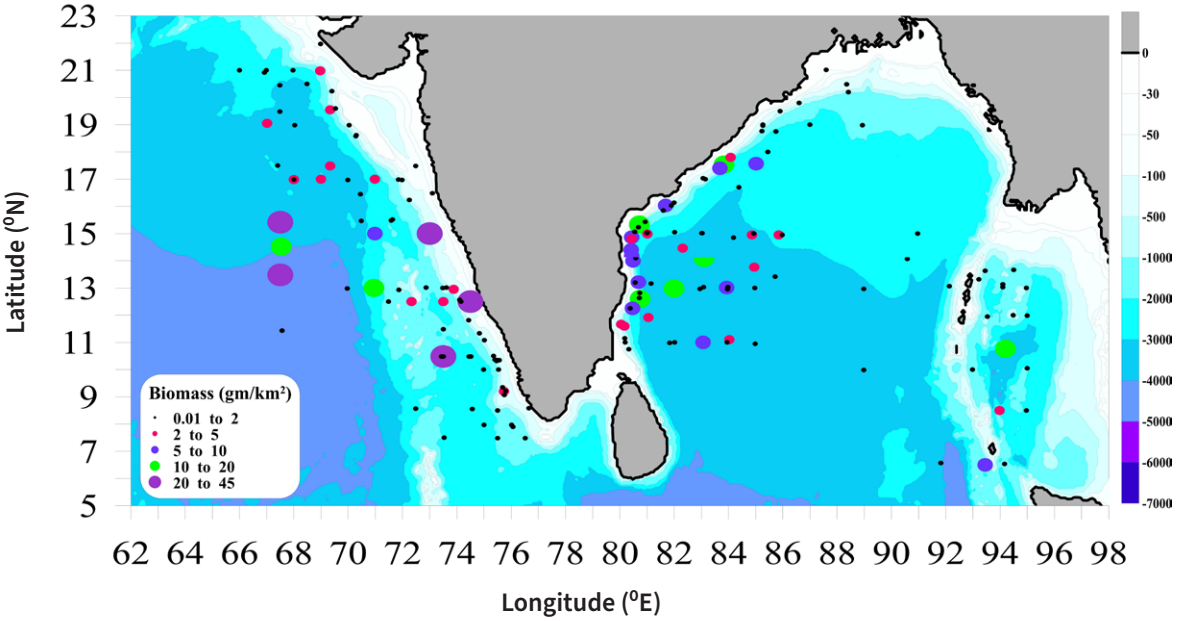



Fig. 3.16: Distribution of Phosichthyidae in the Deep Scattering Layers of the Indian EEZ




Fig. 3.17: Image of Leptocephali

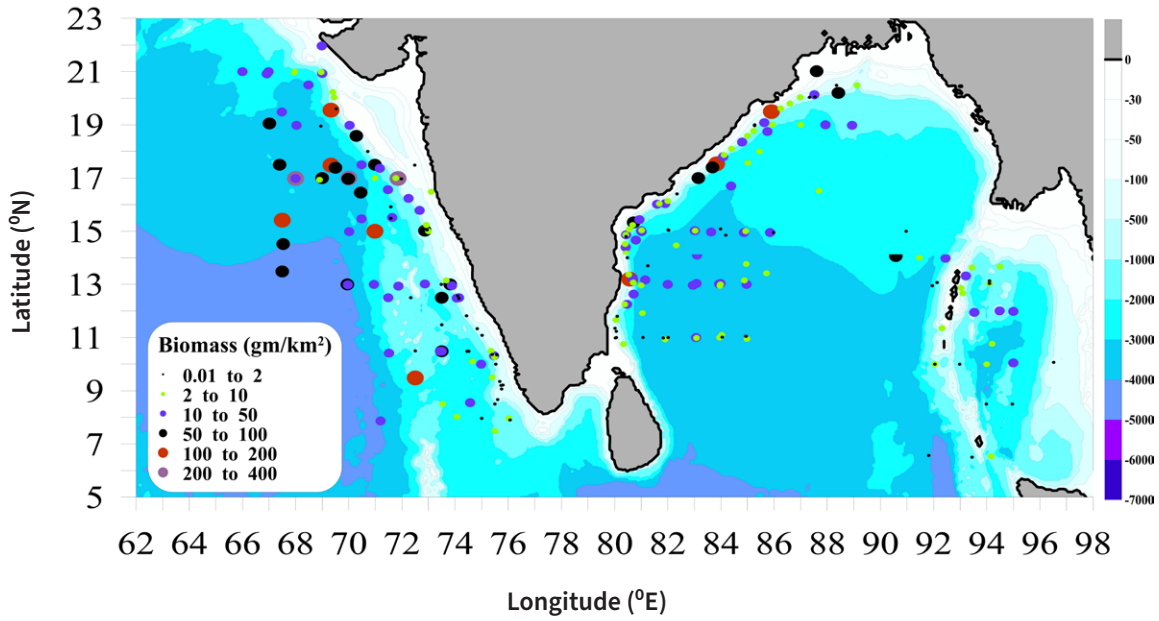



Fig. 3.18: Distribution of Leptocephali in the DSL of Indian EEZ (gm/km$^2$)

and northern Andhra coast (Fig. 3.18). Andaman stations displayed moderate biomass reaching up to ≈78 gm/km$^2$, with localized peaks reflecting distinct ecological conditions and productivity conditions. Overall, leptocephali biomass followed a west-to-east decreasing gradient, with the AS sustaining dense populations. The spatial patterns align with the hypothesis that many eel species spawn offshore, where oceanographic features such as eddies and upwelling zones enhance larval retention and survival.

Most adult species of leptocephalus within the Anguilliformes are treated as bycatch and diverted into poultry feed production. Exceptions include species such as *Muraenesox cinereus* and *Muraenesox bagio*, which are consumed domestically, and certain Ophichthidae (snake eels), which are eaten in Tamil Nadu (Kodeeswaran, 2024). While Congridae species are rarely consumed in India, they hold considerable value in Southeast Asian markets, where they are prepared as sushi, grilled dishes, or fried preparations. Unlocking the ecological and economic potential of eel fisheries in India requires further research into their biology, larval development, and biochemical properties. Such efforts may enhance their market value, improve conservation strategies, and encourage sustainable utilization.

## 3.3.3.Distribution and abundance of Cephalopods

Scientific cruises conducted onboard the FORV *Sagar Sampada* and research activities under the MLR programme have significantly improved our understanding of the cephalopod distribution in Indian waters. The cephalopod biomass data, revealed distinct spatial variations across the Indian EEZ. Varying biomass values reaching up to ≈42.78 gm/km$^2$, indicates strong regional heterogeneity. West coast, recorded moderate to high biomass, particularly off Goa, Karnataka, and Kerala, with peak values exceeding ≈42 gm/km$^2$. Elevated values were also recorded off Gujarat, reflecting enhanced productivity and the availability of mesopelagic prey. In the east coast biomass was generally lower, reaching up to ≈5 gm/km$^2$, with localized enrichments near to northern Andhra coast, possibly linked to riverine nutrient inflow and eddy mixing. Offshore stations occasionally recorded moderate catches, indicating the presence of cephalopods in slope ecosystems. In Andaman Sea waters, sampling yielded variable biomass reaching up to ≈18.9 gm/km$^2$, with high concentrations near the Nicobar waters, indicative of productive island-shelf and eddy-retention zones. Overall, cephalopod biomass exhibited a west-to-east declining trend, with the AS sustaining the highest mean biomass and isolated hotspots around 12°N and 10°N reflecting upwelling-driven productivity (Fig. 3.19).

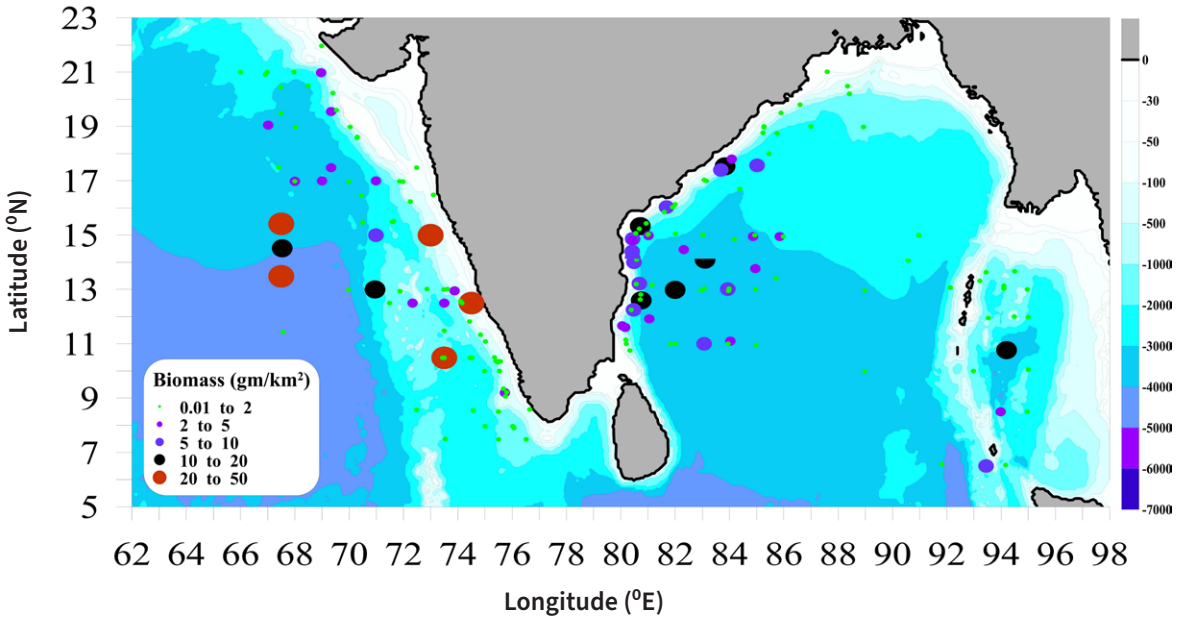



Fig. 3.19: Distribution of cephalopods in the DSL of the Indian EEZ (gm/km$^2$)

## 3.3.4.Shrimps in the Deep Scattering Layer

Pelagic shrimps form a major component of micronekton in the DSL layer. The occurrence of pelagic shrimps in mid and deep-oceanic waters has been documented since the mid-nineteenth century (Pearcy & Forss, 1966; Aizawa, 1969; Foxton, 1970a, b; Omori et al., 1972; Matthews & Pinnoi, 1973). Some species are migratory in the water column, adjusting their movements in response to light and biological needs, thereby adapting to both benthic and pelagic environments. Data from FORV *Sagar Sampada* confirmed that DSL across the Indian EEZ are rich in pelagic shrimps, which constitute one of the most abundant crustacean groups in the mesopelagic zone. A total of 11 families, 19 genera, and 29 species of pelagic shrimps were identified from the DSL samples collected using the Isaacs-Kidd Midwater Trawl (IKMT). The major families represented include Penaeidae, Benthesicymididae, Solenoceridae, Sergestidae, Luciferidae, Oplophoridae, Nematocarcinidae, Pasiphaeidae, Pandalidae, Thalassocarididae, and Stenopodidae. Prominent genera, such as *Gennadas*, *Oplophorus*, *Sergestes*, and *Acetes*, contributed significantly to biomass in the midwater ecosystem.

The distribution pattern of pelagic shrimps exhibited a clear latitudinal gradient, with abundance increasing from north to south. From the total 65-70% of shrimp biomass in the Indian EEZ of the AS, the south-west coast of India accounted for approximately 64% of the total shrimp biomass. The BoB contributes roughly 20-25% of the total biomass, while the Andaman and Nicobar waters account for the remaining 10-15%, further reinforcing the trend of higher shrimp density in India's southern maritime latitudes. (Fig. 3.20).

The depth distribution revealed that shrimps occur throughout the operational range of 10-750 m, with significant variations in biomass according to depth, time of day, and season. Analysis across different depth zones revealed that biomass increased progressively with depth, with ≈54.93% of the total catches recorded at > 300 m (Table 3.3). Around 77% of all shrimp catches were obtained from the 200-300 m and >300 m zones combined. Environmental parameters such as light penetration, temperature gradients, oxygen minima, and food availability significantly influenced their vertical and horizontal distribution. The shrimps exhibited pronounced diurnal migration behaviour, staying deeper (200-500 m) during the day to avoid predators and layers (50-200 m) at night to feed. This DVM is a characteristic behaviour of DSL organisms and contributes to nutrient cycling and energy transfer within the midwater ecosystem.

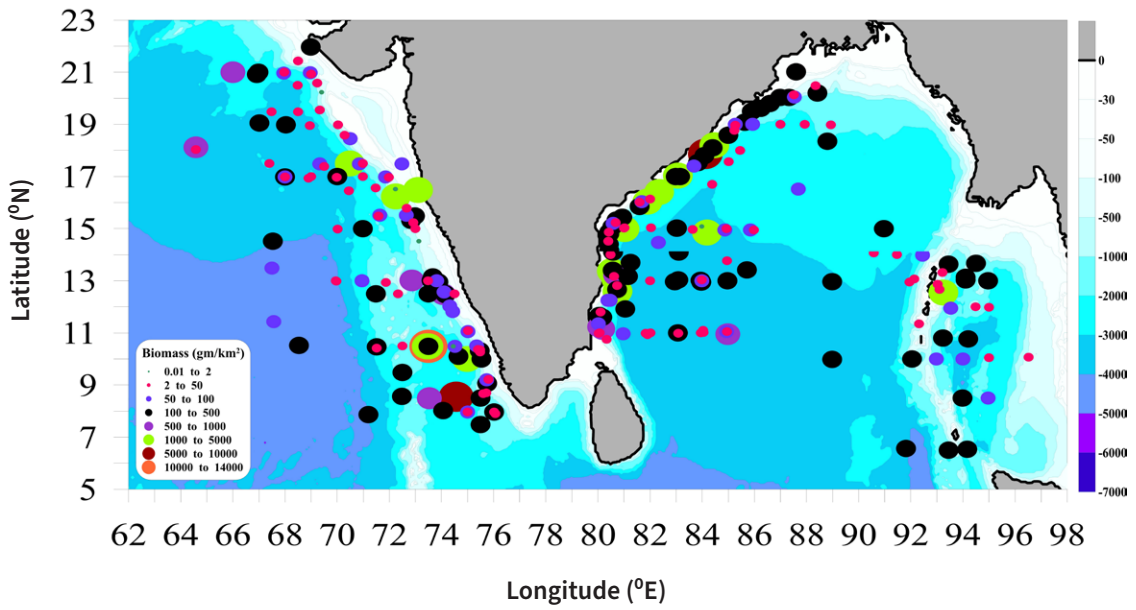



Fig. 3.20: Distribution of Shrimp in the DSL of Indian EEZ (gm/km$^2$) ascending to the upper

Table 3.3: Summary of Shrimp Biomass by Depth Zone (Indian EEZ)

| Depth (m) | Actual Biomass (gm/km$^2$) | Biomass Contribution (%) | Remarks |
|---|---|---|---|
| 0-50 | 1,832 | 2 | Minimal near-surface occurrence |
| 50-200 | 10,058 | 10.98 | Transitional feeding zone |
| 200-300 | 29,395 | 32.09 | Strong midwater presence |
| >300 | 50,317 | 54.93 | Dominant mesopelagic layer |

In conclusion, to address the heavy exploitation of juvenile sardines and mackerels in coastal waters, a time-bound, conditional subsidy regime can serve as a transition instrument to shift a defined portion of fishing effort to a regulated deep-water fishing (DWF) fleet, while simultaneously reducing juvenile removals from nearshore fisheries. The myctophids and other mesopelagic fishes can play a strategic role as an alternative offshore resource capable of absorbing part of the fishing effort presently concentrated in juvenile-prone coastal fisheries. Beyond harvest feasibility, product-chain considerations also matter. Microbiological assessments of myctophid fish from the AS, sampled on deep-sea trawlers, highlight food-safety implications and reinforce the need for handling and contamination monitoring if human consumption or higher-value utilization is envisioned, even where fishmeal dominates, quality assurance remains a practical constraint (Das et al., 2015). Indian investigations have long recognized the occurrence of dense myctophid layers associated with the DSL in offshore waters, while noting that these resources remain unexplored by the domestic fleet (Gopakumar et al., 1983; Menon, 2002). Integrating myctophid exploitation into a conditional subsidy regime- linked to Vessel Monitoring System (VMS) / Automatic Identification System (AIS) compliance, controlled access, and parallel reduction of coastal effort, which could support both resource diversification and juvenile conservation, provided development proceeds cautiously and is embedded within ecosystem-based management principles.

# 4 Deep-Sea Demersal Fishery Resources

India's deep-sea demersal fisheries within its EEZ represent a critical and largely untapped resource with significant potential to contribute to sustainable development, food security, and economic growth. Historically, India's commercial fisheries focused primarily on coastal waters, but deeper offshore areas remain underutilized (Hashim, 2012; Nihal et al., 2025). Deep-sea resource explorations began in the 1950s with government-led initiatives, including the establishment of the Deep-Sea Fishing Station in Mumbai in 1946 and the evolution of the Fishery Survey of India (FSI). The FSI and other organizations have conducted extensive surveys, expanding knowledge on deep-sea biodiversity and resources up to depths of 500 m.

The declaration of India's EEZ in 1976, extending jurisdictional rights up to 200 nautical miles from the coast, marked a milestone that enabled the large-scale exploitation of offshore fisheries, supported by policy reforms, subsidies, and foreign investment. However, early deep-sea fishing activities were limited by the capacity and technology of small vessels, with larger exploratory operations not beginning until the 1980s. A major milestone was the introduction of a comprehensive deep-sea fishing policy in 1991, which provided a roadmap for advancing the sector (D'cruz & Raikar, 2004). Up until the 1980s, trawling operations in India were predominantly confined to smaller vessels operating in coastal waters at depths up to 50 m. Larger vessels from organizations such as the FSI, Integrated Fisheries Project (IFP), Central Institute of Fisheries Nautical and Engineering Training (CIFNET), and the United Nations Development Programme (UNDP)/FAO Pelagic Fisheries Project conducted limited exploratory surveys in the Indian EEZ (James & Pillai, 1990). Under the Indo-Norway Integrated Ocean Initiative, the MoES and Norwegian partners are jointly developing marine spatial planning and integrated ocean management approaches for Indian waters, with MoES institutes, including CMLRE, contributing scientific expertise on marine ecosystems and living resources. A significant leap occurred in 1984 when DOD acquired the FORV *Sagar Sampada*. This research vessel, capable of conducting bottom trawling to depths up to and marginally exceeding 1,000 m, played a crucial role in revealing the rich diversity of deep-sea fish species across India's continental margin. Early exploratory efforts by vessels such as RV *Conch* and RV *Varuna* in the 1990s laid the groundwork for subsequent studies.

Over the past decades, India has implemented various measures to optimize the sustainable use of offshore and deep-sea resources within the EEZ. The Deep-Sea Fishing Policy of 1977 aimed to promote industrial-scale fishing, enhance marine export earnings, and encourage foreign collaboration for technology transfer and vessel acquisition. However, the policy soon faced criticism for excessive foreign involvement, inadequate monitoring, and marginalization of artisanal fishers. In response to these issues, the 1981 revision attempted to restore national control by restricting foreign participation, mandating Indian ownership in joint ventures, and strengthening licensing and monitoring systems.

The 1991 policy was aligned with India's broader economic liberalization reforms and promoted the export of high-value species such as tuna and cephalopods. While foreign collaboration was reintroduced under stricter conditions, concerns arose regarding ecological impacts, resource depletion, and equity. Growing tensions prompted the government to constitute the Murari Committee (1995) to review the policy's outcomes. The committee reported widespread violations by foreign vessels, weak Monitoring, Control, and Surveillance (MCS) systems, and an increasing number of conflicts with artisanal fishers. It recommended suspending foreign deep-sea operations, reserving coastal waters for traditional fishers, promoting Indian-owned

vessels, and enhancing research and infrastructure. Acting on these recommendations, foreign licenses were withdrawn in 1997, marking a decisive shift towards self-reliance in deep-sea fisheries. Further advancements include the Comprehensive Marine Fishing Policy (CMFP) of 2004, which adopted ecosystem-based management with stakeholder participation, and the National Policy on Marine Fisheries of 2017, which emphasized the Ecosystem Approach to Fisheries (EAF), biodiversity conservation, and socio-economic welfare. This policy mandated exclusive Indian ownership and operation of deep-sea fishing vessels, formally ending foreign access to the Indian EEZ (Fig. 4.1).

The 2025 report, "India's Blue Economy: Strategy for Harnessing Deep-Sea and Offshore Fisheries," released by the NITI Aayog, provides a phased, science-based, and sustainable roadmap for developing deep-sea fisheries. It focuses first on laying the foundation and fostering early growth (2025-28), then scaling up to achieve global competitiveness (2029-32), and ultimately aiming to achieve global leadership in sustainable deep-sea fisheries (post-2033). Despite existing policy frameworks, significant challenges remain in effectively harnessing India's deep-sea demersal fisheries. Coastal fisheries are increasingly overexploited, while deep-sea fishing faces critical gaps in infrastructure, finance, technology, and stakeholder engagement. Addressing these issues requires improved harvesting and post-harvesting technologies, robust monitoring systems, and upgraded shore-based facilities, including berthing, handling, and processing centres. Although the domestic market for deep-sea products is currently limited, opportunities for value addition offer considerable economic potential (Hashim, 2012).

## 4.1. Deep-sea fishery potential

In 2018, the potential yield estimates for deep-water resources were categorized into broader geographical

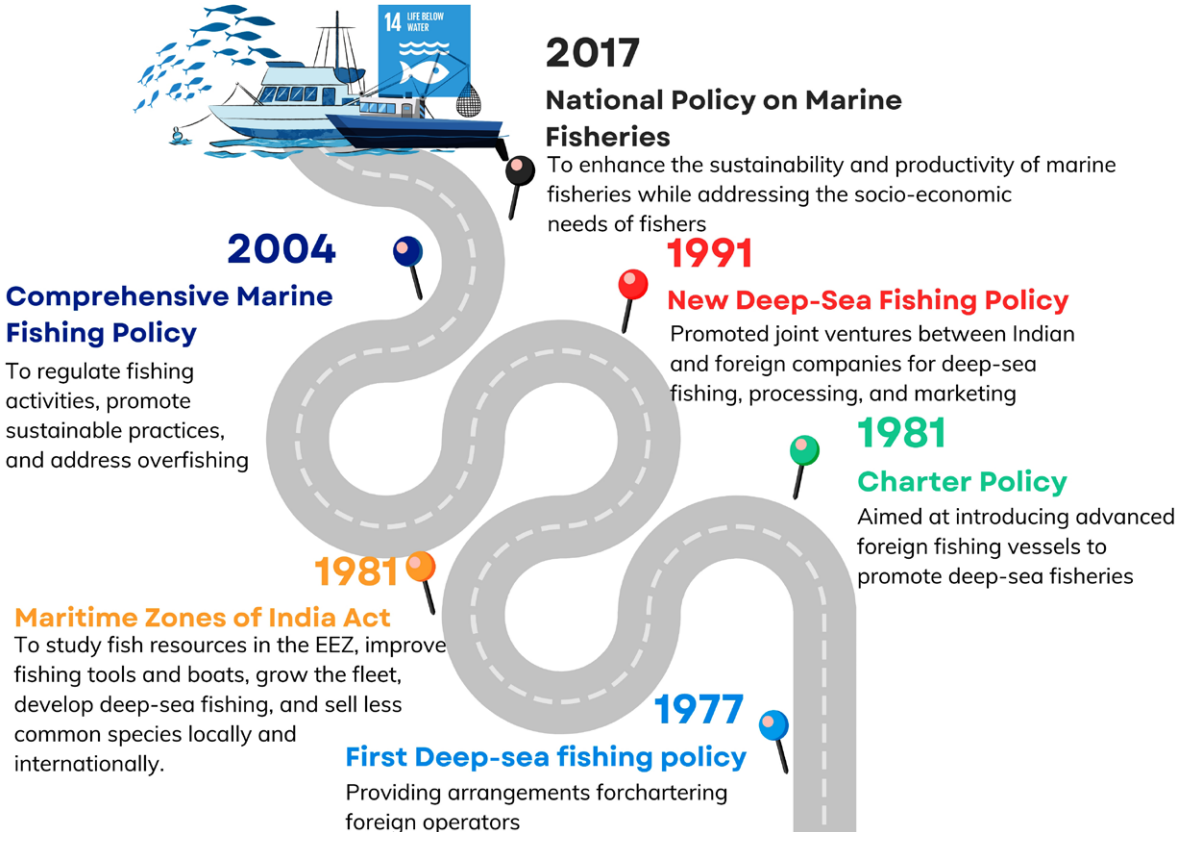



Fig. 4.1: Measures implemented by India for the sustainable utilization of offshore and deep-sea resources within the EEZ over the past decades

regions, viz. northwest, southwest, southeast, and northeast coastal areas, rather than being confined to maritime state boundaries. According to the Expert Committee for Revalidation of the Potential Yield of Fishery Resources in the Indian EEZ, the 2018 assessment for the 200-500 m depth zone was 97,461 tonnes, accounting for approximately 1.8% of the total conventional resources (Table 4.1). The resource potential in these depth zones was highest along the southwest coast (60%) and lowest along the southeast coast (6%) (Fig. 4.2).

Table 4.1: Revalidated potential yield estimation of the conventional fishery resources in 200-500 m depth zones and non-conventional resources from the Indian EEZ.

| **Conventional Resources (200-500m)** | **Quantity (tonnes)** |
|---|---|
| *Demersal resources (mainland)* | *89,000* |
| *Pelagic resources (mainland)* | *8,461* |
| *Sub-total* | *97,461* |
| **Non-conventional resources** | **Quantity (tonnes)** |
| *Deep-sea Myctophids* | *10,00,000* |
| *Ocean squids* | *630,000* |
| *Jellyfish* | *200,000* |
| *Marine macroalgae* | *17,775* |
| *Sub-total* | *18,47,775* |

*(Data source: DADF, 2018)*

# 4.2. FORV *Sagar Sampada*-based estimates of deep-sea and oceanic fishery resources in the Indian EEZ

This section brings together nearly four decades of deep-sea exploration and resource assessment carried out mainly onboard the FORV *Sagar Sampada*, which has been in continuous operation since 1985 and has generated the most comprehensive long-term record of India's deep-sea ecosystems. It presents a

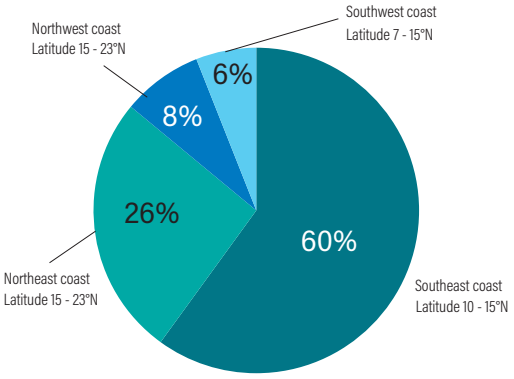



Fig. 4.2: Potential resources within the 200-500 m depth range across various regions of the mainland Indian EEZ *(Data source: DADF, 2018).*

coherent account of the distribution, abundance, stock structure, biodiversity, and fishery potential of deep-sea demersal resources within the Indian EEZ, highlighting both the historical development of the sector and quantitative stock assessments based on swept-area and sector-wise analyses (Table 4.2)

Table 4.2: Sector-wise estimates of total catch, standing stock, and MSY of deep-sea and oceanic resources in the Indian EEZ based on FORV *Sagar Sampada* surveys.

| **Sector** | **Total catch (kg)** | **Standing stock (tonnes)** | **MSY (tonnes)** |
|---|---|---|---|
| *NEAS* | *209* | *6,180* | *3,090* |
| *CEAS* | *1,083* | *11,610* | *5,806* |
| *SEAS* | *16,828* | *29,587* | *14,794* |
| *SWBoB* | *3,969* | *27,130* | *13,565* |
| *NWBoB* | *1,517* | *6,273* | *3,136* |
| *EANI* | *1,898* | *14,408* | *7,204* |
| *WANI* | *2,618* | *16,740* | *8,370* |
| *SANI* | *1,593* | *10,948* | *5,474* |
| *GoM* | *254* | *19,828* | *9,914* |
| *Total* | *29,969* | *1,42,704* | *71,353* |

*NEAS- North Eastern Arabian Sea, CEAS- Central Eastern Arabian Sea, SEAS- South Eastern Arabian Sea, SWBoB- Southwest By of Bengal, NWBoB- Northwest Bay of Bengal, EANI- Eastern Andaman and Nicobar Islands, WANI-Western Andaman and Nicobar Islands, SANI-Southern Andaman and Nicobar Islands, GoM- Gulf of Mannar*

In this section, we examined both the conventional demersal resources, such as deep-sea shrimps, Perciformes, Scombriformes, and flatfishes, and a wide range of non-conventional deep-sea groups, including Ophidiiformes, Gadiformes, Aulopiformes, and several others that have so far remained largely outside mainstream fisheries. For each group, we assessed what is currently known about their resource status, distribution patterns, level of exploitation, and long-term sustainability, and discussed where real exploration opportunities lie.

To maintain a readable main narrative while still doing justice to the richness of the data, the detailed analytical work is presented in the Annexures. Annexure 4 brings together the full station-wise analyses of deep-sea demersal fish diversity, biomass and community structure from the (4a) Arabian Sea, (4c) Bay of Bengal B, and (4b) Andaman & Nicobar region, including the underlying sampling design, bathymetric stratification, species inventories, biomass estimates using the swept-area method, diversity indices, K-dominance patterns, and multivariate analyses (cluster, nMDS and SIMPER). Annexure 5b provides the annotated checklist of all deep-sea demersal fishes recorded from the Indian EEZ during FORV *Sagar Sampada* cruises, which serves as the taxonomic backbone for this report. Taken together, this section represents a collective scientific memory of 40 years of work at sea, and is intended to provide a solid, experience-based foundation for sensible policy, careful development, and long-term stewardship of India's deep-ocean resources.

## 4.3. Conventional deep-sea fishery resources in the Indian EEZ

India's deep-sea fisheries encompass a diverse range of species, including deep-sea shrimps, finfish, cephalopods, crabs, and sharks (Fig. 4.3). The potential of these fisheries is significant but remains underutilized for various reasons. A list of commercially important species is provided in Table 4.3. In the case of shark fisheries, commercial exploitation has been significantly reduced, considering their International Union for Conservation of Nature (IUCN) status (Porcher & Darvell, 2022).



Fig. 4.3: Mixed species composition of deep-sea fishes recorded onboard FORV *Sagar Sampada* during exploratory surveys

Table 4.3: Major deep-sea species with their ecological (IUCN) status.

| Shellfishes | SW Coast | SE Coast | IUCN status |
|---|---|---|---|
| *Aristeus alcocki* | ● | ● | *NE* |
| *Heterocarpus chani* | ● | ● | *NE* |
| *Heterocarpus woodmasoni* | ● | ● | *NE* |
| *Plesionika quasigrandis* | ● | ● | |
| *Plesionika ensis* | ● | ● | |
| *Plesionika spinipes* | ● | ● | *NE* |
| *Plesionika semilaevis* | ● | ● | *NE* |
| *Pontocaris* spp. | ● | ● | |
| *Metapenaeopsis coniger* | ● | ● | *NE* |
| *Metapenaeopsis andamanensis* | ● | ● | *NE* |
| *Penaeopsis jerryi* | ● | ● | *NE* |
| *Solenocera hextii* | ● | ● | *NE* |
| *Puerulus sewelli* | ● | ● | *LC* |
| *Nephropsis carpenteri* | ● | ● | *LC* |
| *Plesionika martia* | ● | ● | *NE* |
| *Heterocarpus gibbosus* | ● | ● | *NE* |
| **Sharks and Finfishes** | | | |
| *Centrophorus cf. granulosus* | ● | ● | *EN* |
| *Centrophorus squamosus* | ● | ● | *EN* |
| *Centrophorus atromarginatus* | ● | ● | *CR* |
| *Alopias superciliosus* | ● | ● | *VU* |
| *Echinorhinus brucus* | ● | ● | *EN* |
| *Hexanchus griseus* | ● | ● | *NT* |
| *Priacanthus hamrur* | ● | ● | *LC* |

● Present ● Absent

## 4.3.1. Status of Deep-sea shrimp fishery

Deep-sea shrimps are India's most valuable crustacean resources and are predominantly found on the upper continental shelf and slope at depths ranging from 200-800 m. The southwest and southeast regions have been identified as promising fishing grounds, with an estimated potential yield of approximately 5,000 tonnes (Suseelan, 1996). India hosts a diverse range of deep-sea penaeid and caridean prawn species, including families such as Pandalidae, Solenoceridae, Crangonidae, Penaeidae, Acanthephyridae, Sergestidae, Aristeidae, Glyphocrangonidae, Hippolytidae, Oplophoridae, Pasiphaeidae, Sicyoniidae, and Stylodactylidae (Purushothaman, 2018). In Indian waters, the catch from both the Arabian Sea (AS) and the Bay of Bengal (BoB) is dominated by several key species, including *Aristeus alcocki*, *Heterocarpus chani*, *Heterocarpus woodmasoni*, *Metapenaeopsis andamanensis*, *Plesionika quasigrandis*, *Plesionika semilaevis*, *Solenocera hextii*, and *Penaeopsis jerryi* (Fig. 4.4).

Along the southwest coast, the Kollam Bank, located between latitudes 8°N and 9°N and longitude 76°E, has been a significant contributor to the deep-sea shrimp fishery. Between 1999 and 2020, the annual average landings of deep-sea shrimp were estimated at 11,315 tonnes, while the corresponding figure for the period 2007-2020 was 9,137 tonnes (Chakraborty et al., 2022). An analysis of catch trends revealed that the fishery peaked in 2000, bottomed out in 2010, and exhibited consistent fluctuations over the years. During 1999-2003, approximately 73% of the shrimp catch at Sakthikulangara fishing harbour originated from this region (Rajool Shanis, 2014) (Fig. 4.5). The contribution further increased to 84% during 2003-2006 and remained consistent from 2007 to 2017, with the exception of a few years between 2008 and 2010. Additionally, the Cochin Fisheries Harbour accounted for about 15% of the recorded landings between 2009 and 2017 (Kuberan, 2019).

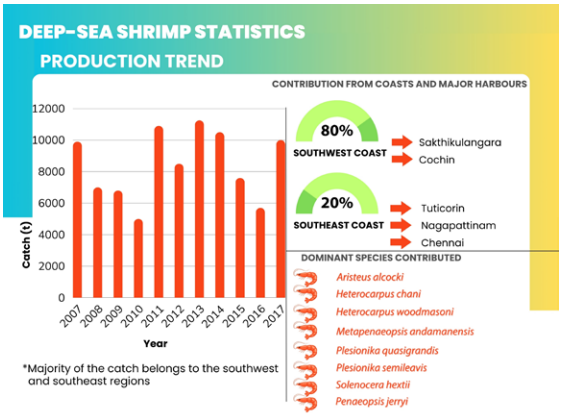



Fig. 4.4: Total deep-sea shrimp production trend in India *(Data source: Purushothaman, 2018)*



Fig. 4.5: Deep-sea shrimp landings at Sakthikulangara harbour

Along the southeast coast, deep-sea fishing grounds are found between Kanyakumari and Chennai, at depths of 250 to 800 m. However, major deep-sea shrimp landings are reported from the Tuticorin, Nagapattinam, and Chennai fishing harbours (Purushothaman, 2018). A total of 25 deep-sea shrimp species have been identified, though the catch is primarily dominated by a few species, such as *Heterocarpus chani*, *Heterocarpus woodmasoni*, *Aristeus alcocki*, *Metapenaeopsis andamanensis*, *Plesionika quasigrandis*, *Plesionika semileavis*, and *Solenocera hextii*. This species composition closely aligns with observations from the southwest coast, and the remaining species contributed only marginally to the overall deep-sea shrimp catch (Kuberan, 2019). Between 2007 and 2014, the annual average catch of deep-sea shrimp was 1,920 tonnes, followed by a threefold increase in 2015 and 2016, reaching 5,686 and 5,907 tonnes, respectively. However, a sharp decline was observed in 2017, with landings dropping to 1,694 tonnes (Purushothaman, 2018). *M. andamanensis* contributed the highest share of the total catch, accounting for 59% in Chennai and 75% in Nagapattinam. The combined landings from these harbours amounted to 15,544 tonnes over the period 2007-2017 (Kuberan, 2019).

## Status of deep-sea shrimps in the Indian EEZ based on FORV *Sagar Sampada* exploratory surveys

Exploratory surveys conducted across the Indian EEZ reveal that deep-sea shrimps form a significant shellfish resource along the continental slope of the AS, BoB, and Andaman Sea (Fig. 4.6). The spatial distribution of standing stock delineates that shrimp resources are mainly concentrated along the upper to mid-slope regions, with values ranging from 0.05 kg/km$^2$ to 2,500 kg/km$^2$. The AS exhibits relatively higher standing stock (11,727 kg/km$^2$) along the southwest continental margin, particularly off the Kerala-Karnataka coast. The species composition in this region is diverse, with *Metapenaeopsis* sp. contributing the highest proportion (34%), followed by *Plesionika spinipes* (14%), *Heterocarpus gibbosus* (10%), *Aristaeopsis edwardsiana* (10%), and *Aristeus alcocki* (6%), while 'other species' collectively account for about 26%. This indicates a multispecies assemblage and suggests the presence of potentially exploitable deep-sea shrimp resources in selected slope areas of the AS.

The BoB waters exhibit comparatively fewer high-standing stock zones (952 kg/km$^2$) and a distinct species structure. The catch composition is largely dominated by 'other species' groups. A caution should be exercised while interpreting this dominance, as the 'other species' category reflects taxonomic ambiguities and species-level identification constraints associated with onboard collection and sorting under exploratory survey conditions. This category is followed by *Aristaeopsis edwardsiana* (17%), while *Aristeus* sp. and *Aristeus alcocki* together contribute less than 10% of the total catch. The Andaman Sea stands out as a distinct region with comparatively moderate biomass (3653 kg/km$^2$) and greater species heterogeneity. The dominant species is *Aristeus alcocki* (33%), followed by *Heterocarpus gibbosus* (25%), *Acanthephyra fimbriata* (7%), *Heterocarpus laevigatus* (6%), *Plesionika martia* (6%), and *Plesionika spinipes* (5%), indicating species diversity and the presence of commercially important deep-sea shrimp taxa in the Andaman region (Fig. 4.7).

The exploratory surveys on deep-sea shrimp indicate that the distribution of these resources is discontinuous, characterized by discrete fishing

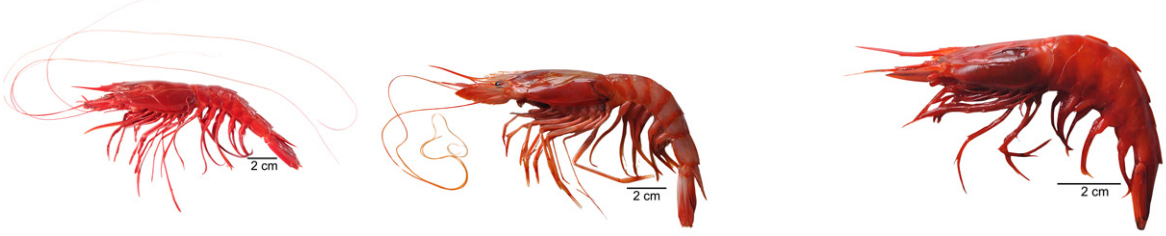


Fig 4.6: Deep-sea shrimp catches observed during survey operations of FORV *Sagar Sampada*

grounds rather than uniform availability across the slope, and with region-specific dominance of species. Although some areas show relatively high shrimp abundance and may have potential for utilization, most species are slow-growing, and current resource estimates remain uncertain (Rajool Shanis, 2014). The




*Metapenaeopsis* sp. *Plesionika* sp. *Heterocarpus gibbosus*




*Aristaeopsis edwardsiana* *Aristeus alcocki* *Acanthephyra fimbriata*

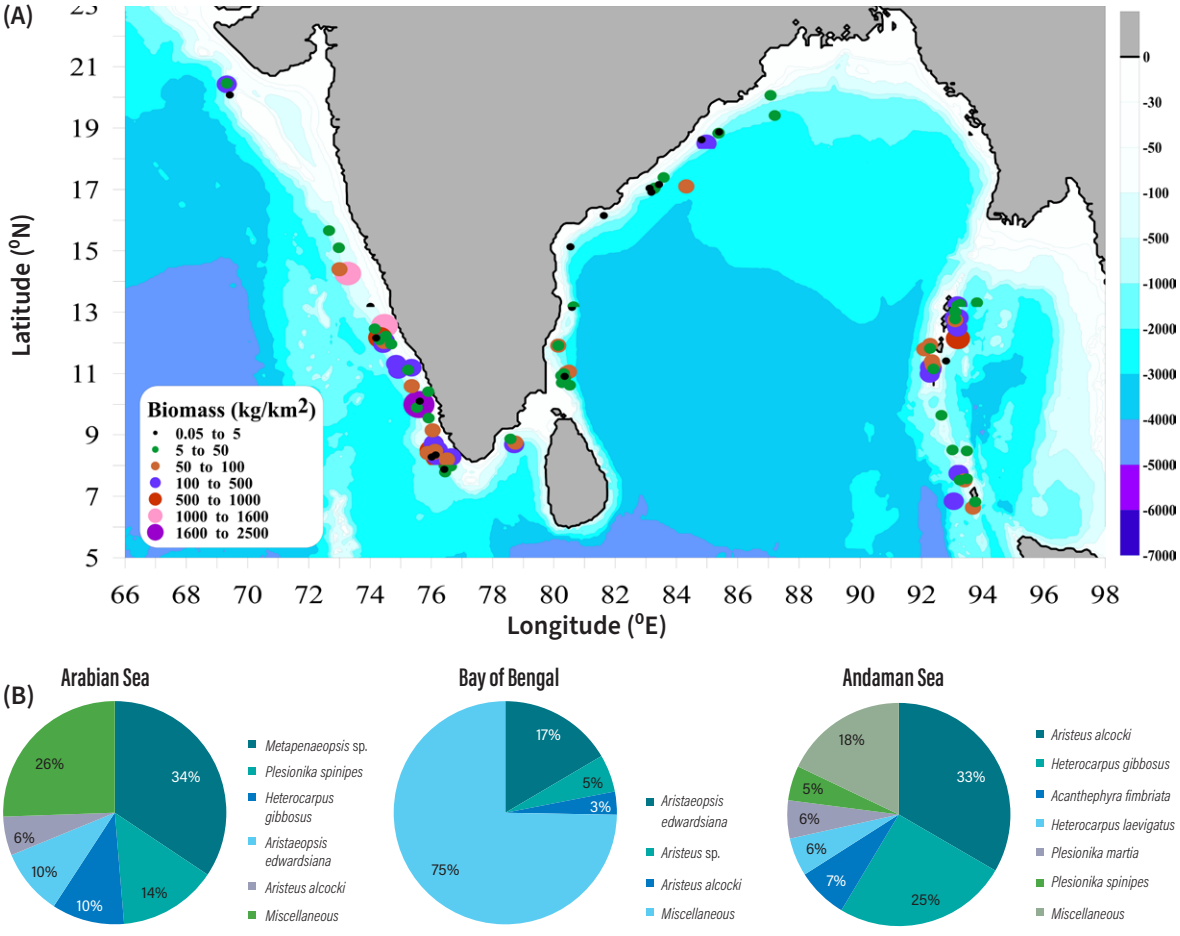



Fig. 4.7: (A) Spatial distribution of deep-sea shrimp standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of shrimps across different regions.

findings emphasize the need for systematic stock assessments and strengthened taxonomic resolution before considering large-scale or targeted harnessing of deep-sea shrimp resources in the Indian EEZ.

## 4.3.2. Deep-sea Perciformes fishery- present status

Deep-sea Perciformes in the Indian EEZ exhibit a distinctly slope-restricted distribution, with the highest standing stock concentrated along productive margin systems rather than in open-ocean basins. The SEAS and the Andaman-Nicobar slope constitute the major standing stock abundance (600-3700 kg/km$^2$). A moderately productive standing stock belt (200-600 kg/km$^2$) continues along the Kerala-Karnataka slope, whereas the central BoB remains sparsely populated (<20-50 kg/km$^2$) (Fig. 4.8). Species composition reflects a diverse multi-species assemblage rather than dominance by a single taxon. The community comprises *Bembrops caudimacula*, *Bembrops platyrhynchus*, *Satyrichthys laticeps*, *Setarches guentheri*, *Pterygotrigla hemisticta*, *Chelidoperca investigatoris* and *Uranoscopus crassiceps*, each contributing in varying proportions across all three regions. Among these, *B. caudimacula* and *B. platyrhynchus* appear more consistently distributed, while *S. laticeps* and *S. guentheri* remain patchier and less abundant, with *P. hemisticta* and *C. investigatoris* forming persistent but minor components, and *U. crassiceps* being the least represented (Table 4.4).




*Bembrops caudimacula*




*Satyrichthys laticeps*




*Bembrops platyrhynchus*




*Setarches guentheri*




*Pterygotrigla hemisticta*




*Uranoscopus crassiceps*




*Chelidoperca investigatoris*




*Scalicus serrulatus*

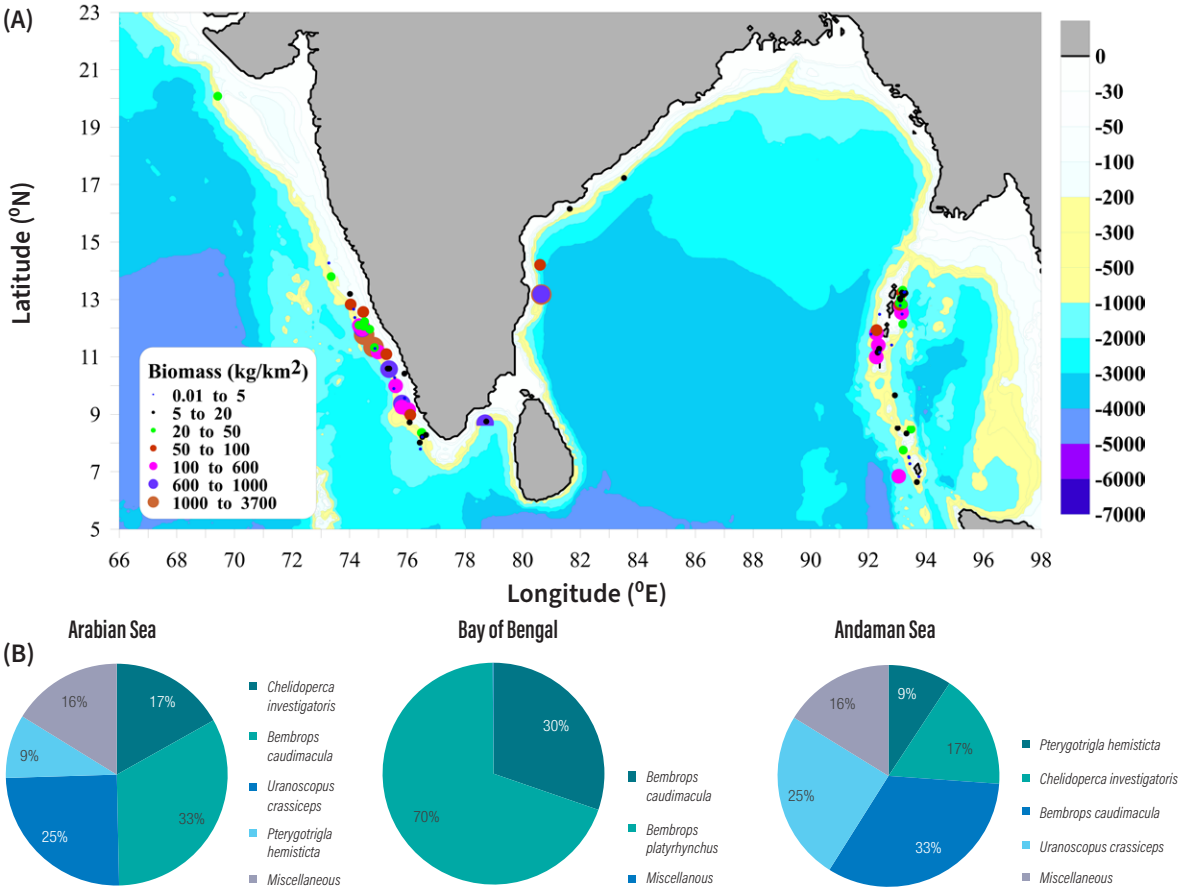



Fig. 4.8: (A) Spatial distribution of Perciformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Perciformes across different regions.

Table 4.4: Spatial patterns in standing stock and species composition of deep-sea Perciformes across Indian EEZ sectors derived from FORV *Sagar Sampada* surveys.

| Sector | Dominant species | Total Standing Stock (tonnes) | MSY (tonnes) |
|---|---|---|---|
| *SEAS* | *Bembrops caudimacula, Uranoscopus crassiceps, Pterygotrigla hemisticta* | *2,557* | *1,279* |
| *CEAS* | *Chelidoperca investigatoris* | *3* | *1* |
| *NEAS* | *Chelidoperca investigatoris* | *520* | *260* |
| *SWBoB* | *Bembrops caudimacula Bembrops platyrhynchus* | *14,188* | *7,444* |
| *NWBoB* | *Bembrops caudimacula* | *64* | *32* |
| *EANI* | *Bembrops caudimacula, Bembrops platyrhynchus* | *1,047* | *523* |
| *WANI* | *Scalicus serrulatus, Bembrops caudimacula, Lythrichthys longimanus* | *521* | *261* |
| *SANI* | *Pterygotrigla hemisticta, Satyrichthys laticeps, Satyrichthys longimanus* | *267* | *149* |
| *GM* | *Bembrops caudimacula Satyrichthys laticeps* | *4,860* | *2,430* |

India has a well-established deep-sea priacanthid fishery, particularly for *Priacanthus hamrur*, which contributes ≈12% of southwest coast landings and peaks in April, August and November, indicating sustained year-round fishery activity (Sivakami et al., 2001) (Fig. 4.9). Exploratory surveys confirm the dominance and commercial significance of *P. hamrur* in the SEAS deep-sea fishery sector (Chakraborty, 1994; Viji et al., 2017). Despite this, the majority of other Indian deep-sea Perciform species remain under-exploited, primarily entering landings as low-value bycatch. Their largely intact population status offers future harvest potential, but only under precautionary, assessment-driven management that avoids the historical over-exploitation trajectory seen in global deep-water fisheries.



Fig. 4.9: Representative catches of priacanthid fishes collected onboard FORV *Sagar Sampada*

## 4.3.3.Deep-sea Scombriformes fishery-present status

Deep-sea Scombriformes along the Indian continental slope forms a structured assemblage shaped by bathymetry, slope productivity, and OMZ-linked hydrography, with *Neoepinnula orientalis, Cubiceps baxteri, C. whiteleggii*, and *Promethichthys* spp. representing dominant taxa (Nakamura & Parin, 1993). Species composition varies across all the Indian EEZ, with *C. baxteri* dominating in the Andaman Sea (52%) while *N. orientalis* being dominant in the AS (49%) and the BoB (58%). Biomass distribution




*Neoepinnula orientalis*




*Cubiceps whiteleggii*




*Cubiceps baxteri*




*Promethichthys* sp.




*Psenopsis cyanea*




*Trichiurus lepturus*




*Gempylus serpens*




*Aphanopus microphthalmus*

highlights two major hotspots: the south-eastern AS slope and the Andaman-southern BoB margin, with standing stock typically ranging from 200-500 kg/km$^2$ and local peaks >1000 kg/km$^2$, whereas the central BoB has comparatively low-yield (<20-50 kg/km$^2$) (Fig. 4.10). Spatial overlap between standing

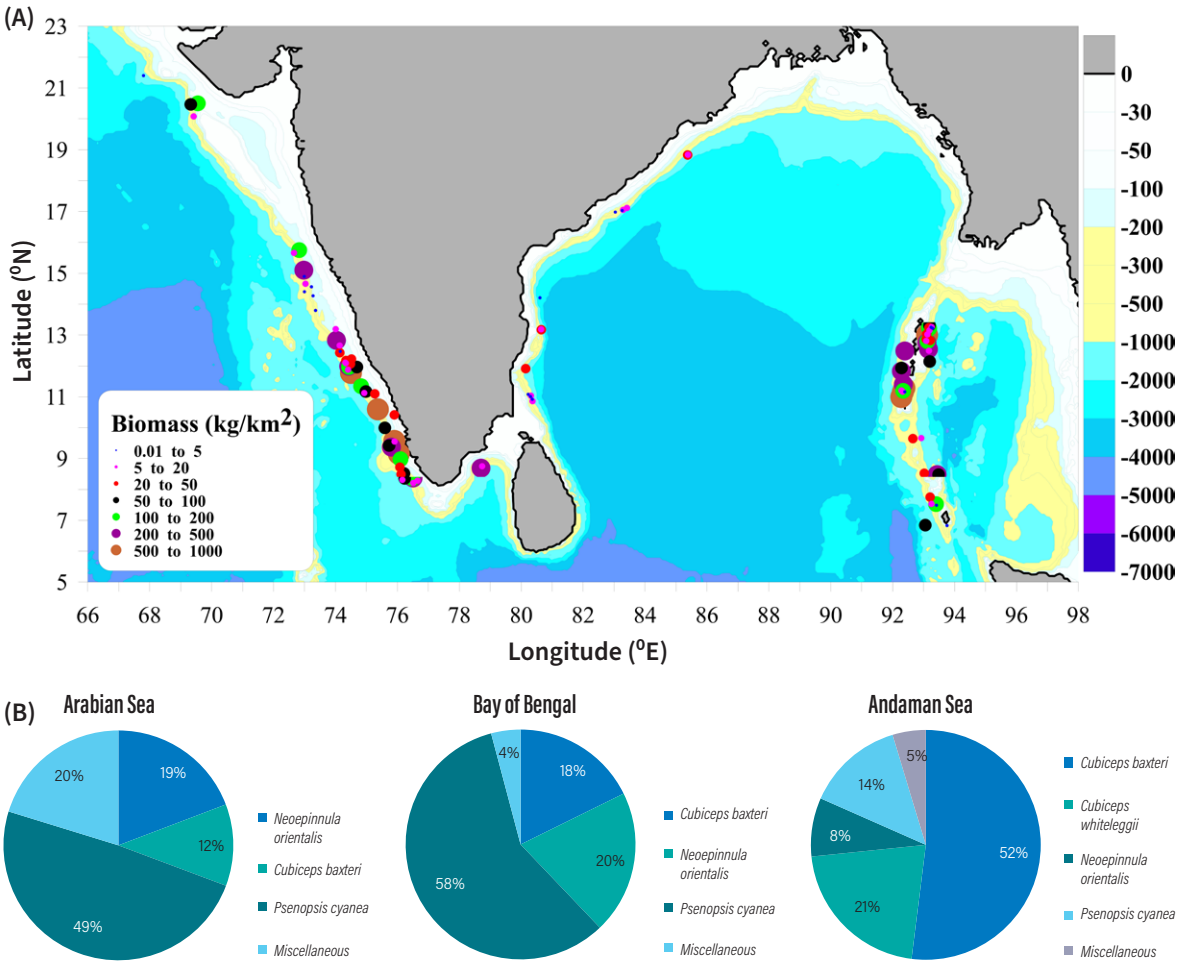



Fig. 4.10: (A) Spatial distribution of Scombriformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Scombriformes across different regions.

stock and species dominance suggests that slope curvature and hypoxic gradients serve as aggregation drivers (Morato et al., 2005), supporting their role as key mediators of mid-trophic energy in deep-slope food webs (Drazen & Haedrich, 2012).

Compared to global fisheries such as *Aphanopus carbo* in the Northeast Atlantic (Bordalo-Machado et al., 2009) and *Rexea solandri* in Australia (Nakamura & Parin, 1993), India remains in a very early exploitation phase for deep-sea scombriforms. Landings are predominantly incidental, sourced from deep-sea trawls and gillnets rather than targeted fisheries. *N. orientalis* is the most consistently landed species, particularly along Tamil Nadu and the Gulf of Mannar, where it appears across seasons (Abdussamad et al., 2011). *Cubiceps baxteri* and *Promethichthys* spp. occur regularly across basins but remain under-harvested relative to higher standing stock (Augustina et al., 2025). Additionally, *Psenopsis cyanea* (Indian ruff) is an under-exploited deep-sea finfish occurring along the west coast of India beyond 200 m depth, with its main distribution on the upper continental slope between 180-300 m. Exploratory trawl surveys conducted onboard FORV *Sagar Sampada* have recorded the species primarily between 7° and 12° N latitude, with higher abundance in the 200-400 m depth range, particularly off Kerala and Tamil Nadu (Venu & Kurup, 2002; Sajeevan & Nair, 2006). It forms a regular component of multispecies deep-sea catches, showing comparatively higher Catch Per Unit Effort (CPUE) in the 300-400 m zone, and occasionally contributes notable landings during upwelling intrusions, such as those reported off Kakinada (Abdussamad & Achayya, 1999). Despite its wide bathymetric occurrence and recurrent presence in trawl catches, *P. cyanea* remains an unexploited, non-conventional resource, with no targeted fishery developed in Indian waters (Venu & Kurup, 2002; Aneesh Kumar et al., 2016). Overall, India is at a favourable pre-development stage, with the stock showing potential for future exploration (Table 4.5). With precautionary, science-driven management, it holds the opportunity to develop one of the most sustainable deep-sea Scombriform fisheries globally, avoiding the collapse-and-rebuild trajectories observed in many already depleted international stocks (Norse et al., 2012).

Table 4.5: Spatial distribution of standing stock and regional species composition of deep-sea Scombriformes in the Indian EEZ based on FORV *Sagar Sampada* surveys.

| Sector | Dominant species | Total Standing Stock (tonnes) | MSY (tonnes) |
|---|---|---|---|
| *SEAS* | *Neoepinnula orientalis, Psenopsis cyanea, Cubiceps baxteri* | *1,371* | *685* |
| *CEAS* | *Neoepinnula orientalis, Cubiceps baxteri* | *632* | *316* |
| *NEAS* | *Neoepinnula orientalis, Psenopsis cyanea, Cubiceps baxteri* | *914* | *457* |
| *NBoB* | *Neoepinnula orientalis, Psenopsis cyanea,* | *58* | *29* |
| *SBoB* | *Psenopsis cyanea, Cubiceps baxteri, Promethichthys prometheus* | *172* | *86* |
| *EANI* | *Psenopsis cyanea, Cubiceps baxteri, Cubiceps whiteleggii* | *3,346* | *1,673* |
| *WANI* | *Cubiceps baxteri, Cubiceps whiteleggii* | *1,366* | *683* |
| *SANI* | *Neoepinnula orientalis, Psenopsis cyanea, Cubiceps baxteri* | *726* | *363* |
| *GM* | *Trichiurus lepturus, Neoepinnula orientalis, Gempylus serpens, Aphanopus microphthalmus* | *2,459* | *1,230* |

## 4.3.4.Deep-sea Pleuronectiformes fishery-present status

The distribution of deep-sea Pleuronectiformes (flat fishes) in the Indian EEZ is strongly slope-associated, with occurrences concentrated along the AS and Andaman continental margins. Biomass values mostly range from 2 to 20 kg/km$^2$ in the AS, although occasional hotspots reach 20-60 kg/km$^2$, with one high-density point exceeding 100 kg/km$^2$ on the southwest slope. In contrast, the Andaman region exhibits denser station clustering, including multiple moderate-to-high-biomass zones and a prominent hotspot exceeding 100 kg/km$^2$, indicating favourable benthic conditions (Fig. 4.11). The central BoB exhibits almost no biomass, indicating low suitability for flatfish habitats (Hashim et al., 2025).




*Chascanopsetta lugubris*




*Laeops macrophthalmus*

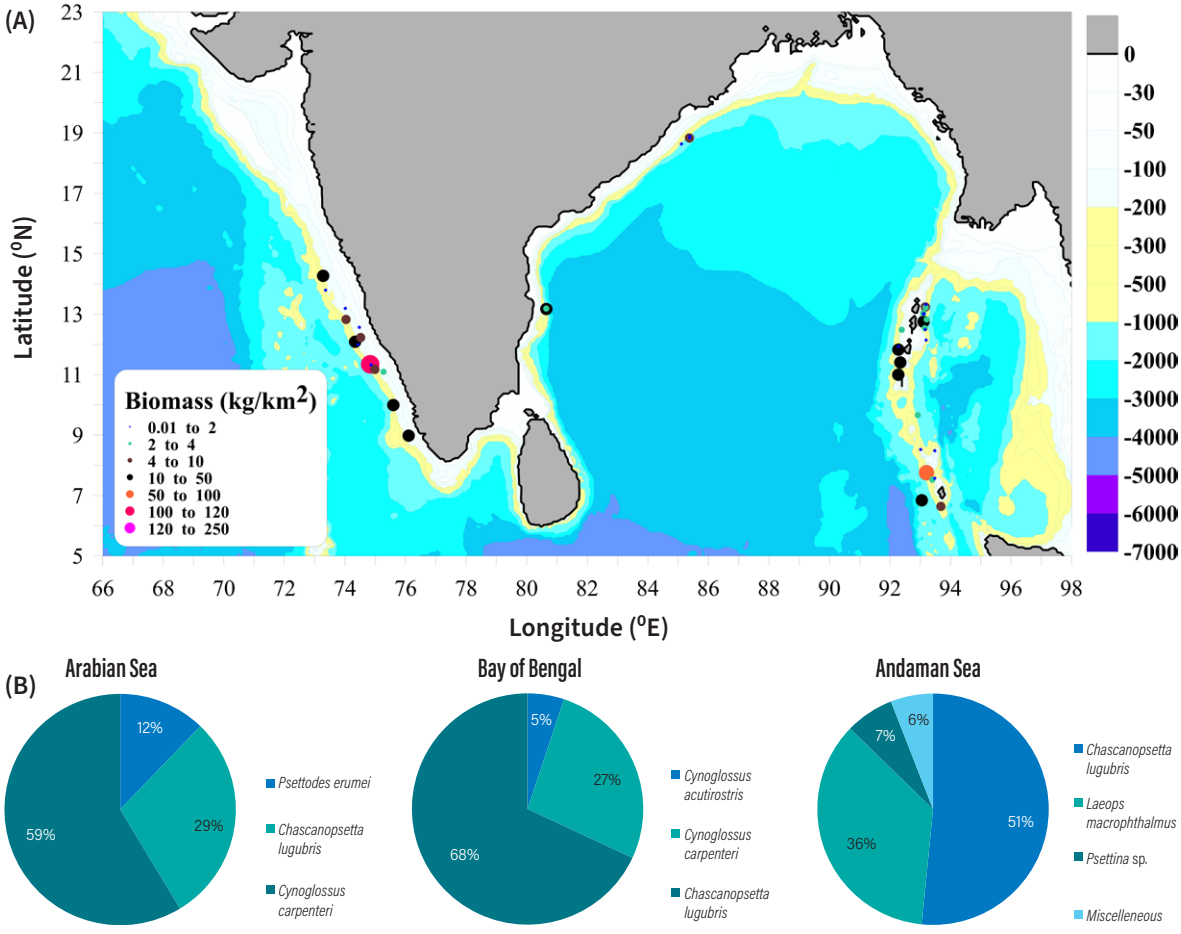



Fig. 4.11: (A) Spatial distribution of Pleuronectiformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Pleuronectiformes across different regions.

Table 4.6: Standing stock distribution and species composition of deep-sea Pleuronectiformes in the Indian EEZ.

| Sectors | Dominant species | Total standing stock (tonnes) | MSY (tonnes) |
|---|---|---|---|
| *SEAS* | *Chascanopsetta lugubris, Cynoglossus carpenteri, Psettodes erumei* | *525* | *263* |
| *CEAS* | *Cynoglossus carpenteri* | *197* | *99* |
| *NEAS* | *Chascanopsetta lugubris, Cynoglossus carpenteri* | *56* | *28* |
| *NBoB* | *Chascanopsetta lugubris, Cynoglossus carpenter, Cynoglossus acutirostris* | *6* | *3* |
| *SBoB* | *Chascanopsetta lugubris, Cynoglossus carpenteri* | *94* | *47* |
| *EANI* | *Chascanopsetta lugubris, Psettina sp.* | *213* | *107* |
| *WANI* | *Chascanopsetta lugubris* | *413* | *207* |
| *SANI* | *Laeops macrophthalmus* | *137* | *69* |

The composition of deep-sea Pleuronectiformes across the Indian EEZ showed sector-wise differences. In the Andaman & Nicobar waters, *Chascanopsetta lugubris* is the most abundant species, contributing 51.58%, followed by *Laeops macrophthalmus* at 35.70%, while *Psettina* sp. and miscellaneous taxa account for 6.79% and 5.93%, respectively. In the BoB, the assemblage is strongly dominated by *Chascanopsetta lugubris* (68.05%), with *Cynoglossus carpenteri* accounting for 26.85% and *C. acutirostris* for 5.10%. In contrast, the AS shows a different pattern, with *Cynoglossus carpenteri* as the predominant species, accounting for 66.65%, while *Chascanopsetta lugubris* accounted for 33.13%. These sectoral differences highlight clear biogeographic variations in pleuronectiform assemblages across the northern Indian Ocean.

Globally, flatfishes of the order Pleuronectiformes contribute significantly to demersal fisheries, though most exploited taxa inhabit shallower depths rather than truly deep-sea slopes (Nelson et al., 2016; FAO, 2020). The deep-sea pleuronectiform species *Chascanopsetta lugubris*, *Cynoglossus carpenteri*, and *C. acutirostris* are not known to be exploited in any targeted commercial fishery globally, and they do not contribute to documented flatfish landings. This pattern is similar in India, where flatfish catches are generally dominated by shallow-water soles such as *Cynoglossus macrostomus*, while deeper-water or slope-associated species remain absent in commercial records and occur only as incidental bycatch in bottom-trawl operations (Table 4.6). As a result, these species are effectively unexploited, with no available information on stock status or fishery pressure at either the global or national scale.

# 4.4.Potential non-conventional resources

## 4.4.1.Ophidiiformes-resource status

The standing stock of Ophidiiformes within the Indian EEZ exhibited significant spatial heterogeneity, reaching 13,390 kg/km$^2$. The highest standing stock was observed in the AS, moderate in the BoB, and




*Lamprogrammus niger*




*Lamprogrammus brunswigi*




*Bassozetus robustus*




*Hypopleuron caninum*

relatively low in other regions, reflecting a patchy distribution. The AS assemblage was strongly dominated by *Lamprogrammus niger*, contributing approximately 74% to the total Ophidiiformes standing stock. In the BoB region, *L. brunswigi* accounted for about 44% of the standing stock. In the Andaman Sea, *Bassozetus robustus* contributed 32%, followed by *Hypopleuron caninum* (14.6%) and *L. brunswigi* (14%) (Fig. 4.12).

Many deep-sea ophidiiform fishes are not currently targeted in commercial fisheries and are mostly recorded as bycatch during deep-sea trawl operations. The available global and regional fishery databases indicate that *Monomitopus nigripinnis* has demonstrated clear potential as a non-conventional commercial resource, particularly along the Indian coast (Chennai harbour) (Kizhakudan & Rajapackiam, 2013), where it is regularly landed in deep-sea trawls and sold in local markets. Species such as *Hypopleuron caninum* and *Neobythites steatiticus* are frequently encountered in deep-sea catches and exploratory surveys (Venu, 2013), suggesting a possible scope for future utilisation if economic feasibility and

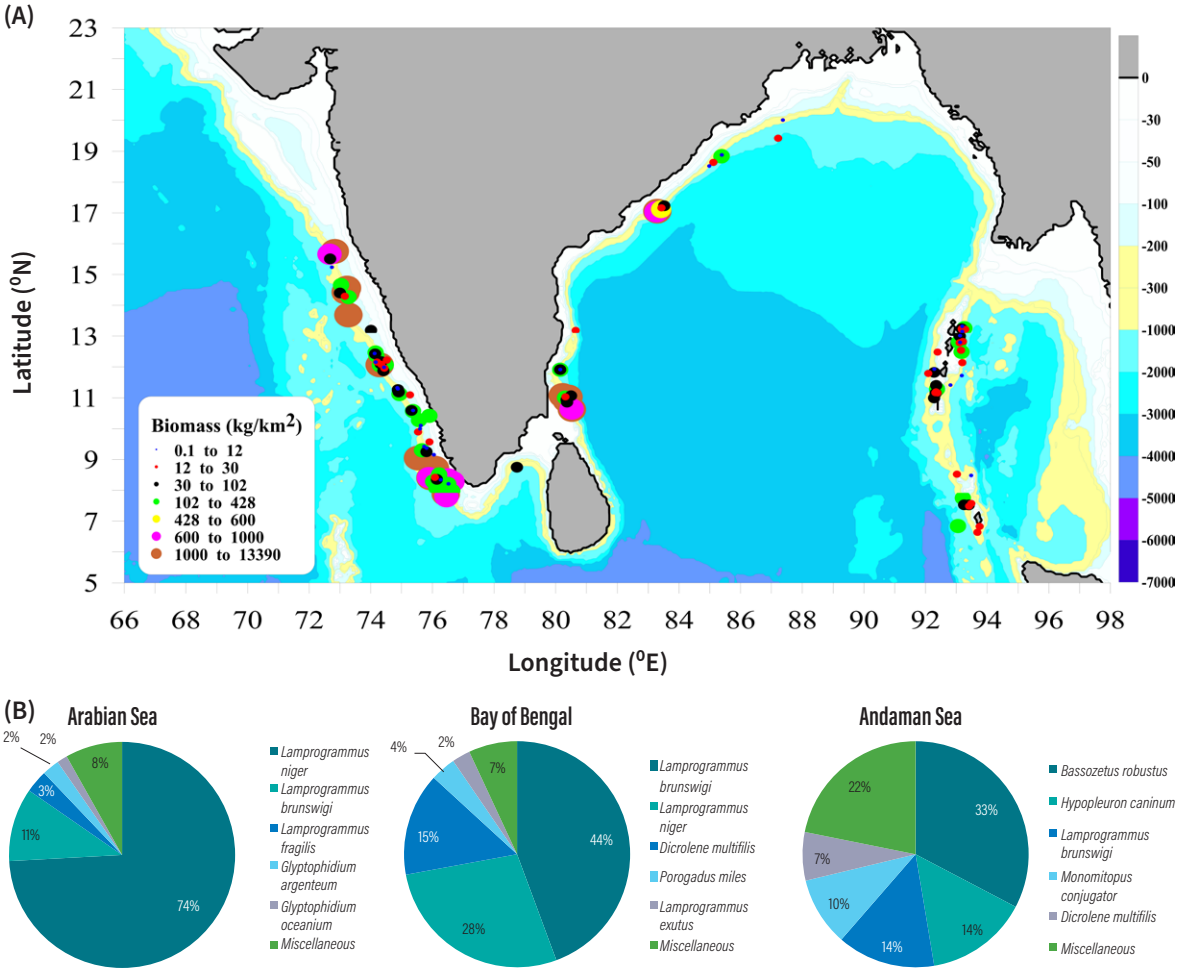



Fig. 4.12: (A) Spatial distribution of Ophidiiformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Ophidiiformes across different regions.

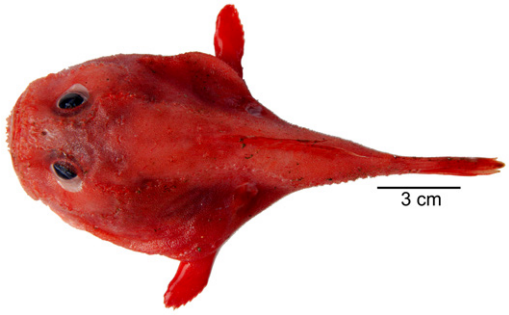
market demand increases. The remaining species in this group consistently occur in deep-sea bycatch, highlighting the need for further investigation into their biological characteristics, stock potential, and sustainable exploitation prospects.

## 4.4.2.Lophiiformes- resource status

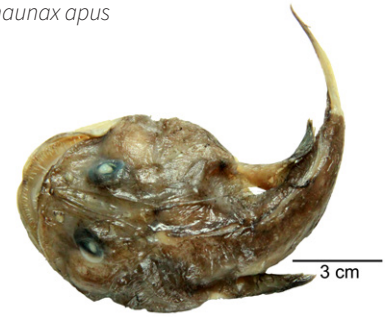
Along the Indian EEZ, Lophiiformes standing stock exhibited a discontinuous distribution pattern, reaching 638 kg/km$^2$. The Andaman Sea demonstrated the highest standing stock (> 300 kg/km$^2$), dominated by species *Chaunax multilepis* (56%) and *C. apus* (29%). In the AS, several stations recorded standing stock of 35-100 kg/km$^2$, dominated by *Lophiodes mutilus* (42%) and *L. lugubris* (26%). The BoB recorded the least standing stock (Fig. 4.13). The smooth anglerfish (*Lophiomus setigerus*) is widely and commercially exploited in bottom trawl fisheries across the Western Pacific and Indian Ocean due to demand for its high-quality flesh. Species within the genus *Lophiodes* are also commercially fished, forming part of global monkfish landings, while most other listed species, such as ceratioid anglerfishes and deep-sea batfishes, are too small, scarce, or biologically unviable for any large-scale commercial capture (Fariña et al., 2008).



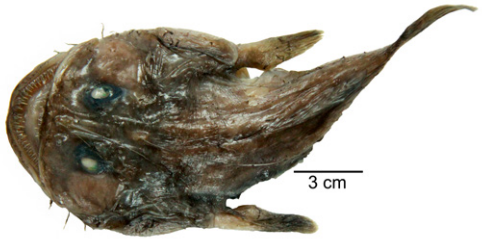

*Chaunax multilepis*



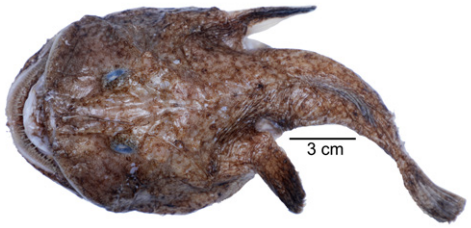

*Chaunax apus*




*Lophiodes mutilus*




*Lophiodes lugubris*




*Lophiomus setigerus*

## 4.4.3.Gadiformes-resource status

The primary hotspot for Gadiformes is recorded along the coast of Kerala and southern Karnataka, with the highest standing stock ranging from 933 to 6000 kg/km$^2$. Moderate and low standing stock was observed in the northeastern BoB, the northern AS, and the Andaman Sea. The AS was dominated by *Physiculus roseus* (45%) and *Coryphaenoides hextii* (24%), while *P. natalensis* (67%) was most abundant in the BoB and the Andaman Sea (Fig. 4.14). *Coelorinchus braueri* (26%) and *C. flabellispinis* (18%) formed major components. *Bregmaceros mcclellandi* is commercially exploited by dol net along the coastal waters of Maharashtra and Gujarat (Reghu et al., 1996; Nalwa et al., 2017), as well as in eastern Thailand (Torii et al., 2003). Deep-sea grenadiers and cods (*Coelorinchus* sp., *Coryphaenoides* sp., and *Malacocephalus* sp.) are commonly caught as bycatch in deep-water trawling operations.

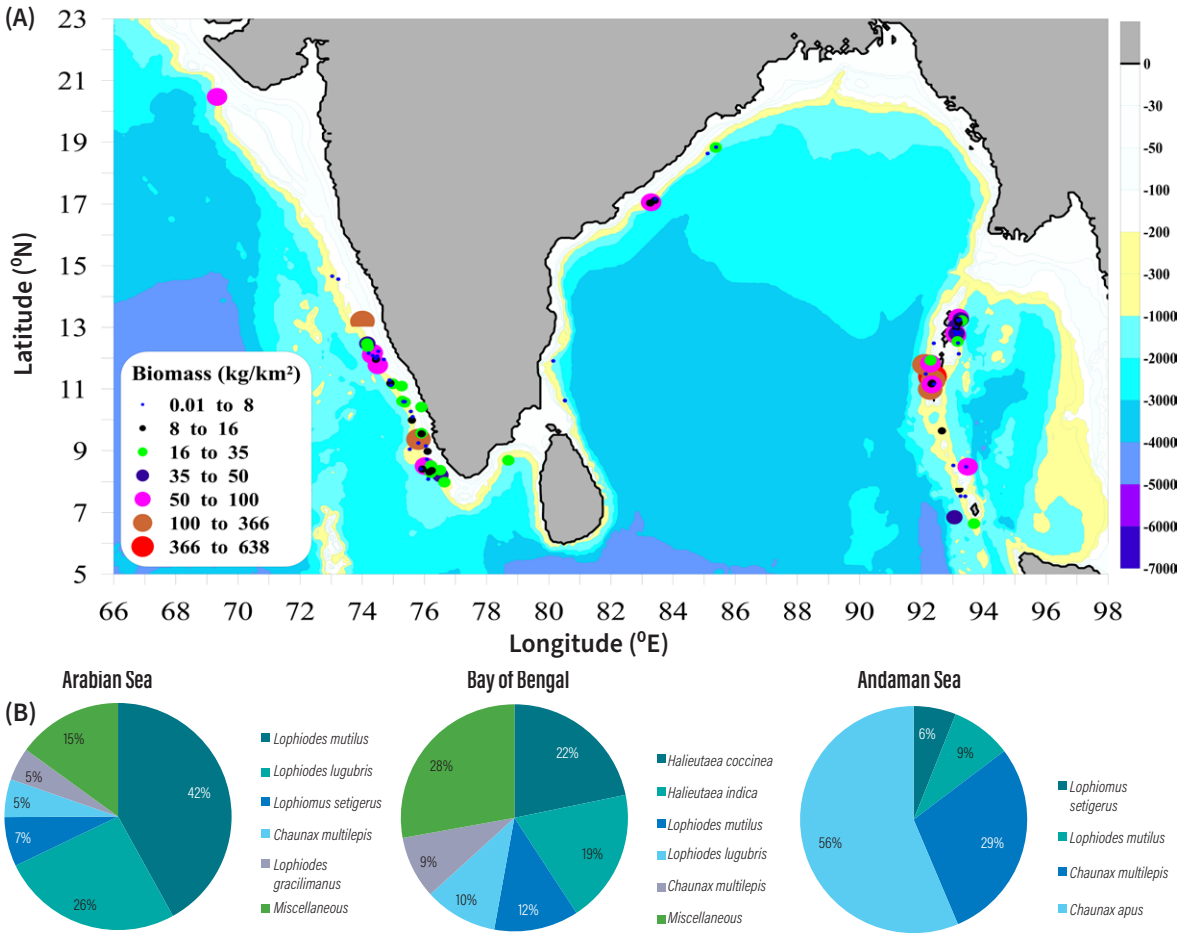



Fig. 4.13: (A) Spatial distribution of Lophiiformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Lophiiformes across different regions.




*Coelorinchus braueri*




*Physiculus roseus*




*Coryphaenoides hextii*

While some grenadiers form significant incidental catches, they are generally not targeted commercially on a large scale due to limited market demand and inherent biological vulnerabilities, such as slow growth and late maturity (Koslow, 2000; Hashim, 2012). Therefore, most of the listed species can be considered viable candidates for future large-scale commercial exploitation only after a thorough understanding of their life-history traits.

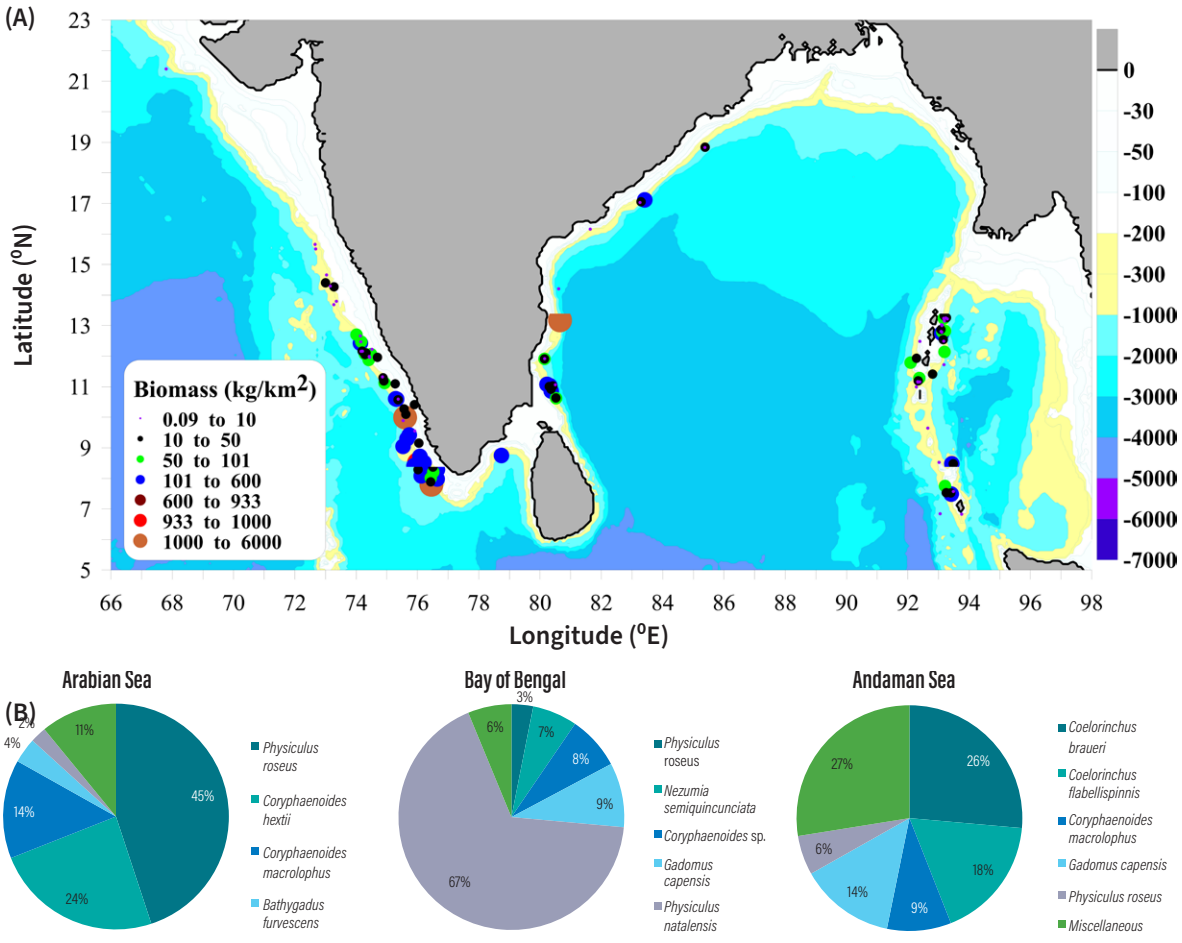



Fig. 4.14: (A) Spatial distribution of Gadiformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Gadiformes across different regions.

## 4.4.4.Anguilliformes-resource status

The standing stock of Anguilliformes ranged from 0.1 to 2700 kg/km$^2$, with pronounced spatial variability: the highest in the AS, followed by the BoB, and the Andaman Sea. *Gavialiceps taeniola* was the predominant species across all regions, with a standing stock contribution of 44% each in the AS and BoB, and 75% in the Andaman Sea (Fig. 4.15). Among the recorded taxa, *Muraenesox cinereus* was the only species of significant commercial value, observed only in the AS, with a standing stock contribution of 0.1%.

Despite its low abundance in our findings, the species is economically important in Japan and India (Watari, 2014). In these regions, it is marketed fresh, processed into fish balls, and valued for its swim bladder in export markets (Akhilesh, 2022). Classified as Least Concern by the IUCN, *Muraenesox cinereus* continues to support regional coastal fisheries. Other deep-sea Anguilliformes encountered during the assessment were primarily non-target species and occurred mainly as incidental bycatch in deep-sea trawl operations.




*Gavialiceps taeniola*

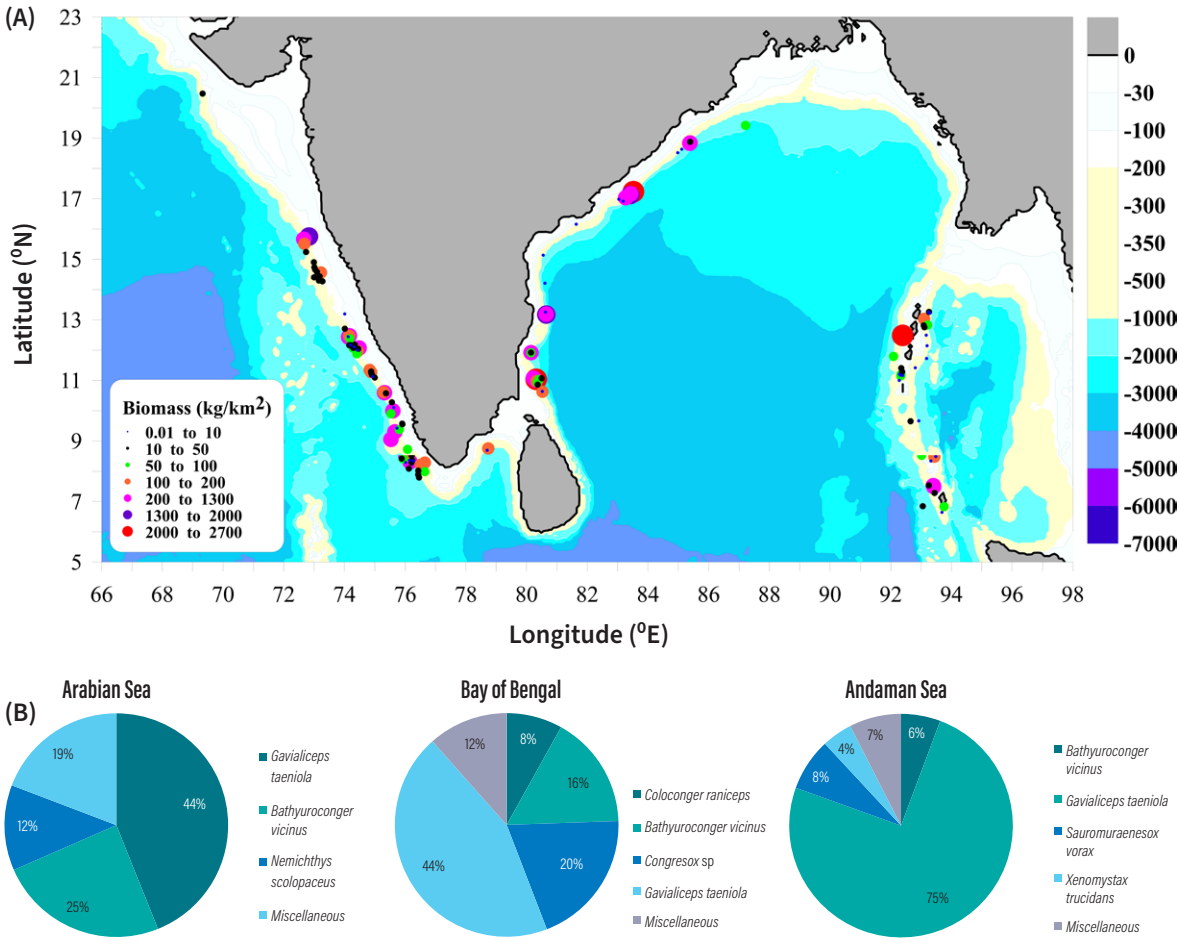



Fig. 4.15: (A) Spatial distribution of Anguilliformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Anguilliformes across different regions.

## 4.4.5.Aulopiformes-resource status

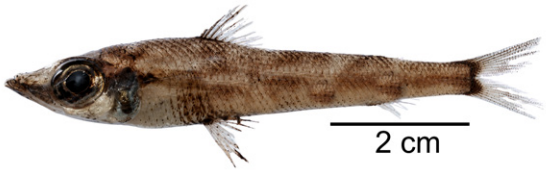
Aulopiformes showed substantial spatial variation in the Indian EEZ, with standing stocks reaching 2500 kg/km2. The standing stock peaked in the AS, was moderate in the Andaman Sea, and was lowest in the BoB. *Chlorophthalmus corniger* dominated the assemblage in both the AS (54%) and BoB (70%), whereas the Andaman Sea was characterized by *C. nigromarginatus* (54%), followed by *C. agassizi* (21%) and *C. corniger* (10%). In the BoB, *Harpadon squamosus* accounted for 20% of the standing stocks, followed by *Harpadon* sp. (9%) (Fig. 4.16). While *H. squamosus* has limited commercial importance and is typically caught as an incidental bycatch, its congener, *Harpadon nehereus* (Bombay duck), is a major fishery species in the Indian Ocean (Kapoor, 2002; Trivedi, 2020). These findings suggest a potential commercial scope for *Harpadon* spp. in the BoB, provided that sustainability considerations are taken into account.




*Chlorophthalmus corniger*




*Chlorophthalmus nigromarginatus*




*Chlorophthalmus agassizi*




*Harpadon squamosus*

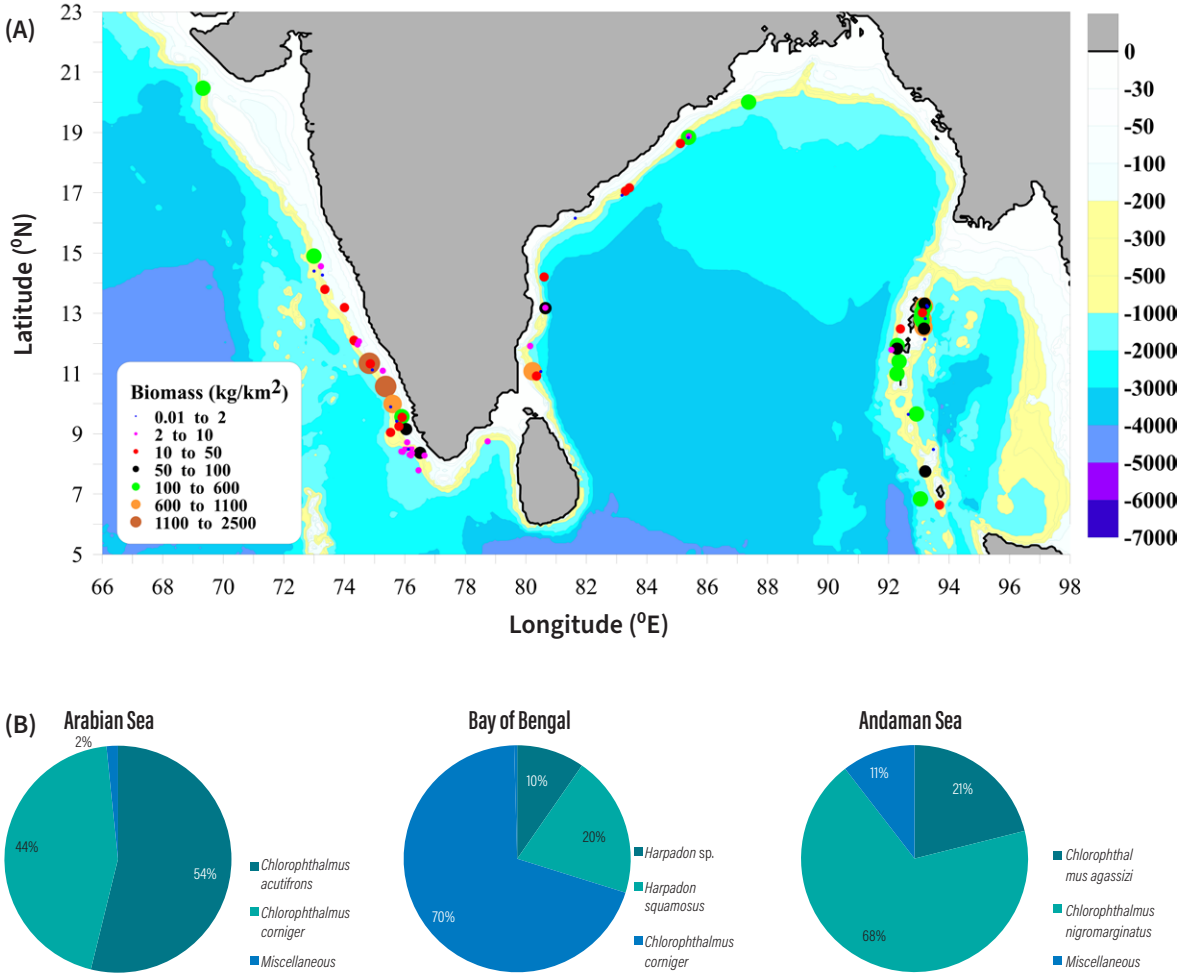



Fig. 4.16: (A) Spatial distribution of Aulopiformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Aulopiformes across different regions.

## 4.4.6.Acropomatiformes-resource status

The standing stock distribution of Acropomatiformes in the Indian EEZ shows a patchy but slope-associated pattern, reaching 1400 kg/km$^2$. High standing stock clusters occur along the SEAS, especially off Kerala-Goa. Moderate standing stock extends northward towards Gujarat. In the BoB, standing stock is comparatively lower but includes localized pockets along the coast of Odisha and northern Andhra Pradesh. The Andaman & Nicobar region shows several high-standing stock stations, reflecting favourable deep-slope conditions (Fig. 4.17). Overall, Acropomatiformes exhibit a strong association with depths of 200-1000 m, where upwelling, complex topography, and prey availability enhance their distribution (Priede, 2017).




*Acropoma japonicum*




*Bathyclupea hoskynii*




*Parascombrops philippinensis*




*Neobathyclupea elongata*

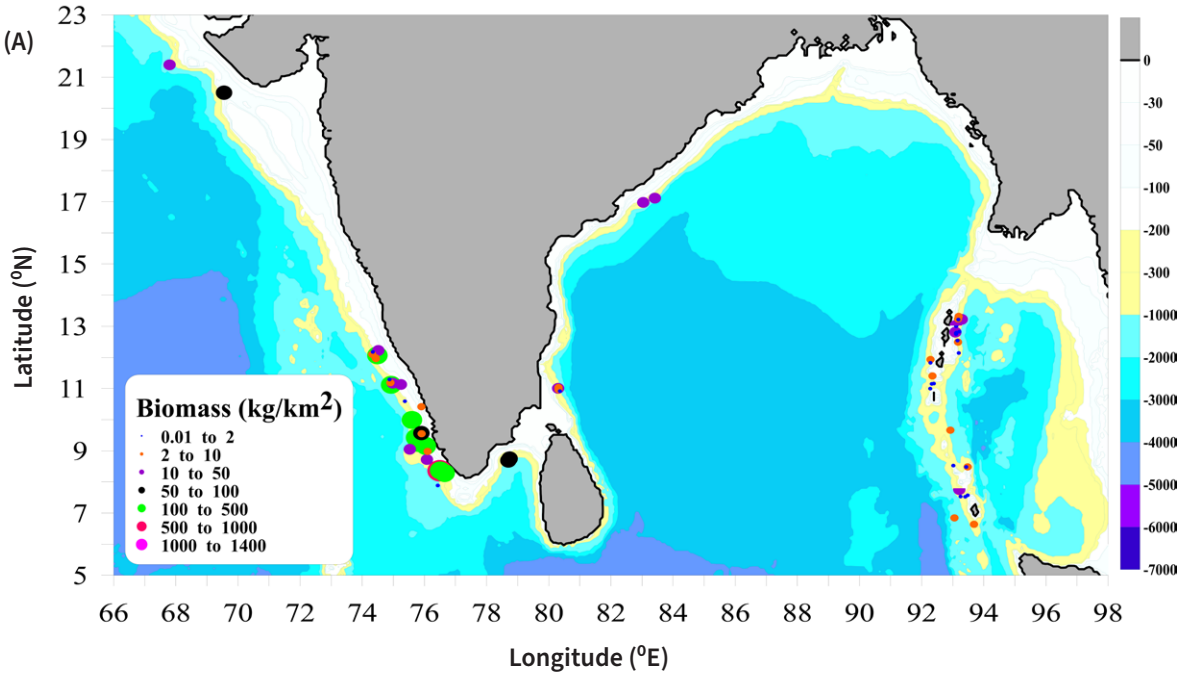



Fig. 4.17: (A) Spatial distribution of Acropomatiformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Acropomatiformes across different regions.




*Anoplogaster cornuta*



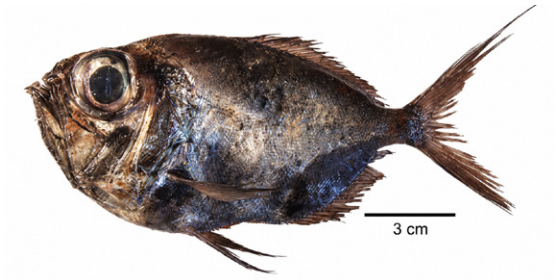

*Hoplostethus rubellopterus*




*Gephyroberyx darwinii*




*Hoplostethus melanopus*




*Diretmoides veriginae*

Across the Indian EEZ, Acropomatiformes exhibit regionally distinct biomass patterns. In the AS, *Acropoma japonicum* overwhelmingly dominates with 85.65% of total standing stock, followed by *Parascombrops pellucidus* and *Bathyclupea hoskynii*. The BoB exhibits a sharply skewed assemblage, with *Neobathyclupea elongata* contributing 94.73%, and *P. philippinensis* (5.27%) appearing sparsely. In the Andaman Sea, *Synagrops japonicus* forms 50% of the standing stock, accompanied by *A. japonicum* (16.4%), *Acropoma* sp. (12.9%), and *P. pellucidus* (13.8%). Overall, the distribution indicates strong regional dominance by a single species.

Globally, Acropomatiformes are not targeted in major fisheries, and most species are caught incidentally in deep-sea trawl, longline, and trap operations (Froese & Pauly, 2025). Only a few taxa, such as *Acropoma japonicum* and *Synagrops japonicus*, are found in small coastal markets in Japan and Southeast Asia (Nelson et al., 2016). Deep-slope genera, such as *Bathyclupea*, *Neobathyclupea,* and *Parascombrops,* remain poorly exploited due to their low commercial value and distribution beyond conventional fishing depths (Priede, 2017). In India, Acropomatiformes have no dedicated fishery; they are primarily caught as bycatch in deep-sea trawlers operating along the AS, the BoB, and the Andaman & Nicobar slopes. Occasional landings of *Acropoma* and *Parascombrops* are reported, but their contribution to deep-sea landings is minimal compared to commercial perches and snappers (Ramkumar et al., 2024). Overall, these species remain biologically present but minimally exploited, indicating very low fishing pressure in both global and Indian waters.

## 4.4.7.Trachichthyiformes-resource status

Trachichthyiformes had comparatively low biomass in the Indian EEZ, reaching 320 kg/km$^2$, with the highest densities in the AS, moderate levels in the Andaman Sea, and minimal values in the BoB. Five species were documented overall: *Anoplogaster cornuta*, *Hoplostethus rubellopterus*, *H. melanopus*, and *Gephyroberyx darwinii* in the AS; *H. melanopus* in the BoB; and *Diretmoides veriginae*, *H. rubellopterus*, *H. melanopus*, and *G. darwinii* in the Andaman Sea (Fig. 4.18). Among them, *G. darwinii* is the most widely

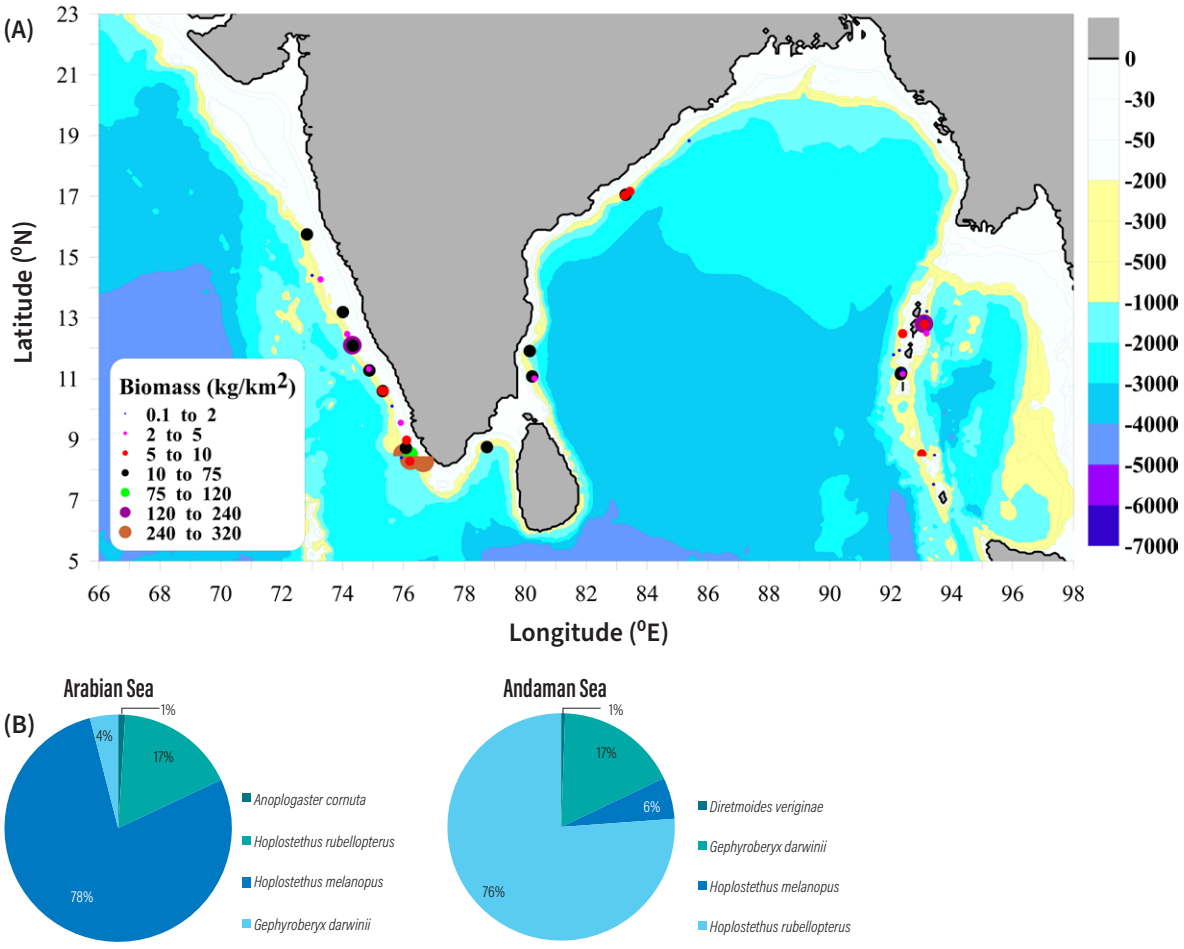



Fig. 4.18: (A) Spatial distribution of Trachichthyiformes standing stock in the Indian EEZ using FORV *Sagar Sampada*. (B) Species-wise percentage contribution of Trachichthyiformes across different regions.

utilised globally, being processed into fishmeal and fish oil in the eastern central Atlantic (FAO, 2002), though commercial records may be limited due to misidentification. In the Indian EEZ, *G. darwinii* contributed 57 kg/km$^2$ (4%) of the Trachichthyiformes biomass in the AS and 32 kg/km$^2$ (17%) in the Andaman Sea, reflecting its minor yet ecologically relevant presence in deep-sea assemblages.

# 5 Distant-Water Fishery Resources

Distant-water fisheries comprise highly migratory, straddling, and distant-water resources occurring beyond national EEZs, dominated by large pelagic predators and oceanic cephalopods. Major commercially and ecologically important groups exploited in the high seas include tunas, billfishes, sharks, oceanic squids, and Antarctic krill. These species are widely distributed across ocean basins and exhibit long-distance migrations, making their management complex and requiring international cooperation. High-sea resources play critical roles in global food security and in international fisheries economies. They are key elements in the global marine food web; however, increasing fishing pressure, climate-driven oceanographic changes, and the expansion of distant-water fleets are placing increasing stress on these resources. These resources are managed through Regional Fisheries Management Organizations (RFMOs), such as the Indian Ocean Tuna Commission (IOTC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), the Western and Central Pacific Fisheries Commission (WCPFC), the Inter-American Tropical Tuna Commission (ITTC), the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), under international legal frameworks. Through appropriate national policies, active participation in international fisheries agreements, and compliance with RFMO management frameworks, India can responsibly harness these resources.

The assessment presented in this section is primarily based on FAO information, stock assessment reports from relevant RFMOs, and published scientific literature. Systematic national-level datasets for most of these high seas' resources are presently limited; Antarctic krill remains the only resource group for which a dedicated Indian exploratory investigation (FIKEX) was undertaken. The chapter, therefore, synthesizes available global information to examine stock status, catch trends, geographic distribution, management measures, and the broader implications for India's potential engagement in distant-water fisheries within a precautionary and ecosystem-based framework.

The sustainable development of distant-water fisheries will require the deployment of technologically advanced fishing vessels equipped with modern monitoring and navigation systems such as Vessel Monitoring Systems (VMS), satellite communication, onboard processing facilities, and improved fishing gear. Strategic expansion into distant-water fisheries, supported by scientific research and ecosystem-based management, therefore represents an important opportunity for enhancing national seafood production, export potential, and maritime economic growth.

## 5.1. Tuna fishery

Tunas are among the most commercially valuable groups of fish in the global seafood market and play a significant role in international capture fisheries. Global catches of tuna and tuna-like species have continued to increase, reaching a record 8.3 mt in 2022 (FAO, 2024). These fisheries are dominated by a few major commercial species viz., skipjack (*Katsuwonus pelamis)*, yellowfin (*Thunnus albacares)*, bigeye (*Thunnus obesus)*, albacore (*Thunnus alalunga)*, and bluefin (*Thunnus* sp.*)*, contributing a total of 5.8 mt in 2024 (ISSF, 2026) (Fig. 5.1). Among these, skipjack tuna contributed approximately 58% of the total catch, followed by yellowfin tuna (30%), bigeye tuna (7%), albacore (4%), and bluefin tuna (around 1%). In terms of stock status, approximately 87% of global tuna stocks are considered to be fished at biologically sustainable levels, indicating comparatively effective international management through RFMOs (FAO, 2024).

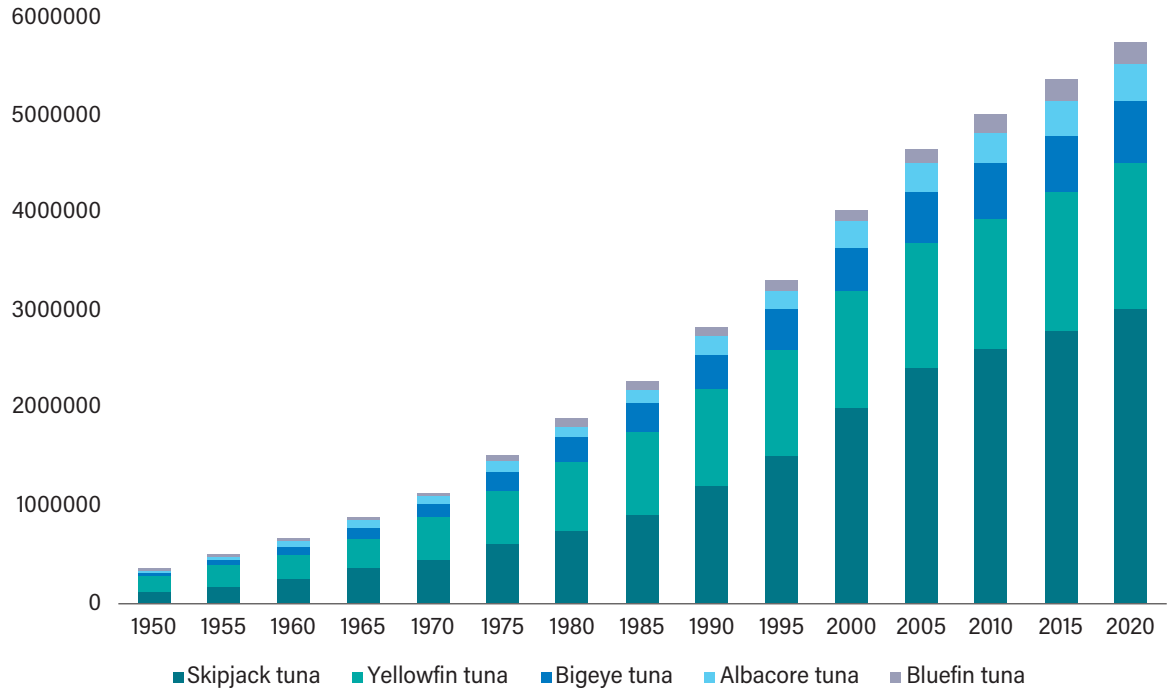



Fig. 5.1: Global trends in catch (mt) of major commercial tunas, by species (left) from 1950-2020 (Data Source-ISSF, 2026)

Globally, tuna fisheries are dominated by industrial fishing gears operating across EEZs and the high seas. Purse seine fisheries account for the largest share of catches (66%), followed by longline (9%), pole-and-line (7%), gillnets (3%), and other gears (15%). Purse seine fisheries primarily target skipjack and juvenile yellowfin associated with fish aggregating devices (FADs), whereas longline fisheries target larger species such as bigeye and albacore for sashimi markets. The dominance of purse seine fisheries reflects the industrialization of tropical tuna fisheries, particularly in the Pacific and Indian Oceans, which together contribute a major share of global tuna production (FAO, 2024; ISSF, 2024).

## Indian Ocean region

The Indian Ocean accounts for approximately 23% of global tuna production, making it the second-most-important tuna-fishing region worldwide after the Western and Central Pacific Ocean (Fig. 5.2). In 2024, the combined catches of the major tuna species, skipjack, yellowfin, bigeye, and albacore, were estimated at about 1.24 mt, showing a 2% decline compared with 2023 (ISSF, 2024). Skipjack accounts for 53% of the catches in weight, followed by yellowfin (37%), bigeye (7%), and albacore (3%). Purse-seine vessels take about 42% of the total catch, followed by gillnets (15%), pole-and-line (11%), and longline (9%) (Fig. 5.3).

In the Indian Ocean, bigeye tuna catches were estimated at approximately 87,000 tonnes in 2024, an 8% decline from 2023. The fishery is dominated by purse-seine (41%) and longline (37%) fisheries. The most recent stock assessment conducted by the IOTC Scientific Committee in 2025 indicates that the stock is overfished, but overfishing is not currently occurring. The MSY is estimated at approximately 1,00,000 tonnes, which is higher than the 2024 catch of 87,000 tonnes, indicating reduced fishing pressure on the stock.

Yellowfin tuna is widely distributed across the tropical waters of the Indian Ocean and is harvested by both industrial fleets and small-scale coastal fisheries. The total catch reached approximately 4,89,700 tonnes in 2024, a 15% increase from 2023. During the period 2020-2024, catches were mainly obtained using purse-seine (29%), handline fisheries (28%), gillnets (15%), coastal longline (15%), longline (9%), and pole-and-line (3%). The MSY for yellowfin tuna is estimated at about 4,21,000 tonnes, recent catches (4,89,700 tonnes) exceed this level.

Skipjack tuna represents the largest tropical tuna fishery in the Indian Ocean. In 2024, catches were

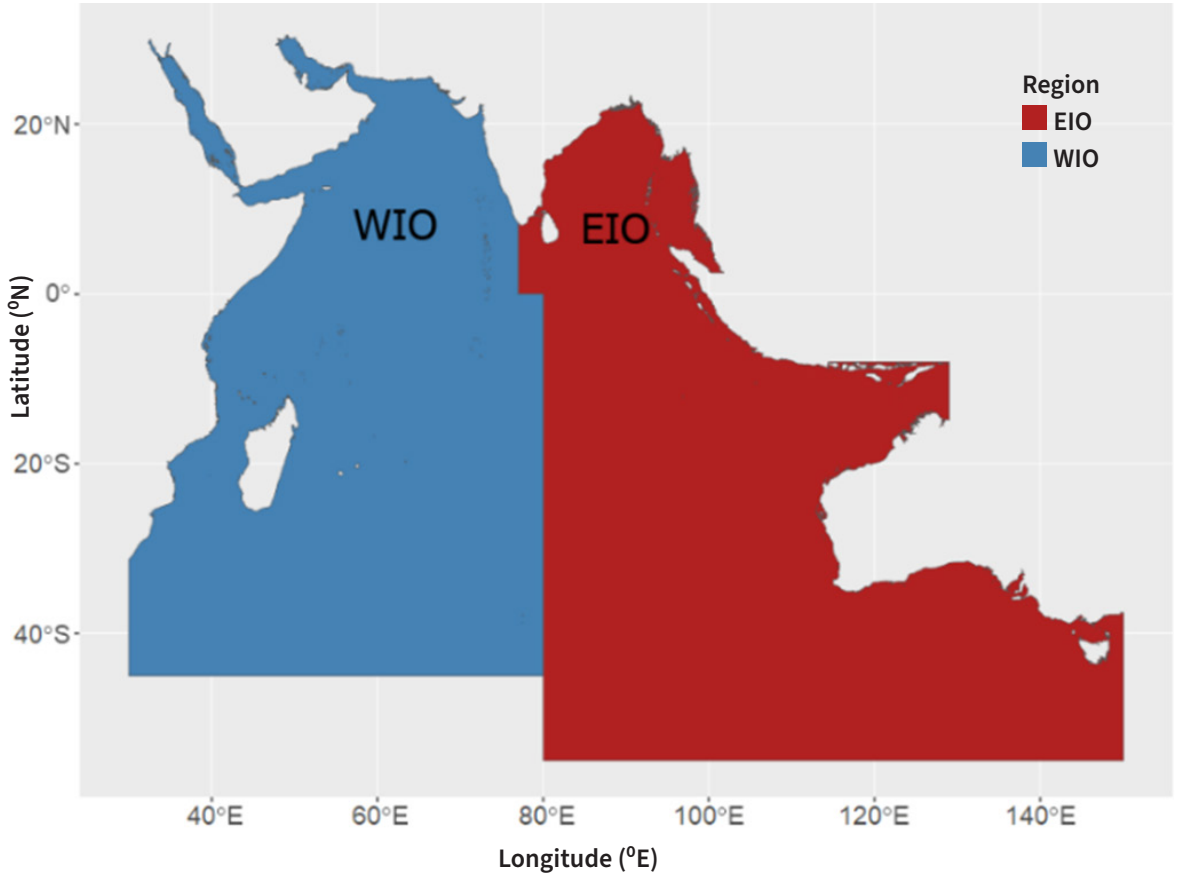



Fig. 5.2. Map showing the extent of the Indian Ocean (Western and Eastern Indian Ocean Regions) (Data courtesy: FAO (Area 51 and 57).

estimated at approximately 6,24,600 tonnes, reflecting a 10% decrease from 2023. The fishery is dominated by purse-seines (53%), followed by pole-and-lines (19%) and gillnets (17%). The MSY estimate is approximately 5,84,800 tonnes, although the 2024 catch (6,24,600 tonnes) exceeded this level, the 2023 stock assessment indicated that the stock is not overfished yet. Despite this, high recruitment events, possibly linked to

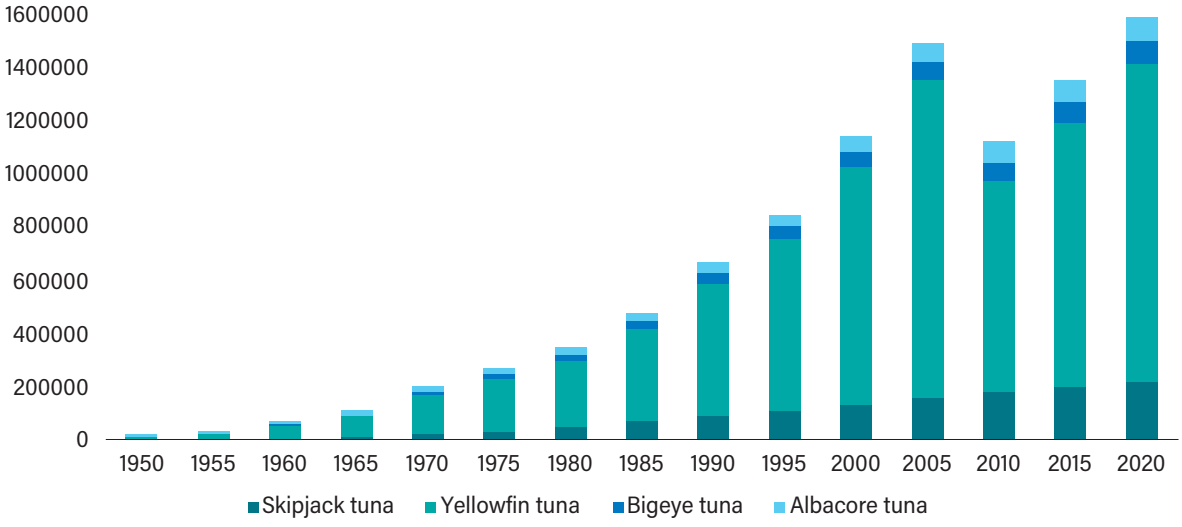



Fig. 5.3. Tuna species-based catch (mt) trends in the Indian Ocean region (Data Source-ISSF, 2026)

favorable environmental conditions, have helped maintain stock abundance (ISSF, 2026).

Albacore tuna catches in the Indian Ocean were estimated at 36,500 tonnes in 2024, representing a 22% decrease from 2023. The fishery is primarily conducted by pelagic longline vessels (82%), followed by handline, coastal longline, and troll fisheries (15%). According to the most recent 2025 stock assessment, the Indian Ocean albacore stock is not overfished, although there remains considerable uncertainty in the assessment results. The MSY for albacore tuna is estimated at approximately 44,300 tonnes, which is higher than the 2024 catch, suggesting that current exploitation levels remain within sustainable limits.

## Oceanic tuna resources in Indian waters

Oceanic tuna species have become increasingly important in the Indian marine fisheries sector over the last few decades. Among the major oceanic tuna species exploited in Indian waters are yellowfin tuna, skipjack tuna, and bigeye tuna (Restrepo et al., 2016). Although the Indian tuna fishery was historically dominated by neritic tuna species, over the past few decades, there has been a gradual shift toward the exploitation of oceanic tuna resources. Analysis of tuna landing statistics from 1997 to 2022 indicates that skipjack and yellowfin tuna each account for approximately 20% of total tuna landings in India, averaging around 18,000 tonnes annually (FishStatJ Database, 2023; OP et al., 2025). Growth trend analysis further reveals that yellowfin tuna recorded a Compound Annual Growth Rate (CAGR) of 6.27%, while skipjack tuna showed a CAGR of 4.62% during the same period. In contrast, bigeye tuna exhibited a high but statistically insignificant CAGR of 21.44%, largely attributed to initially low catch records followed by an increase in reported landings in later years.

Species-wise landing data further illustrate the increasing contribution of oceanic tuna species. For example, yellowfin tuna landings increased from 6,575 tonnes in 1997 to 17,248 tonnes in 2022, while skipjack tuna increased from 8,089 to 22,286 tonnes (FishStatJ Database, 2023) (Fig. 5.4). Similarly, bigeye tuna catches, which were almost negligible during the late 1990s, increased to 534.88 tonnes by 2022, suggesting an expansion in exploitation and improved reporting of this species. Recent fishery assessments further confirm the dominance of oceanic tuna species in Indian landings. According to CMFRI (2024), oceanic tuna landings in India were dominated by yellowfin tuna (21.5%), followed by skipjack, bigeye tuna, and other species accounting for the remaining 57.5%. This growing contribution from oceanic species reflects the increasing importance of offshore tuna resources in India's marine fisheries sector.

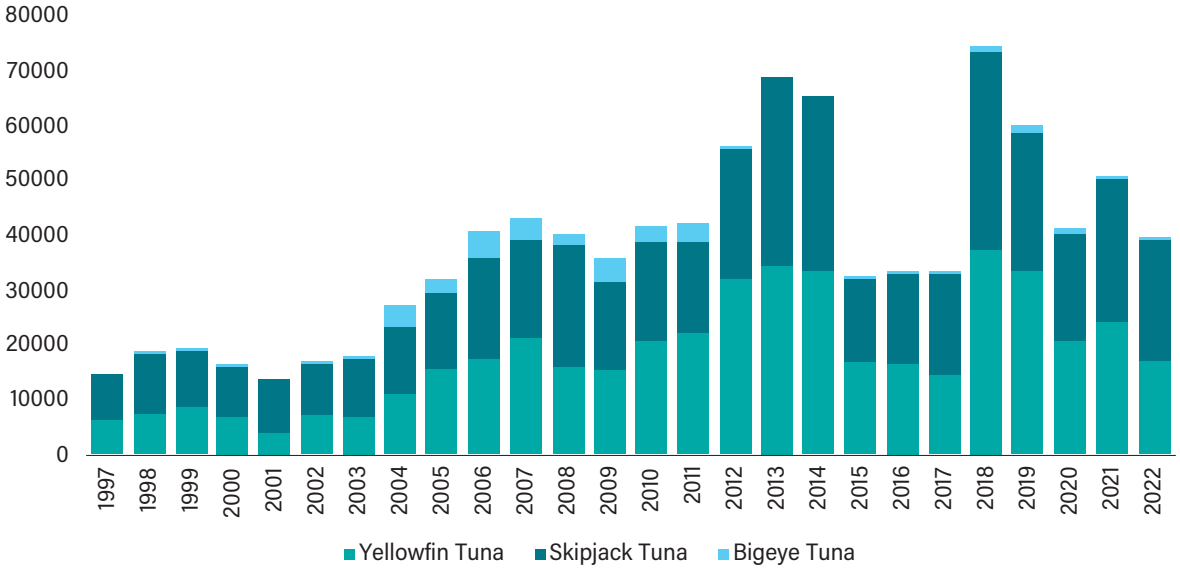



Fig. 5.4: Trends of major oceanic tuna species landings along the Indian EEZs from 1997-2022 (Data Source-OP et al., 2025; FishStatJ Database, 2023).

Lakshadweep represents the most prominent region in India where targeted oceanic tuna fisheries are practiced, particularly for skipjack tuna. The tuna fishery in this region relies primarily on traditional pole-and-line methods, which are considered environmentally sustainable. Skipjack tuna, locally known as "*Mass Choora*", forms the backbone of the island fishery and is widely processed into *Masmin*, a dried tuna product that plays a vital role in the local diet and economy (Dhaneesh et al., 2011). Species-wise landing statistics from 2004 to 2012 demonstrate the dominance of skipjack tuna in Lakshadweep's tuna fishery. During this period, skipjack tuna landings ranged between 1,640 and 7,059 tonnes, representing the largest share of total tuna catches in the islands. In comparison, yellowfin tuna catches ranged from 523 to 2,588 tonnes (Koya, 2021). Recent fishery statistics also confirm the continued importance of tuna resources in the Lakshadweep Islands. Tuna accounts for nearly 80% of the total fish landings, making it the most economically significant fishery resource in the region (CMFRI, 2024). In 2023, the total fish landings were 14,430 tonnes, a 24% increase from the previous year, with tuna accounting for approximately 11,620 tonnes (80.5%) of the total catch (CMFRI, 2024).

The Andaman and Nicobar Islands represent another important region for oceanic tuna resources within the Indian EEZ. The waters surrounding these islands in the Bay of Bengal (BoB) support some of the most productive tuna fishing grounds in India, with considerable potential for the exploitation of oceanic tuna species such as yellowfin and skipjack tuna (NFDB, 2013). However, despite the availability of substantial tuna resources, the fishery in this region remains relatively underexploited. This is primarily due to limited fishing capacity, inadequate infrastructure, and weak market linkages, which restrict the development of targeted offshore tuna fisheries in the islands (NFDB, 2013). Strengthening fishing infrastructure, improving cold storage and processing facilities, and enhancing market access are therefore considered essential for improving the utilization of these oceanic resources.

Recognizing this untapped potential, the Government of India has recently initiated several measures to promote tuna fisheries development in the Andaman and Nicobar Islands. In 2024, the Department of Fisheries notified a Tuna Cluster under the PMMSY to attract investment and strengthen fisheries infrastructure in the region. According to estimates from the Department of Fisheries, Andaman and Nicobar Islands, the combined potential yield of oceanic and neritic tuna resources is approximately 64,500 tonnes annually, while the current harvest remains significantly below this level, indicating substantial opportunities for expansion of tuna fisheries. To support this initiative, infrastructure development projects worth ₹58.91 crore have been approved under PMMSY, including the acquisition of deep-sea fishing vessels, upgrading of existing vessels for export competitiveness, and the establishment of cold storage and ice plants. These initiatives aim to strengthen the tuna value chain, improve export potential, and promote sustainable development of offshore fisheries in the island region (GOI, 2024).

## Management of Indian Ocean tuna fisheries

Tuna fisheries in the Indian Ocean are managed by the IOTC through a range of conservation and management measures designed to ensure sustainable exploitation of tuna and tuna-like species. These measures include harvest strategies, total allowable catch (TAC) limits, stock assessments, and monitoring of fishing effort. Management frameworks incorporate reference points such as Fishing Maximum Sustainable Yield (FMSY) and Spawning Stock Biomass Maximum Sustainable Yield (SSBMSY), and several species, such as bigeye and skipjack, already operate under management procedures and harvest control rules (HCRs). Additional regulations include limits on FADs, bans on discarding tropical tuna by purse-seine vessels, requirements for biodegradable, non-entangling FAD designs, catch limits allocated to member countries, and measures to reduce the number of supply vessels in purse-seine fisheries. The IOTC Scientific Committee regularly evaluates stock status and provides advice for adaptive management, while monitoring systems and compliance mechanisms aim to ensure that catches remain within sustainable levels and that tuna resources in the Indian Ocean are conserved for long-term ecological and economic sustainability. Overall, the Indian Ocean tuna fishery reflects a complex interaction between industrial distant-water fleets and coastal artisanal fisheries. While several

stocks remain within biologically sustainable limits, others show signs of increasing exploitation pressure. Continued monitoring through stock assessments, coupled with adaptive management strategies under RFMOs, remains critical to maintain the long-term sustainability of tuna resources in the Indian Ocean.

## 5.2. Billfish fishery

Billfishes constitute a significant component of offshore pelagic ecosystems. These species exhibit a wide geographic distribution across tropical, subtropical, and temperate regions of the world's oceans and play an important role in pelagic ecosystems (Thoya et al., 2022). Although their contribution to total catch is comparatively lower than that of tunas, they represent a valuable resource for both commercial and recreational fisheries globally. In the Indian Ocean, six species of billfishes are commonly reported, namely the Indo-Pacific sailfish (*Istiophorus platypterus*), black marlin (*Istiompax indica*), blue marlin (*Makaira nigricans*), striped marlin (*Kajikia audax*), shortbill spearfish (*Tetrapturus angustirostris*), and swordfish (*Xiphias gladius*) (Surya et al., 2021; Thoya et al., 2022). The Indian Ocean represents a major fishing ground for billfishes, accounting for approximately 43% of global billfish catches (IOTC Secretariat, 2024).

The development of billfish fisheries in the Indian Ocean dates back to the early 1950s, and catches have steadily increased over time. Between 1950 and 2007, industrial fleets contributed nearly 73% of the total billfish catch. However, since the late 2000s, coastal fisheries have become increasingly important, particularly gillnet and line fisheries operating within national waters. Overall, billfish catches have shown a long-term increasing trend with fluctuations driven by changes in fishing effort, fleet distribution, and regional socio-economic conditions. Total billfish catches reached 93,500 tonnes in 2022, an 11% increase compared to 2021 (IOTC Secretariat, 2024). The largest proportion of catches is contributed by gillnet (47.7%), followed by longline (24.4%) and line (26.3%). Swordfish constitutes the largest share of the total catch (36%), followed by Indo-Pacific sailfish (25%), black marlin (15%), blue marlin (14%), and striped marlin (9%). While swordfish are mainly caught in longline fisheries, sailfish and marlins are commonly captured in coastal gillnet and line fisheries. Despite improvements in data reporting and monitoring in recent years, uncertainties still remain due to limited data from artisanal and recreational fisheries, which complicates stock assessment and management efforts (IOTC Secretariat, 2024).

Swordfish is one of the most widely distributed billfish species in the Indian Ocean, occurring throughout tropical and temperate waters. Longlines are the primary method for targeting swordfish in the region. The average catch of 28,922 tonnes was recorded during 2018-2022. The stock is considered not overfished, with catches below the estimated MSY of approximately 30,000 tonnes, although localized depletion may occur in some fishing areas (IOTC Secretariat, 2024).

Black marlin is distributed throughout the tropical Indo-Pacific region and is mainly caught as a non-target species in industrial and artisanal fisheries. Landings are dominated by gillnet (59.7%), followed by line (28.3%) and longline (8%). Catches increased substantially, averaging 18,235 tonnes during 2018-2022. The stock is considered not overfished, but with an MSY of 13,900 tonnes, it shows that fishing mortality is above the sustainable level, improved monitoring and management are required to prevent future overexploitation (IOTC Secretariat, 2024) (Fig. 5.5).

Blue marlin occurs in tropical and subtropical waters of the Indian Ocean and is mainly caught with a longline. The recent catch recorded 5,658 tonnes in 2022, with an average catch of 7,175 tonnes during 2018-2022, while the estimated MSY is 7,140 tonnes. This indicates that the Indian Ocean stock is overfished and still subject to overfishing. Declining CPUE trends since 2015 suggest increasing fishing pressure and the need for improved management measures (IOTC Secretariat, 2024).

Striped marlin is distributed across tropical and temperate waters of the Indo-Pacific region and is primarily caught in the north-western Indian Ocean. Landings are dominated by gillnet (59.5%), followed by longline and line. The recent catch was recorded at 3,225 tonnes in 2022, with an average catch of 2,856 tonnes during 2018-2022. The species is considered overfished and subject to overfishing. Recovery of the stock would require substantial reductions in fishing mortality and improved catch monitoring (IOTC Secretariat, 2024).

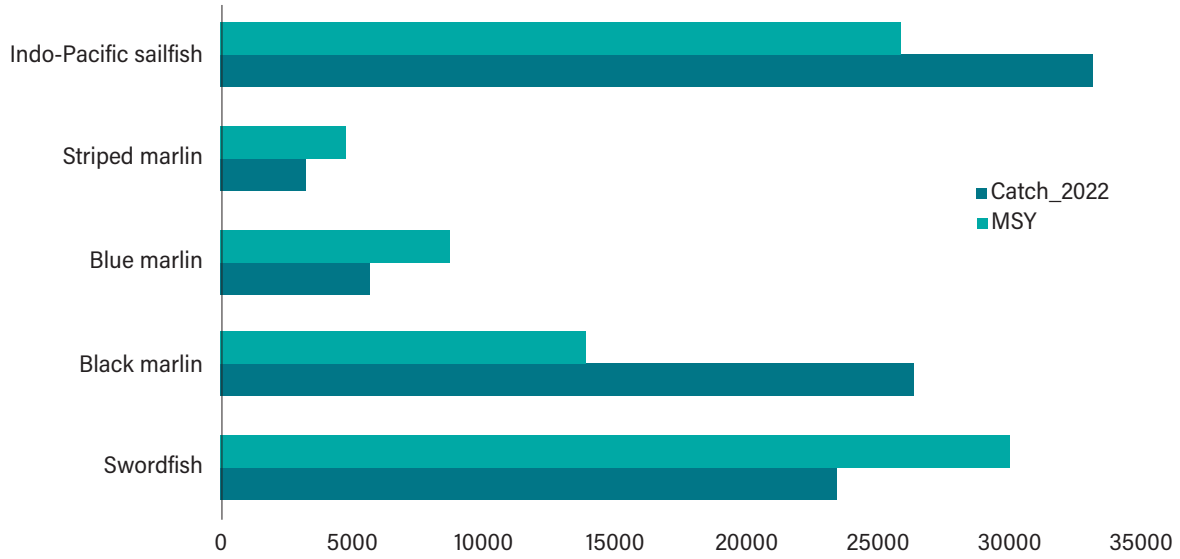



Fig. 5.5. Species-wise comparison of 2022 reported catches and estimated maximum sustainable yield (MSY) for major billfish species in the Indian Ocean (Data source: IOTC Secretariat, 2024).

Indo-Pacific sailfish remains one of the most abundant billfish species in the region, with catches of 33,135 tonnes in 2022 and an average of 32,750 tonnes during 2018-2022. Stock assessment indicates that the sailfish stock is not overfished and not subject to overfishing, although catches have exceeded MSY level (25,905 tonnes) in recent years. Present status emphasizes the need for improved monitoring, catch reporting, and effective management measures to sustainably exploit billfish resources in the Indian Ocean (IOTC Secretariat, 2024).

## Billfish fishery in the Indian marine fisheries sector

In India, billfish fisheries are largely non-target fisheries, and most catches occur as bycatch in offshore tuna fisheries, particularly in pelagic longline, trolling, and oceanic drift gillnets (Surya et al., 2021). Mechanized multiday gillnetters and longliners contribute the major share of billfish landings along the Indian coast. The west coast of India accounts for nearly 60% of annual billfish landings, underscoring the importance of the EAS for the exploitation of these resources (Surya et al., 2021). Landings in India have increased since the 1990s, indicating the growing exploitation of offshore pelagic resources (Surya et al., 2021). The total billfish catch in India reached approximately 14,759 tonnes in 2019, highlighting the importance of this group in the large pelagic fishery sector (Surya et al., 2021). The species composition of billfish landings in the EAS during 2009-2019 was dominated by Indo-Pacific sailfish (51%), followed by swordfish (20%), black marlin (16%), blue marlin (10%), and striped marlin (3%) (Surya et al., 2021). Stock assessment suggested that fishing mortality and exploitation rates for these species in the EAS remain within sustainable limits, indicating relatively healthy stocks in this region (Surya et al., 2021). However, a recent assessment by the IOTC indicates that black marlin, blue marlin, and striped marlin are overfished, while sailfish is undergoing overfishing, whereas swordfish stocks are not currently subject to overfishing (IOTC, 2020; Thoya et al., 2022). The exploitation is closely linked to industrial tuna fisheries, particularly longline targeting tunas and swordfish, in which billfish are frequently caught as bycatch (Thoya et al., 2022).

Overall, the billfish fishery in the Indian Ocean illustrates the complex balance between resource utilization and conservation of highly migratory pelagic species. While some stocks, such as swordfish and sailfish, remain relatively stable, others, including blue marlin and striped marlin, show clear signs of overexploitation. These contrasting patterns emphasize the need for strengthened monitoring systems, improved species-level catch reporting, and the implementation of precautionary harvest control measures within regional fisheries management

frameworks. Continued scientific assessments and adaptive management approaches will therefore be essential to maintain sustainable levels of exploitation and ensure the long-term resilience of billfish populations in the Indian Ocean.

# 5.3.Shark fishery

Sharks are wide-ranging, circumglobal taxa that inhabit tropical, subtropical, and temperate marine waters across all major ocean basins. They constitute an economically important yet biologically vulnerable component of global marine capture fisheries. These species belong to the class Chondrichthyes, which comprises sharks, batoids (including skates, rays, guitarfishes, and sawfishes), and chimaeras. Globally, chondrichthyans include approximately 34 shark families (~536 species), 23 batoid families (~611 species), and 3 chimaera families (~52 species) (Dulvy et al., 2021). Sharks are both directly targeted and incidentally captured in fisheries for their fins, meat, liver oil, cartilage, and other derivatives (Dent & Clarke, 2015). However, their life-history characteristics are typically K-selected, including slow somatic growth, late sexual maturity, prolonged gestation, and low fecundity (Cortés, 2000). These traits confer inherently low population productivity and limited capacity to recover from depletion. The limited availability of species-specific catch and biological data, together with an incomplete understanding of population structure and migratory behaviour, poses substantial challenges to effective stock assessment and conservation planning. Across the WIO, these challenges are compounded by factors such as overexploitation, bycatch in commercial fisheries, and habitat degradation. Consequently, many chondrichthyan stocks in the region are subjected to unsustainable fishing pressure, leading to significant population declines that have been widely documented in recent assessments (Dulvy et al., 2024; Pollom et al., 2024; Cochran et al., 2026).

## Global status of the shark fishery

A comprehensive global reassessment conducted under the IUCN Red List framework found that 391 of the 1,199 evaluated chondrichthyan species (32.6%) are threatened with extinction (Dulvy et al., 2021). Assessment shows that rays are threatened, with 51% of the 611 assessed species; sharks follow, with 36% of the 536 species threatened; and chimaeras show the lowest risk, with 9% of the 52 species near threatened (Dulvy et al., 2021). Although more than 500 shark species have been described globally, commercial fisheries are largely concentrated on a limited number of pelagic and semi-pelagic taxa, particularly in the Indian Ocean. These commonly exploited species include the Blue shark (*Prionace glauca*), Oceanic whitetip shark (*Carcharhinus longimanus*), Shortfin mako shark (*Isurus oxyrinchus*), Silky shark (*Carcharhinus falciformis*), Scalloped hammerhead (*Sphyrna lewini*), and thresher sharks (*Alopias* sp.).

Global catches of sharks, rays, and chimaeras date back to the 1950s with progressively increasing landings, reaching a maximum of 8,88,336 tonnes in 2000. However, the catch had declined gradually by approximately 14% and stabilized in recent years at 700,000-800,000 tonnes annually. Countries such as Indonesia, Spain, and India consistently rank among the top three shark-fishing nations (Lack & Sant, 2009; Dent & Clarke, 2015; Okes & Sant, 2019). Although landings may be recorded at species level within a catcher, the majority of catches are aggregated to general shark groups and not to species level for submission to the FAO (Cashion et al., 2019), making it difficult to identify many global-level taxon-specific trends in shark catches.

The Blue shark (*Prionace glauca*) is reported among the principal shark species landed by major fishing nations, including Spain, Portugal, Brazil, Taiwan, Namibia, Indonesia, and Mexico across the Atlantic, Indian, and Pacific Oceans. Although this species is seldom the primary target of commercial fisheries, it constitutes a substantial proportion of retained secondary catch in pelagic longline and driftnet operations, particularly those conducted by distant-water fleets operating on the high seas. The global landings of blue sharks increased steadily from the late 1990s, when they accounted for approximately 5% of total shark landings, to 81,437 mt (about 11%) by 2008. Catches rose further, exceeding 130,000 mt in 2011 and reaching a maximum of 137,973 mt in 2013, accounting for nearly 18% of global shark landings. Subsequently, reported landings declined markedly to 103,528 mt by 2017, corresponding to roughly 16% of total reported shark catches (Okes

& Sant, 2019). In the absence of region-specific catch limits in many areas, this downward trend may reflect reductions in population abundance rather than changes in reporting or fishing effort alone. According to IUCN assessments, the blue shark is currently categorized as Near Threatened globally and in European waters, while populations in the Mediterranean Sea are listed as Critically Endangered (Stevens, 2009; Sims et al., 2016).

The largest reported landings of Silky shark (*Carcharhinus falciformis*) have originated from the Eastern Indian Ocean (EIO) (notably Sri Lanka), the Eastern Central Pacific (particularly Costa Rica), and the Western Indian Ocean (WIO) (including Iran). The Silky Shark has exhibited a marked decline in reported global landings over the past two decades. According to data compiled by the FAO (2019), catches peaked at approximately 25,000 mt in 1999, then decreased to 4,610 mt by 2010 and further to 632 mt by 2017. The species is exploited in both directed and non-directed fisheries. While it is intentionally targeted in certain regions, it is more commonly recorded as bycatch in coastal longline and gillnet operations, as well as in offshore pelagic longline fisheries. Management interventions have been implemented in several jurisdictions; for example, retention of Silky Sharks has been prohibited in many oceanic pelagic fisheries outside the Indian Ocean under regulations adopted by the WCPFC in 2013. The Silky Shark is commercially valuable in international markets, particularly for its fins, which are considered high quality. It is among the most frequently traded shark species in the global fin trade and ranks second in prevalence after the Blue Shark, with both meat and fins contributing to its economic importance.

The Oceanic Whitetip shark (*Carcharhinus longimanus*) is an epipelagic species distributed throughout tropical and subtropical oceans, where it has historically been captured primarily as bycatch in pelagic longline and purse seine fisheries. Sustained fishing pressure has resulted in pronounced global population declines. In response, major tuna RFMOs, including the IATTC, ITOC, and WCPFC, have implemented retention bans requiring live release and mandatory reporting. The species is also listed in Appendix II of Convention on International Trade in Endangered Species (CITES), which regulates international trade. Reported landings submitted to the FAO averaged approximately 458 mt annually during 2008-2017. However, following the implementation of RFMO retention bans and CITES listing, reported landings declined markedly, reaching 65 mt in 2016 and 62 mt in 2017 globally. The IUCN classifies the Oceanic Whitetip Shark as Critically Endangered. Current assessments indicate a very high probability (>80%) of population reduction over three generation lengths (approximately 61.2 years), with some estimates suggesting declines approaching 98% in certain ocean regions (Rigby, 2019).

The three large species of hammerhead sharks (Scalloped Hammerhead, *Sphyrna lewini*; Great Hammerhead, *S. mokarran*; and Smooth Hammerhead, *S. zygaena*) are also traded primarily for their fins and are amongst the preferred species for shark fin soup (Dent & Clarke, 2015). The Scalloped and Great Hammerheads have a circumglobal distribution in coastal temperate and tropical waters, whereas the Smooth Hammerhead occupies comparable coastal and pelagic habitats but extends further into higher temperate latitudes relative to the other two species. These three species are frequently reported by genus, as “Hammerhead sharks nei”, which is applied to 94% of the catch reported to FAO. Population assessments indicate substantial declines. The IUCN has reported a 64% reduction in hammerhead populations globally, with particularly severe declines in the WIO. The CPUE indices have shown pronounced decreases since the late 1970s, reflecting sustained fishing pressure. Consequently, the Scalloped and Great Hammerheads are currently classified as Critically Endangered at the global scale, whereas the Smooth Hammerhead is listed as Vulnerable under the IUCN Red List criteria.

The thresher sharks comprise three species: the Bigeye Thresher (*Alopias supercilosus)* and Common Thresher (*A. vulpinus*), both circumglobally distributed, and the Pelagic Thresher (*A. pelagicus)*, which is largely confined to the Indo-Pacific. However, approximately 77% of thresher shark catches reported to the FAO are recorded at the genus level as “Thresher sharks nei,” limiting species-specific stock assessments. Between 2008 and 2017, species-level reporting of Pelagic Thresher was mainly from the Southeast Pacific, particularly by Ecuador, while Bigeye Thresher catches were also predominantly documented from the same region. The Pelagic Thresher is globally classified as Endangered, whereas the Bigeye Thresher is listed

as Vulnerable globally and Endangered in the AS due to population declines driven by life-history constraints and fishing pressure. In Indian waters, especially off Gujarat, demand for thresher products has intensified exploitation, prompting the IOTC to implement management interventions to enhance conservation and monitoring efforts.

## Shark fishery in India

According to the CMFRI, Indian waters support approximately 160 elasmobranch species, comprising 88 shark species from 44 genera and 21 families, along with 53 rays and 19 skates. Among these, 18 species dominate commercial fisheries, while 27 species frequently occur in coastal landings, particularly from the families Carcharhinidae, Sphyrnidae, Alopiidae, Lamnidae, Hemiscyllidae, and Triakidae. India ranks among the world's leading shark-fishing nations, standing third in global shark and ray harvests after Indonesia and Spain, with an average annual landing of approximately 67,391 tonnes between 2007 and 2017, as reported by the FAO in 2019. However, IUCN assessments indicate a significant decline in shark populations along the west coast of India. Shark landings fluctuated between 33,112 and 47,207 tonnes during 1985-1998 and reached 35,215 tonnes in 2004, but subsequently declined to 21,138 tonnes by 2018. Overexploitation of coastal shark stocks has also driven fishing activities further offshore, although oceanic shark landings remain relatively low, indicating continued stock depletion. Overall, declining landings and CPUE trends suggest persistent overexploitation caused by intensified fishing pressure and environmental factors affecting shark abundance and catchability. The current status of elasmobranch populations highlights the urgent need for increased conservation attention in India. However, several hurdles and knowledge lacunae continue to impede the development of comprehensive and effective conservation policies for these species (Akhilesh et al., 2023).

## Conservation measures

Managing sharks in India is challenging due to the high diversity of species and the complex nature of the fishery. India strengthened shark conservation efforts in 2001 by listing ten shark species under Schedule I of the Wildlife (Protection) Act, 1972, making their capture and killing a cognizable offence. Internationally, India has supported the inclusion of five shark species, four found in Indian waters, and two manta ray species under CITES Appendix II to regulate fin and gill plate trade and curb unsustainable exploitation. While these actions reflect a strong commitment, India's shark and ray conservation policies need further research on species-specific risks, vulnerable species, habitat-use patterns, and critical areas such as spawning, nursery, and feeding grounds. Globally, the FAO has guided shark conservation through the International Plan of Action for Sharks (IPOA-Sharks), adopted in 1999, which encourages countries to develop National Plans of Action (NPOA-Sharks) aligned with its framework and subject to periodic revision. Effective national plans and international cooperation remain essential for protecting vulnerable shark species.

# 5.4. Oceanic squids' fishery

Oceanic squids are important high-sea resources distributed across all oceans and are considered straddling species, playing a critical role in pelagic ecosystems while increasingly supporting global fisheries. Their biological traits, including rapid growth, short life cycles, and high trophic plasticity, enable rapid responses to environmental variability, but also result in strong interannual fluctuations in stock abundance. Globally, squid catches increased from roughly 1 mt in the early 1970s to about 2 mt by the late 1980s and early 1990s, with oceanic ommastrephid squids accounting for a substantial share of these landings (Rodhouse, 2005). Major fisheries are concentrated in the Pacific and Atlantic Oceans, particularly off Peru, Chile, Japan, and the Falkland Islands, supporting large-scale exploitation of species such as Humboldt Squid (*Dosidicus gigas*) and shortfin squids (*Illex* spp.) (Arkhipkin et al., 2015). Other notable oceanic squid species of global importance include the Giant Squid (*Architeuthis dux*), Colossal Squid (*Mesonychoteuthis hamiltoni*), Vampire Squid (*Vampyroteuthis infernalis*), and Firefly Squid (*Watasenia scintillans*), each occupying distinct ecological niches within marine ecosystems. The global expansion of squid fisheries highlights

their growing economic importance, particularly in offshore and high-seas environments.

The Indian Ocean remains relatively underexploited for oceanic squid fisheries, while some localized fishing grounds exist off the coasts of Oman and South Africa. This underutilization is primarily due to technological limitations, operational challenges in offshore environments, and the inherent difficulty of assessing highly migratory and short-lived species. Consequently, stock status across much of the Indian Ocean is considered data-limited, with assessments relying on fragmented datasets and limited survey coverage (Arkhipkin et al., 2021). The Indian Ocean hosts a range of oceanic squid resources, primarily dominated by members of the family Ommastrephidae, including species such as purpleback flying squid (*Sthenoteuthis oualaniensis*), neon flying squid (*Ommastrephes bartramii*), and other large pelagic squids. These squids are typically targeted using light-assisted jigging techniques, particularly in international waters, although fishing intensity remains significantly lower than in Pacific fisheries. Their abundance is strongly influenced by environmental factors such as sea surface temperature, productivity, and oceanographic features, making stock assessment and management complicated (Arkhipkin et al., 2015). Despite these challenges, the region holds considerable potential for the development of oceanic squid fisheries, particularly in high-seas areas.

The purple-back flying squid (*S. oualaniensis*) is a highly abundant, fast-growing, and widely distributed oceanic species across the Indo-Pacific region, exhibiting high productivity and complex population structure. The targeted fisheries, particularly developed by China using advanced jigging techniques, have expanded in recent decades, but there is no clear evidence of global stock depletion. The species is currently classified as "Least Concern" (IUCN), with stocks generally considered underexploited to moderately exploited despite limited regional assessments (Xinjun, 2007; Yu, 2019). Similarly, *Thysanoteuthis rhombus* (rhomboid squid) supports mainly localized fisheries, with the bulk of global catches concentrated in the Sea of Japan and the Okinawa Islands. However, in Indian waters, it is minimally exploited or occurs as bycatch, and it is listed as "Least Concern," with no evidence of significant global stock decline, though regional data remain sparse (Bower & Miyahara, 2005; Pérez et al., 2012). Overall, while none of these species currently show signs of global overexploitation, significant gaps persist in stock-specific data, particularly in the Indian Ocean and high-seas regions, highlighting the need for improved monitoring, species-level assessments, and ecosystem-based management approaches (FAO, 2024).

The AS region is recognized as one of the most productive areas for oceanic squid resources in the Indian Ocean, with significant scope for fishery development (Mohamed et al., 2018; Sajikumar et al., 2021). Despite this potential, the fishery in Indian waters remains largely underexploited, with activities mainly confined to exploratory operations using light-assisted jigging, hand jigging, and occasionally gillnets and trammel nets. Fishing is predominantly conducted at night, taking advantage of squids' phototactic behaviour. The species is known to dominate the epipelagic zone of the AS in terms of abundance and biomass, with mean biomass estimates of around 4.5 t/km$^2$. Global stock estimates range between 8 and 11 mt, with the AS identified as the most promising region, supporting a fishable stock of approximately 1-1.5 mt (Mohamed et al., 2011; Wang et al., 2017; Ragesh et al., 2023). These figures suggest that the resource is abundant and can support a targeted fishery, particularly along the western coast of India. The species is characterized by a short life span of approximately 0.5-1year, rapid growth, and high turnover, making it highly productive but also requiring adaptive and continuous stock assessment (Ragesh et al., 2023).

The diamondback squid *Thysanoteuthis rhombus* occurs sporadically, with no evidence of fishable concentrations; most individuals recorded were small, though occasional large specimens (~ 585 mm and 5.3 kg) were observed, suggesting low stock density. Other species, such as *Onychoteuthis banksii*, showed moderate occurrence in certain regions (notably Andaman-Nicobar waters), but overall abundance remained low and patchy (Ragesh et al., 2023). A diverse assemblage of small-sized oceanic squids (e.g., *Abralia*, *Abraliopsis*, *Cranchia*, *Histioteuthis*) was frequently encountered, yet these taxa are not commercially exploited due to their small size, low biomass, and poor catch rates (Sreenivasan & Sarvesan, 1990).

At the global and regional scale, oceanic squid fisheries have expanded significantly in high-seas areas, particularly in the Northwest Indian Ocean. Satellite-based monitoring has shown a rapid increase in distant-water fishing fleets, especially Chinese jigging vessels, operating exclusively in ABNJ regions outside EEZs. The number of vessels increased from 4 in 2015 to over 50 by 2017, indicating the emergence of a large-scale, industrial high-seas squid fishery (SIOFA Secretariat, 2017). These operations are highly mobile and supported by transshipment through refrigerated cargo vessels, allowing continuous fishing and efficient catch transport.

## Oceanic Squids of the Indian Ocean–Exploratory Surveys by FORV *Sagar Sampada*

A major contribution to understanding the characteristics of these resources was made through the exploratory surveys onboard FORV *Sagar Sampada* across the Indian EEZ and adjacent oceanic waters (Nair et al., 1990; Sreenivasan & Sarvesan, 1990; Nair et al., 1996; Mohamed et al., 2018; Sajikumar et al., 2021). In the Indo-Pacific region, commercially exploited species include *Uroteuthis duvaucelii*, widely targeted by artisanal fisheries, and oceanic species such as *Symplectoteuthis oualaniensis*, which support emerging offshore fisheries utilizing jigging and light-assisted fishing techniques (Nair et al., 1996). Oceanic squids were found to be widely distributed pelagic organisms inhabiting midwater depths of approximately 120-250 m, with high occurrence in pelagic trawl operations (~90% of stations) while their contribution to demersal trawl catches remained low (3-12%). The dominant species identified was *S. oualaniensis*, which occurred consistently across the AS, the BoB, and the Andaman-Nicobar region, followed by *Thysanoteuthis rhombus*, *Onychoteuthis banksii*, and *Ancistrocheirus lesueurii*. In addition, a diverse assemblage of mesopelagic squids, including *Abralia andamanica*, *Abraliopsis gilchristii*, *Cranchia* spp., *Liocranchia* spp., *Enoploteuthis* sp., *Chiroteuthis* sp., and *Histioteuthis* sp., was recorded, indicating high taxonomic diversity in oceanic ecosystems (Nair et al., 1990, 1996; Sreenivasan & Sarvesan, 1990). Populations exhibited a wide spatial distribution but low density and patchy occurrence, with evidence of localized aggregations, including large concentrations of juveniles (>3,500 nos./haul). Despite clear evidence of resource availability and biological productivity, oceanic squid fisheries in Indian waters remain largely underexploited. The findings from the FORV *Sagar Sampada* surveys continue to serve as a scientific foundation for future resource assessment, management strategies, and the sustainable development of oceanic squid fisheries in the Indian Ocean region.

# 5.5.Antarctic krill

Antarctic krill (*Euphausia superba*) represents one of the largest single-species biomasses in the global ocean and constitutes a keystone species in the Southern Ocean ecosystem. Krill forms a critical trophic link between primary producers and higher predators, including fish, seabirds, seals, and whales. India has demonstrated its capability to operate in the Southern Ocean through the First Indian Antarctic Krill Expedition (FIKEX), conducted between December 1995 and March 1996 onboard FORV *Sagar Sampada*. An average catch rate of 379 kg/haul was achieved, resulting in a total biomass landing of 12 tonnes (Fig. 5.6). Antarctic krill constituted 47.1% of the catch. These results established the operational feasibility of Indian distant-water fishing activities in Antarctic waters and provided a valuable baseline for future engagements (Boopendranath et al., 2013). CCAMLR regulates krill harvesting through a precautionary catch limit system designed to protect the Antarctic ecosystem. The current trigger level for krill harvesting in the Southwest Atlantic sector (Statistical Area 48) is approximately 6,20,000 tonnes, while the Indian Ocean sector (Area 58) remains comparatively underexploited, offering potential for future, scientifically regulated fisheries development (Boopendranath et al., 2012c).

Recognising the ecological importance of krill and its potential as a marine resource, comprehensive investigations were conducted during FIKEX, extending beyond harvesting, to include post-harvest processing, storage-related biochemical changes, product development, and by-product utilisation. These studies aimed to assess the feasibility of sustainable krill exploitation in alignment with CCAMLR's precautionary framework. Post-harvest handling of Antarctic krill poses significant technological challenges due to its extreme fragility,



Fig. 5.6: Antarctic krill catches recorded from FORV *Sagar Sampada* during FIKEX

rapid post-mortem proteolysis, and high fluoride content in the exoskeleton. Field observations showed that krill becomes unsuitable for food processing within four hours of capture, highlighting the need for immediate onboard handling. Accordingly, strict operational measures, such as limiting haul duration, minimising mechanical damage, and ensuring rapid transfer to processing lines, were implemented to preserve quality (Boopendranath et al., 1998).

Onboard processing of Antarctic krill involved cleaning, weighing, blast freezing at -35 °C, and storage at -30 °C. Intermediate products prepared included whole frozen krill, headless krill, tail meat, boiled krill, krill mince, boiled mince, and krill coagulate. Yield analysis showed that the cephalothorax accounted for 33% of total body weight, while tail meat contributed 25-33%, with the remainder comprising carapace and processing losses. Onboard value-added products (krill *chutney* powder, cutlets, and *masala*) showed good sensory acceptability, while shell waste was retained for chitin, chitosan, and krill meal production, supporting integrated and sustainable utilisation of krill resources. These results provide key inputs for evaluating processing efficiency and economic feasibility.

India's Antarctic krill studies are closely aligned with CCAMLR's ecosystem-based management framework. Deliberations at the CCAMLR Ecosystem Monitoring and Management (EMM) meeting in 2008 highlighted that inefficient post-harvest handling increases wastage and may indirectly elevate fishing pressure, thereby linking improved onboard processing and reduced spoilage to both economic efficiency and conservation outcomes. Fluoride accumulation in krill products is a major limitation to market expansion, as substantiated by Indian observations of fluoride migration during frozen storage. The shifting from volume-based exploitation to value-added utilisation is consistent with India's onboard product development and by-product recovery approaches.

Despite the large biomass available and the potential for exploiting krill in Area 58 in the Indian Ocean Sector of the Southern Ocean (IOSO), the ecological or biogeochemical role of krill and the possibility of recruitment anomalies were not a serious concern until 2015. Although the Scientific Committee on Antarctic Research (SCAR, 2012) reported conservation threats to species, ecosystems, and resources due to regional warming, ocean acidification, and changes in sea-ice distribution, information on their impacts on krill resources was scarce. This demanded impact assessment studies, including understanding the abundance, distribution patterns, and environmental linkages of these species under varying climate conditions. This also stresses the need for reliable biomass estimations, enabling sustainable management of these resources, utilising invasive techniques like fisheries acoustics, and strengthening these efforts to more areas has been discussed as a priority subject in the Working Group-Ecosystem Monitoring and Management (WG-EMM) meeting of 2018. Further, at the WG-EMM 2019, India and Russia highlighted the need for krill-larvae-associated studies to understand krill-ecosystem dynamics and assess possible recruitment anomalies under varying environmental scenarios (CCAMLR, 2019; Smitha et al., 2019).

In addition to ecological considerations, the economic potential of krill resources has attracted increasing global attention in recent years. Growing

global demand for krill-derived aquaculture feeds, nutraceuticals, and pharmaceuticals, particularly krill oil rich in omega-3 fatty acids and astaxanthin, is expected to drive increased fishing interest. For India, the under-exploited IOSO (CCAMLR Area 58) presents a strategic opportunity for distant-water operations, contingent on addressing logistical, technological, and environmental constraints (Boopendranath et al., 2012a). India's krill investigations highlight the importance of integrating harvesting technology, post-harvest processing, food safety management, and value-added product development within CCAMLR's ecosystem-based management framework.

## CMLRE and Future Perspectives for Distant-Water Fishery Resources

Overall, distant-water fishery resources highlight the growing strategic importance of oceanic and high-seas resources to India's future fisheries sector. However, unlike coastal fisheries, systematic scientific investigations on distant-water resources in the Indian Ocean region remain limited, fragmented, and largely dependent on secondary information and international assessments. In this context, CMLRE and the research platform provided by FORV *Sagar Sampada*, is uniquely positioned to bridge critical knowledge gaps and establish a dedicated national framework for distant-water fisheries research and monitoring. India's expanding interests in oceanic tunas, billfishes, sharks, oceanic squids, and other pelagic resources demand sustained scientific observations covering resource distribution, stock structure, spawning grounds, larval ecology, migration pathways, and ecosystem linkages. CMLRE has already laid an important scientific foundation in this direction through earlier studies on tuna eggs and larvae, primary productivity-based estimates of tuna and tuna-like resources, acoustic surveys, and tuna tagging initiatives (INCOIS) that contributed to understanding oceanic fish movements and pelagic ecosystem dynamics in the Indian Ocean. Such studies demonstrate our capability to integrate fisheries oceanography, biodiversity assessments, and ecosystem-based approaches for the management of highly migratory resources.

Moving forward, FORV *Sagar Sampada* can play a central role in developing a sustained monitoring framework for distant-water fishery resources through regular oceanographic cruises, acoustic biomass estimation, habitat mapping, tagging programmes, and exploratory surveys in offshore and oceanic waters. Continuous observations from such cruises are essential for generating long-term datasets on species distribution, abundance trends, recruitment variability, and climate-driven shifts in pelagic ecosystems. In addition, the vessel can support integrated ecosystem assessments by linking fisheries data with physical and biogeochemical oceanographic characteristics such as, oxygen minimum zones, productivity gradients etc. Such multidisciplinary observations are increasingly important under changing climatic conditions, where shifts in oceanographic processes directly influence the availability and distribution of distant-water fishery resources. The application of acoustic methods, eDNA-based monitoring, satellite-linked observations, AI-assisted analytics, and ecosystem modelling along with ship based in-situ surveys can further improve the precision of stock assessments and resource forecasting. CMLRE's experience in Antarctic ecosystem investigations, including studies associated with the FIKEX, also reflects the institution's growing capability in conducting research beyond conventional fishing grounds and contributing to international-scale marine ecosystem studies.

As India advances towards strengthening its blue economy and enhancing its participation in regional and international fisheries governance, the need for a dedicated scientific framework for distant-water fisheries becomes increasingly important. In this regard, CMLRE, supported by FORV *Sagar Sampada*, can serve as a national nodal institution for long-term ecosystem monitoring, resource assessment, and scientific advisory support for distant-water fisheries management. By integrating multidisciplinary research, advanced technologies, and sustained observations, CMLRE can significantly contribute towards the development of science-based, precautionary, and ecosystem-oriented strategies for the sustainable utilization and conservation of distant-water fishery resources in the Indian Ocean region thereby contributing to the SDGs.

# 6 Biodiversity Hotspot: Potential MPAs In Indian EEZ

India currently has 31 major MPAs notified under the Wildlife (Protection) Act, 1972, primarily focusing on coastal and nearshore ecosystems (PIB report, 2022). These MPAs cover approximately 9,640 sq km, accounting for less than 0.5% of India's Exclusive Economic Zone (EEZ). They represent a mosaic of diverse habitats, encompassing coral reefs, thriving mangrove forests, intricate estuaries, expansive lagoons, and productive seagrass beds (Singh, 2003). The largest concentration of MPAs exists along the east coast and the Andaman & Nicobar Islands, while the west coast and the Lakshadweep Islands remain significantly underrepresented. MPAs are increasingly recognised as a crucial tool for managing and conserving marine resources. However, they face significant challenges in India due to the absence of specific legislation (Dardi & Shanthakumar, 2023).

Several MPAs, such as the Gulf of Mannar Marine National Park and the Sundarbans Biosphere Reserve, are recognized for their ecological importance. However, the management effectiveness of these areas remains questionable due to inadequate financial resources, fragmented institutional frameworks, poor management, weak enforcement, and minimal community involvement (Singh, 2003). The Indian government has initiated efforts to expand MPA coverage, aligning with global targets such as the Aichi Biodiversity Targets and the Kunming-Montreal Global Biodiversity Framework, which aim to protect at least 30% of land, marine, and coastal areas by 2030 (Tiwary & Bajaj, 2021). Despite these commitments, deep-sea MPAs within Indian waters remain largely uncharted. Abdulla et al. (2013) highlight the global challenge of establishing deep-sea MPAs due to data scarcity and enforcement difficulties. India's situation mirrors these challenges, with significant gaps in scientific knowledge, technological limitations, and the complexities of enforcement in deep-sea environments. Some of the critical challenges facing India's MPA network include:

**Legal and Institutional Gaps:** The existing legal framework for MPAs in India is fragmented and lacks specificity. While the Coastal Regulation Zone (CRZ) Act, 1991, provides some protection, it does not address the unique management needs of MPAs (Rajagopalan, 2020). This results in ambiguities in jurisdiction and enforcement responsibilities.

**Scientific and Technological Constraints:** The deep-sea environment remains poorly understood, with significant gaps in baseline data on species distribution, ecological interactions, and ecosystem health. Advanced monitoring technologies, such as remote sensing and AUVs, require substantial investment (Hibberd, 2017).

**Community Engagement and Livelihood Conflicts:** Many coastal communities depend on marine resources for their sustenance. Successful MPA management requires active stakeholder participation to align conservation efforts with community needs (Bennett & Dearden, 2014).

Kollam Bank, Angria Bank, the off-Mangalore deep-sea slope, the Terrace off Trivandrum (ToT), Lakshadweep, and the Andaman-Nicobar Islands together form a network of marine biodiversity hotspots in the Indian EEZ. They host exceptional coral diversity, structurally complex benthic habitats, rare and endemic deep-sea fauna, and rich pelagic and demersal fish communities, including commercially important tunas, deep-sea shrimps, and apex predators. Scientific surveys, particularly those conducted on FORV *Sagar Sampada*, have shown that these regions combine high species richness, unique geomorphology, and critical life-history functions, such as spawning, nursery, and feeding grounds. At the same time, they are highly vulnerable to bottom trawling, climate-driven coral bleaching, bycatch, and emerging pressures like

tourism, pollution, and potential deep-sea mining. Recognising and managing these areas as biodiversity hotspots is therefore essential to safeguard both India's marine natural heritage and the long-term sustainability of its fisheries.

## 6.1. Kollam Bank

The Kollam Bank, located between 8°00'N and 9°00'N off the southwest coast of India, is not just one of the most productive deep-sea fishing grounds in the Arabian Sea (AS), it is a critical ecological asset whose hotspot status demands urgent recognition and protection. This submerged plateau, lying mainly within the 275-375 m depth range, stands out from the surrounding shelf because of its interaction with monsoonal upwelling and deep boundary currents. These processes fuel intense primary productivity (Smitha et al., 2008) and support a high biomass of demersal and mesopelagic organisms (Jacob, 2017). Ecologically, this productivity underpins a commercially important deep-sea crustacean fishery, dominated by deep-water shrimps such as *Heterocarpus woodmasoni* (Indian nylon shrimp), *Aristaeomorpha foliacea* (Giant red shrimp), and *Aristeus alcocki* (Arabian red shrimp), along with deep-water lobsters such as *Puerulus sewelli.* These species inhabit the continental slope and form the main targets of deep-sea trawlers from Sakthikulangara and Cochin fisheries harbors.

However, the same fishery that demonstrates the bank's richness also exposes its vulnerability. While the target is crustaceans, the fishery is characterised by extremely high bycatch (CMFRI 2002; 2020; 2021; 2022; 2023; 2024). Non-target catch often forms a substantial portion of the total haul, with deep-sea finfishes dominating the discarded fraction (Vipin, 2015). The major families in this shrimp trawl bycatch include Myctophidae (lanternfishes), Gonostomatidae (bristlemouths), and Sternoptychidae (hatchetfishes). Because these mesopelagic fishes, especially myctophids, serve as a key forage source for higher trophic level predators, their large-scale removal poses a significant ecological risk. It threatens to disrupt vertical energy transfer and destabilise the slope food web.

The biological richness of Kollam Bank is further linked to the AS OMZ, which enhances prey aggregation and, in turn, supports a diverse assemblage of megafauna. The area sustains populations of bottlenose dolphins (*Tursiops truncatus*), spinner dolphins (*Stenella longirostris*), and Risso's dolphins (*Grampus griseus*), and is recognised as a habitat for the Arabian Sea blue whale (*Balaenoptera musculus indica*), a genetically distinct population dependent on upwelling-driven productivity (Anderson et al., 2012). The presence of the deep-sea shark *Cephaloscyllium silasi* (Indian swellshark) in bycatch (Akhilesh et al., 2014) further underlines the bank's role in sustaining demersal predators. The deep-sea ichthyofauna of the Kollam Bank (200-500 m) includes 144 finfish species across 76 families, with Perciformes (17.52%) and Acropomatiformes (16.93%) being particularly abundant (Augustina et al., 2025). Seasonal shifts, including dominance of *Synagrops japonicus* and, in 2022, a surge in the myctophid *Diaphus watasei* (26.99%), and higher post-monsoon richness, reveal a dynamic and productive system. The trophic analysis revealed a "top-heavy" structure with many apex predators (trophic levels 4.0-4.5) and an absence of planktivores, highlighting new distributional records for the west coast (e.g., *Grammonus robustus, Ophidion smithi*). The conservation signal is clear: 4.6% of species are threatened (including the Critically Endangered *Centrophorus atromarginatus*), and 21.5% are Data Deficient, underscoring knowledge gaps and the urgency of habitat protection.

Given this combination of high biodiversity, key ecological functions, and mounting fishing pressure, Kollam Bank must be treated as a priority hotspot, with stricter management non-negotiable. Management measures, such as the use of mandatory Bycatch Reduction Devices (BRDs) in shrimp trawls, seasonal closures during peak breeding periods of deep-sea sharks and crustaceans, and restrictions on bottom trawling in critical benthic zones, are essential to preserve both biodiversity and long-term fishery productivity (Pravin et al., 2013).

## 6.2. Angria Bank

Angria Bank, a submerged plateau in the EAS approximately 105 km west off Vijaydurg, Maharashtra, is one of India's most biologically significant yet least protected marine ecosystems. Rising abruptly from surrounding depths of 1,000-1,400 m to a shallow crest of 20-40 m, this feature shapes regional

hydrography through topographically enhanced mixing and upwelling. These processes sustain a mosaic of habitats, making Angria Bank the largest submerged coral reef system in India, spanning approximately 1,300 km$^2$ and featuring a core coral habitat of roughly 350 km$^2$ (Sivakumar & Joshi, 2015).

Recent surveys, especially the 2019 Joint Expedition by CMLRE and WCS-India (WCS-India, 2022) onboard FORV *Sagar Sampada*, confirmed that Angria Bank hosts dense, diverse coral frameworks adapted to offshore, high-energy conditions. Dominant coral families include Faviidae and Poritidae, with robust populations of Acropora, Montipora, and Porites. These communities function as a climate refuge: situated away from turbid, sediment-laden nearshore waters, they appear more resilient to thermal stress than many coastal reefs. The 2019 expedition recorded over 3,000 individual reef fishes from 172 species and 80 genera, with abundant Chaetodontidae and high-biomass piscivores indicative of a well-structured, functioning reef system, in stark contrast to many degraded coastal reefs elsewhere.

The ecological and fishery connectivity of Angria Bank further elevates its hotspot status, highlighting its role in supporting large aggregations of myctophids associated with the DSL (Sivakumar & Joshi, 2015). These myctophids are central to carbon transport and serve as prey for commercially important pelagic fishes such as *Thunnus albacares* (yellowfin tuna) and *Katsuwonus pelamis* (skipjack tuna), reinforcing Angria's function as a spawning and feeding ground (Varghese et al., 2019; Lakra et al., 2021). The bank also acts as a foraging and navigational corridor for cetaceans, elasmobranchs (including whale sharks), and multiple marine reptile species. This likely makes Angria Bank a "source" reef, where currents export larvae and propagules that help sustain other ecosystems along the Konkan coast (Ravindran et al., 2023).

Angria Bank clearly meets multiple criteria for protection. It aligns with India's Convention on Biological Diversity (CBD) commitments (Aichi Target 11) and qualifies as an Ecologically and Biologically Significant Area (EBSA) due to its uniqueness, biological diversity, and importance for life-history stages (Sivakumar & Joshi, 2015). Yet, despite its offshore location, it is already experiencing pressures from unregulated tourism (anchoring, reef walking), mechanised fishing, potential oil exploitation, and heavy shipping traffic. Recognising and legally notifying Angria Bank as a Priority Biodiversity Hotspot and as a Designated Area under the Maritime Zones Act (1976) or as a Marine Protected Area (MPA) is essential if India is to safeguard this irreplaceable coral and pelagic reservoir and the fisheries that depend on it.

## 6.3. Off-Mangalore Deep-Sea Slope

The deep-sea slope off Mangalore, spanning depths of 229-1070 m, is one of the most ecologically complex slope habitats in the EAS and merits recognition as a deep-sea biodiversity hotspot of national importance. FORV *Sagar Sampada* surveys have repeatedly identified this sector as a premier region for deep-sea ichthyofauna along the southwest coast of India. The region is reported to have 77 deep-sea fish species representing 51 families and 20 orders, including characteristic slope species such as *Psenopsis cyanea, Bathyuroconger braueri, Coelorhynchus flabellispinis, Lamprogrammus exutus, Luciobrotula bartschi, Neobythites analis,* and *Synagrops japonicus* (Jayaprakash et al., 2006). The trophic structure is equally remarkable: deep-sea sharks such as *Etmopterus granulosus* and *Centrophorus lusitanicus* indicate a trophically complete ecosystem capable of supporting apex demersal predators. The slope also supports productive crustacean grounds in the 250-700 m range, with commercially important species such as *Heterocarpus woodmasoni, H. gibbosus, Aristeus alcocki* and *Plesionika spinipes* forming a key resource base.

The discovery of the hexactinellid glass sponge *Hyalonema* at a depth of around 900 m, the first confirmed record of this genus from the Indian deep-sea, demonstrates the presence of fragile, habitat-forming taxa (Vinod et al., 2007). These sponges, anchored by long stalks in soft sediments, act as structural engineers, adding complexity to an otherwise featureless slope. The occurrence of the giant isopod *Bathynomus giganteus*, alongside *Hyalonema*, reflects a stable, undisturbed environment that supports both sessile filter feeders and large mobile scavengers. Given the extreme

sensitivity and slow growth rates of deep-sea sponges and their associated fauna, proactive measures to prevent destructive fishing are crucial for maintaining ecological stability and preserving the resources.

## 6.4. Terrace off Trivandrum

The Terrace off Trivandrum (ToT), part of the Alleppey-Trivandrum Terrace Complex (ATTC) in the SEAS, is a bathyal feature at depths of 900-2,000 m that, through CMLRE's work, has emerged as one of the most outstanding deep-sea biodiversity hotspots in the northern Indian Ocean. Systematic FORV *Sagar Sampada* surveys under the MLR programme, revealed that the ToT harbours exceptionally high species richness compared to any typical deep-sea environment. Within the 900-1,500 m depth zone alone, 148 megafaunal species spanning 122 genera, 86 families, and 5 phyla were recorded. Diversity indices such as ES50 (expected number of species per 50 individuals) was found to be approximately 13.6 for fish and 11 for invertebrates, exceeding even well-known hotspots like the deep-sea off Cape Hatteras (Jacob, 2017).

The ToT serves as a refuge for rare and historically known taxa. FORV *Sagar Sampada* rediscovered species, including *Coryphaenoides woodmasoni, Harpadon squamosus, Nezumia brevirostris, Dicrolene vaillanti,* and *Zoroaster alfredi*. The region also yielded species new to the Northern Indian Ocean or to science, such as *Bufoceratias shaoi*, a rare anglerfish previously known only from the Pacific, and the king crab, originally reported as *Neolithodes alcocki* and now described as *N. indicus*.

A striking feature of the ToT is the prevalence of deep-sea gigantism, with a "core area of abundance" for exceptionally large forms such as *Colossendeis colossea* (sea spider up to 50 cm leg span), *Bathynomus keablei* (giant isopod up to 48 cm), *Lamprogrammus brunswigi* (cusk-eel up to 130 cm), and *Deepstaria enigmatica* (a massive jellyfish). Contrary to the typical decrease in biomass with depth, megafaunal biomass in the ToT averages 2,558 kg/km$^2$ in the summer monsoon and rises to 23,992 kg/km$^2$ in the winter monsoon. This anomaly is linked to the downwelling Lakshadweep High (a warm-core eddy), which funnels particulate organic matter from productive surface waters to bathyal depths, creating a food-rich environment for shrimps and top predators.

Crucially, the ToT sits just below the OMZ, with relatively well-oxygenated bottom waters (0.8-1.2 ml/L), functioning as a refuge for hypoxia-intolerant species displaced from adjacent oxygen-deficient slopes. Based on CBD criteria, CMLRE's work (Jacob, 2017) demonstrates that the ToT meets six of the seven EBSA criteria: Uniqueness/Rarity, Special importance for life history, Vulnerability, Biological Productivity, Biological Diversity, and Naturalness. This makes the case for the ToT to be prioritised for immediate conservation action, especially against emerging threats such as unmanaged deep-sea trawling and potential seabed exploitation.

## 6.5. Lakshadweep Ecosystem

The Lakshadweep ecosystem comprises 36 islands in the SEAS, including 12 atolls, 3 reefs, 5 submerged banks, and 10 inhabited islands. This archipelago constitutes India's sole atoll-type coral reef ecosystem, consisting of low-lying reef islands formed from biogenic carbonate deposits (MoEFCC, 2017). They are organized around reef flats and fore-reef slopes associated with the Laccadive-Chagos Ridge (LCR) and shallow lagoons (Ashalatha et al., 1991). Beyond providing physical support, the ridge also creates strong environmental gradients over short spatial scales, which are fundamental to the ecological functioning and biodiversity patterns observed across the Lakshadweep ecosystem.

Despite its small geographic extent, Lakshadweep supports remarkable biological diversity. Studies documented 165 species of scleractinian (hard) corals (De et al., 2020) and 37 species of soft corals (Alderslade & Shirwaiker, 1991; Vennam & van Ofwegen, 1996; Mary & Sluka, 2014). Reef-associated ichthyofauna are equally diverse, with approximately 890 fish species reported (Rajan et al., 2021a; Sandra et al., 2022; Kar et al., 2022, 2023a, 2023b, 2024; Sureshkumar, 2023; Konhamkakkada, 2023). The invertebrate community further highlights this richness, including 768 mollusc species (Ravinesh & Bijukumar, 2015), 121 sponge

species (Varsha et al., 2021), and 93 echinoderm species (Sastry, 2007). Among echinoderms, 23 species of sea stars (Nowshad et al., 2019), 40 valid species of brittle stars (Parameswaran, 2020), and 21 species of sea cucumbers (Nowshad, 2021) have been documented. Macroalgal communities are also well represented, with 65 species of seaweeds found in intertidal and subtidal habitats (Shabeena et al., 2023). Additionally, lagoon environments support seven species of seagrasses, which play critical ecological roles in sediment stabilization, nutrient cycling, carbon sequestration, and provision of nursery habitats for juvenile marine organisms (Nobi et al., 2011). Collectively, these biodiversity indicators demonstrate that Lakshadweep sustains a disproportionately large share of marine life relative to its terrestrial area. Species richness is strongly structured by the reef-lagoon mosaic that underpins ecosystem productivity and island livelihoods.

Oceanographic surveys conducted by FORV *Sagar Sampada* have expanded this perspective beyond reef-associated communities by documenting significant pelagic and demersal resources in surrounding waters. National syntheses of cruise data report elevated zooplankton biomass, pronounced DSLs, and abundant micronekton assemblages around the atolls (Balachandran & Abdul, 1989; James & Pillai, 1990), identifying the region as an important forage-fish hotspot in the AS. Several taxa recorded from Lakshadweep are listed as threatened on the IUCN Red List, underscoring the archipelago's global conservation significance. Critically Endangered species include the hawksbill turtle (*Eretmochelys imbricata*) (Mortimer & Donnelly, 2008) and the oceanic whitetip shark (*Carcharhinus longimanus*) (Rigby et al., 2019). The whale shark (*Rhincodon typus*) and the humphead wrasse (*Cheilinus undulatus*) are currently categorized as Endangered (Pierce & Norman, 2016).

The total fish landings in Lakshadweep during 2023 were estimated at 14,430 tonnes, with tuna accounting for approximately 80% (11,620 tonnes) (CMFRI, 2023). In 2024, Skipjack tuna accounted for 64% of total tuna landings, followed by yellowfin tuna (31%) and other tunas (5%) (CMFRI, 2024). Live-bait fisheries provide a critical support system for these tuna operations. The major live bait species for the skipjack pole-and-line fishery comprised *Spratelloides delicatulus* (blue sprat), constituting 42% of the total bait, followed by *S. gracilis* (Silver Sprat), and other reef-associated fishes such as green chromis, fusiliers, and cardinal fishes. The yellowfin handline fishery predominantly depends on species such as *Odonus niger* (triggerfish: 47% contribution), followed by *Ceasio* spp., *Pteroceasio* spp., and *Chromis caeruleus*. Beyond tuna, reef fisheries form the second major component of the Lakshadweep catch, with snappers contributing 42% of reef landings in 2024, followed by groupers (21%), emperors (20%), and other reef-associated species, reflecting the ecological linkage between lagoon, reef, and oceanic fishing systems in the islands.

The ecological vulnerability of Lakshadweep is shaped by its low elevation and atoll geomorphology, making the islands highly sensitive to climate-related impacts, including sea-level rise, coastal erosion, and coral bleaching (Vinoth et al., 2012; MoEFCC, 2017). Major climate anomalies, including strong warm pools, El Niño events, and tropical cyclones (e.g., the Okhi cyclone in 2017), have already caused significant impacts on the coral ecosystem and reef degradation (Ammanabrolu et al., 2025). Rising sea levels and increasing ocean acidification further threaten reef growth and increase the risk of shoreline erosion and inundation (IPCC, 2021). In addition to climate stress, local pressures such as dredging, land reclamation, sewage discharge, and unsustainable fishing can increase turbidity, alter lagoon circulation, and disrupt ecological balance, weakening reef resilience (MoEFCC, 2017). Although bottom trawling is prohibited in Lakshadweep waters, localized impacts from baitfish extraction, anchoring, and lost fishing gear may still damage reef habitats, highlighting the need for integrated fisheries governance and ecosystem-based conservation (Koya et al., 2019).

A study from the FORV *Sagar Sampada* cruise showed that near-reef waters around Minicoy are crucial nursery grounds for tuna larvae across multiple seasons, firmly linking coral reef health to the sustainability of the pelagic fishery (Aneesh Kumar et al., 2020). Taken together, the coral inventories, FORV *Sagar Sampada* based pelagic work, and recent stress studies demonstrate that Lakshadweep is an atoll-scale hotspot where geomorphology, physics, and biology interact to generate high biodiversity and biomass. At the same time, the rapid impacts of climate change and pollution make it a highly

fragile system that requires evidence-based, reef- and fishery-level protection measures.

## 6.6. The Andaman Waters

The Andaman ecosystem is among the most distinctive in India, occurring around volcanic and sedimentary islands and developing primarily as fringing reefs, barrier reefs, patch reefs, and coral communities attached to rocky substrates. This geological setting generates steep bathymetric gradients, underwater ridges, deep basins, and narrow continental shelves, creating heterogeneous habitats over short spatial scales and promoting high species coexistence and ecological complexity (Varkey et al., 1996; Yatheesh et al., 2021).

Geographically, the Andaman and Nicobar Union Territory consists of 572 islands, islets, and rocky outcrops extending over nearly 800 km from north to south, although only 38 islands are permanently inhabited (Census of India, 2011). The Ten Degree Channel separates the Andaman and Nicobar groups, forming two distinct biogeographic clusters within the same archipelago (MoEFCC, 2019). The presence of India's only active volcano, Barren Island, and the dormant volcanic island Narcondam confirms the region's volcanic origin and contributes to habitat heterogeneity in the surrounding marine environments (GSI, 2006). These geological characteristics play a critical role in shaping marine biodiversity by creating diverse underwater habitats ranging from coral reefs and mangrove lagoons to deep-sea slopes and seamount-like structures.

The archipelago supports approximately 11,069 animal species, representing more than 10% of India's faunal diversity within a relatively small land area (ZSI, 2025). Marine fish diversity is particularly remarkable, with more than 1,500 species reported across numerous families and habitats, making this one of the richest marine fish regions in Indian waters (Rajan et al., 2021b; ZSI, 2025). Coral diversity is also high, with approximately 418 reef-building coral species recorded from Indian reefs, a substantial proportion of which occur in the Andaman region (MoEFCC, 2019). The islands further support diverse assemblages of molluscs, echinoderms, crustaceans, and other marine invertebrates that contribute to the structural and functional complexity of reef ecosystems (ZSI, 2025). Coastal ecosystems are enriched by 12 species of seagrasses and 43 species of true mangroves, which provide essential ecological services including nursery habitat provision, nutrient cycling, carbon sequestration, and shoreline stabilization (Gole et al., 2023; IUCN, 2024; ZSI, 2025).

FORV *Sagar Sampada* played a central role in revealing the benthic dimension of this hotspot and showed that sediments rich in biogenic and volcanic material support diverse macrobenthic communities dominated by polychaetes along the continental margin (Gopal & Saramma, 2017). High diversity in the deep-sea demersal fishery (Hashim, 2012; Rajeeshkumar et al., 2018; Sileesh et al., 2020) is consistent with the heterogeneous habitats of the Andaman ecosystems. The region's sensitivity is underscored by the impacts of the 2004 earthquake on benthic habitats (Ilayaraja & Krishnamurthy, 2010) and by the influence of the Bay of Bengal (BoB) OMZ at mid-depths, which significantly modified community structure (Helly & Levin, 2004; Jaleel et al., 2014). The unusual coexistence of tropical rainforests on land and coral ecosystems underwater adds to its uniqueness.

While the Andaman and Nicobar Islands constitute only about 0.25% of India's geographical area, they are widely recognized as a biodiversity hotspot, often described as being "home to nearly one-tenth of India's faunal species" (Chandra & Raghunathan, 2018). The islands support a remarkable level of biodiversity, with approximately 11,009 faunal species recorded, including 1,067 endemic species (Chandra & Raghunathan, 2018). Coral reef ecosystems are particularly rich, with 523 species of scleractinian (hard) corals (De et al., 2020) and 272 species of soft corals (Raghunathan & Yogesh Kumar, 2025). The ichthyofaunal diversity is equally notable, comprising 1,434 fish species across 576 genera, 33 orders, and 165 families, of which about 400 are commercially important (Rajan et al., 2021b).

The invertebrate fauna delineates this richness, encompassing 1,763 molluscan species (Subba Rao & Dey, 2000; Venkataraman & Sivaperuman, 2014; D'Souza & Shenoy, 2023), 159 sponge species (Sivaleela & Raghunathan, 2024), and 478 echinoderm species (Nigam & Raghunathan, 2018). In addition,

macroalgal communities are extensively represented, with more than 300 species of seaweeds (Palanisamy, 2012). The Andaman Sea region also supports 13 of the 16 seagrass species recorded in India (Mishra et al., 2023) and 43 species of true mangroves (Macintosh et al., 2023), which collectively provide critical ecosystem services such as nursery grounds for marine organisms, nutrient cycling, carbon sequestration, and shoreline stabilization.

The Andaman and Nicobar Islands recorded a total marine fish landings of 16,990 tonnes in 2024 (CMFRI, 2024), an 8% decline from 18,381 tonnes in 2023 (CMFRI, 2023). The catch composition was evenly distributed between pelagic (49.8%) and demersal finfishes (49.2%), with crustaceans (0.8%) and molluscs (0.2%) forming minor components. The species composition indicates that snappers formed the dominant group, followed by *Caranx* spp. (jacks and trevallies), rays (Batoidea), Indian mackerel (*Rastrelliger kanagurta*), and rock cods/groupers (Serranidae). Spatially, 77.7% of total landings were concentrated at the Junglighat landing centre, and the South Andaman district accounted for about 85% of the total production. Biodiversity assessments of trawl-net landings documented 52 genera under 37 families, with Leiognathidae (pony fishes) emerging as the most dominant family, contributing 21.38% of the trawl catch (Kaliyamoorthy et al., 2023). The compositional pattern reflects the multi-gear, multi-species nature of the island fishery, characterized by reef-associated demersal and oceanic pelagics operating within a spatially constrained but biologically diverse marine ecosystem.

Despite its richness, the Andaman marine ecosystem is highly sensitive to climate change and anthropogenic pressures. Oceanographic processes strongly regulate the functioning of Andaman marine ecosystems. Seasonal monsoonal winds influence coastal circulation, sediment transport, nutrient fluxes, and water-column mixing, thereby affecting coral growth, plankton productivity, and larval dispersal patterns (Varkey et al., 1996). The Andaman

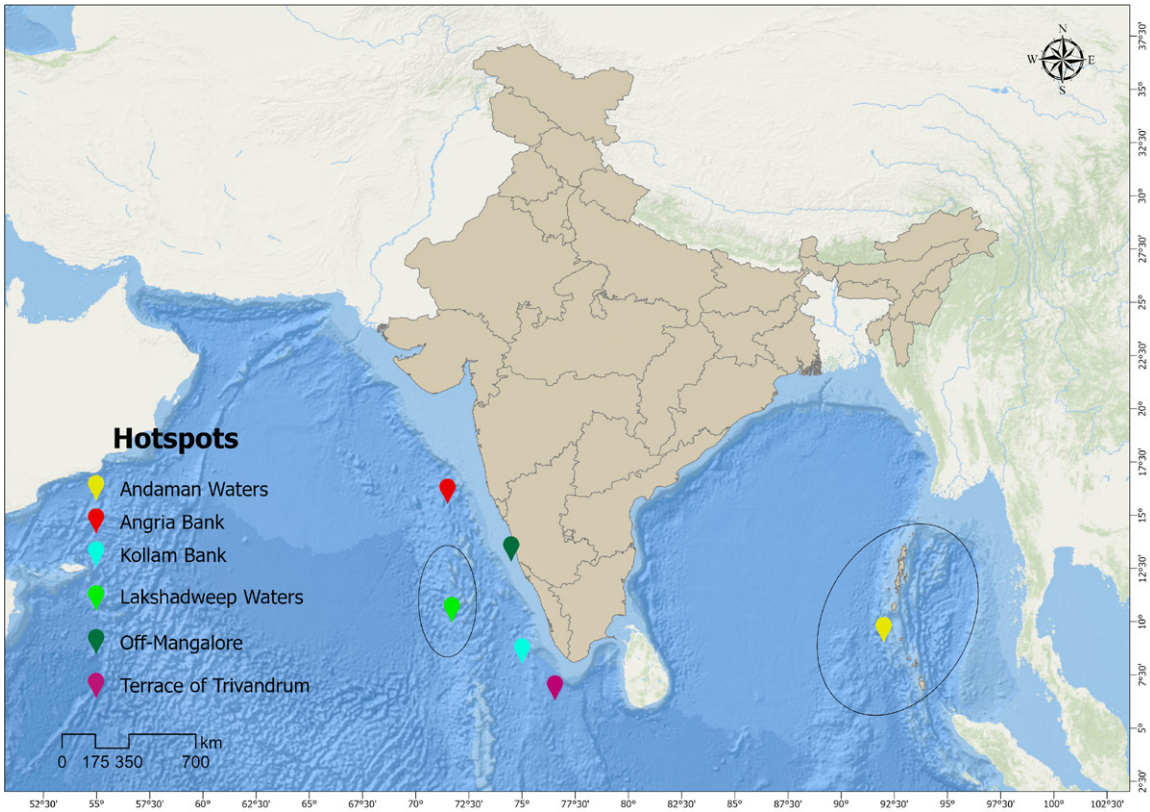



Fig. 6.1: Potential biodiversity hotspot regions within the Indian Exclusive Economic Zone (EEZ). The identified regions include Angria Bank, off Mangalore, Lakshadweep waters, Kollam Bank, Terrace of Trivandrum, and Andaman waters. Bathymetric shading represents water depth (m).

Sea also exhibits complex mesoscale circulation, including eddies, upwelling zones, and tidal mixing, which influence biological productivity and trophic connectivity (Shetye et al., 1996). At greater depths, oxygen-deficient waters associated with the BoB margin influence benthic community composition and ecosystem functioning, particularly along slope and basin environments in the Andaman region (Helly & Levin, 2004).

National reef assessments identify warming-related coral bleaching, ocean acidification, and extreme climatic events as major threats to Indian coral reefs, including those in the Andaman region (MoEFCC, 2019). Climate projections indicate that increasing sea surface temperatures, sea-level rise, and declining ocean pH will reduce coral calcification and reef resilience globally (IPCC, 2021). Local oceanographic processes such as internal wave-driven cooling may create spatial variability in coral stress responses by generating thermal refugia or hotspots of vulnerability (Wall et al., 2015). Human-induced pressures, including coastal development, sedimentation, pollution, and unsustainable resource extraction, further contribute to ecosystem degradation (MoEFCC, 2019).

Together, the coral ecosystems, the benthic diversity revealed by FORV *Sagar Sampada*, and the deep-sea and pelagic assemblages indicate that the Andaman region is a multi-layered hotspot. Its combination of high species richness, functional diversity, and environmental sensitivity makes it a critical reservoir of marine biodiversity in the northern Indian Ocean. Safeguarding this region through spatial protection, careful fisheries management, and continuous monitoring is essential if its ecological and fisheries benefits are to be maintained for the future.

Globally, deep-sea MPAs have been established in regions such as the Northeast Atlantic (OSPAR network) and Antarctica (CCAMLR MPAs) (Smith, 2020), providing valuable lessons in terms of governance, monitoring, and enforcement. Potential areas in India for deep-sea MPA designation include regions with unique biodiversity and ecological significance, such as the Andaman Trench, Laccadive Basin, Angria Bank, and the seamounts of the Central Indian Ocean (Thomas et al., 2024). These areas require further scientific exploration to assess species distribution, habitat vulnerability, and ecological interactions, thereby informing effective conservation planning. By establishing protected areas where fishing is prohibited or heavily restricted, MPAs can safeguard vulnerable habitats and allow populations to recover.

India has a strategic advantage in deep-sea exploration and research through institutions such as CMLRE and its dedicated research vessel, FORV *Sagar Sampada*, which have been instrumental in advancing the scientific understanding of India's deep-sea ecosystems. The CMLRE, under the MoES, conducts extensive research on marine biodiversity, ecosystem dynamics, and fisheries resources, providing valuable baseline data critical for MPA planning and management. The FORV *Sagar Sampada*, equipped with advanced oceanographic instruments, facilitates deep-sea exploration, biodiversity assessments, and resource mapping, making it a key asset in identifying potential deep-sea MPAs. Leveraging the capabilities of CMLRE and FORV *Sagar Sampada* can significantly enhance India's deep-sea conservation efforts by addressing existing knowledge gaps, improving habitat monitoring, and informing policy decisions with robust scientific data. A holistic approach involving legal reforms, scientific advancements, community engagement, and technological innovation is essential for India to develop a resilient and sustainable MPA network capable of conserving its rich marine biodiversity while supporting the livelihoods of coastal communities.

In summary, the six identified regions collectively represent a strategically interconnected network of marine biodiversity hotspots within India's EEZ, spanning coral atolls, submerged banks, continental slopes, bathyal terraces, and volcanic island systems (Fig. 6.1). Together, they exhibit exceptional species richness, unique geomorphological features, critical spawning and nursery grounds, deep-sea refugia, pelagic benthic coupling, and strong fisheries linkages. Simultaneously, they are increasingly exposed to pressures from intensive fishing, high bycatch, habitat disturbance, climate-driven warming and acidification, pollution, and emerging seabed activities. Their ecological importance extends beyond localized productivity, contributing directly to national fisheries security, trophic stability, carbon pathways, and India's regional and global biodiversity commitments.

Recognising these areas as a coherent yet ecologically diverse network calls for an integrated, science-based conservation framework. Given their marked differences in depth, habitat configuration, productivity regimes, biological communities, and exposure to anthropogenic stressors, a uniform management model would neither be appropriate nor effective. Management must therefore be ecosystem-specific while guided by a common objective of long-term biodiversity conservation, ecosystem resilience, and sustainable resource use. Coral reef and atoll systems require spatial zoning, regulation of tourism and reef-associated fisheries, protection of nursery habitats, and climate-resilience measures. In contrast, deep-sea banks, slopes, and bathyal terraces necessitate precautionary restrictions on bottom trawling, mandatory bycatch mitigation, protection of fragile benthic habitats and slow-growing fauna, and strict oversight of emerging seabed activities. A differentiated yet coordinated approach will be essential to safeguard ecological integrity and resource security across these diverse marine hotspots amid accelerating environmental change.

# 7 Current Status of Fisheries and Marine Ecosystems in India

Sustainable management of deep-sea and distant-water fisheries has gained increasing importance as coastal and shelf resources face growing pressure and exploitation expands into deeper and more remote oceanic regions. These ecosystems are characterized by strong environmental variability, limited baseline data, and species with slow growth and low resilience, making them vulnerable to overexploitation. The assessment and management of fishery and MLR as a whole in such environments are further constrained by logistical challenges, sparse observations, and uncertainties in species-specific parameters. This necessitates a precautionary and science-driven approach that moves beyond conventional fisheries management towards integrated, ecosystem-based management frameworks tailored to deep-sea and oceanic systems.

In this context, advancements in observational and analytical tools, particularly the application of trophodynamic models, active acoustic techniques, combined with satellite observations, *in situ* measurements, and ecosystem modelling, provide a robust pathway for improving resource assessment of the Indian waters, including in deep-sea and distant-water domains. These approaches enable large-scale, non-invasive monitoring of biomass distribution and ecosystem structure, addressing critical knowledge gaps in poorly explored regions such as the mesopelagic zone and deep demersal realms. Strengthening multi-institutional collaboration, expanding long-term observation programmes, and integrating emerging methodologies are essential to support adaptive, data driven management. This chapter therefore discuss on the status of advancing sustainable fisheries and marine ecosystem management in deep-sea and distant-water regimes, aligning scientific innovation with policy frameworks to ensure responsible utilization and conservation of our ocean resources.

## 7.1. Present Status and Major Challenges

India's coastline beyond the 200 m depth contour remain largely underutilised, with many deep-sea species caught only as bycatch. Accurate estimation of deep-sea fishery potential, and possible impacts due to a regular commercial scale exploration is crucial for sustainable growth, balancing economic development with ecological conservation. Given the fishing pressure in nearshore waters and the high demand, exploring deep-sea and non-conventional resources offers promising solutions for nutritional security. This involves implementation of advanced assessment models, remote sensing-based assessment and prediction capabilities, fisheries acoustics and science-based management approach with the back-up of strong biological research. Challenges such as limited infrastructure and insufficient data hinder effective exploration. Nevertheless, with proper management, deep-sea resources can provide sustainable income for coastal communities while contributing to India's blue economy. Developing targeted fisheries must consider both economic viability and ecosystem health to avoid high fishing pressure and preserve biodiversity, aligning with India's commitment to sustainable development and marine conservation.

Effective management strategies can be built only based on a strong understanding on the fishery, and its ecological interactions, and needs regular resource assessments for sustainable harvesting. The knowledge base on our ecosystems is presently being updated through the exploratory surveys onboard the research vessels of MoES, Council of Scientific and Industrial Research (CSIR), Indian Council of Agricultural Research (ICAR) and Fishery Survey of India (FSI) (Details of the research platforms available

in India are given in Annexure 2a & 2b). The vast tropical system surrounding India, is complex to predict with any existing models or assessment protocols, and this demands system specific methodologies and approaches for the regulatory frame works. Presently, the Ministry of Fisheries, Animal Husbandry and Dairying engages working groups for Revalidating the Potential of Fishery Resources in the Indian EEZ, which have given the responsibility of estimating the fishery resources of India based on catch (CMFRI), survey (FSI) and trophodynamics (CMLRE/MoES) approaches. The task also includes the estimation of additional harvestable yield and the fleet size, that could be obtained on a sustainable basis and to give suggestions on conservation of fishery stocks in light of the existing legislation and various global conventions.

## 7.2. Trophodynamic-based assessment of Maximum Sustainable Yield (MSY) for the Indian EEZ

Trophodynamic modelling provides a robust ecosystem-based approach for estimating sustainable fishery potential by linking primary productivity to higher trophic level biomass through empirically derived transfer efficiencies (TEs). In the Indian EEZ, this approach has been applied to quantify Maximum Sustainable Yield (MSY) across four major marine ecosystems-the South Eastern Arabian Sea (SEAS), North Eastern Arabian Sea (NEAS), South West Bay of Bengal (SWBoB), and North West Bay of Bengal (NWBoB). The method integrates estimates of primary production (PP), secondary production (zooplankton) (SP), benthic production, and detritus pathways, thereby capturing the multi-pathway energy flow characteristic of tropical marine ecosystems.

The estimated annual primary production in these ecosystems (Sanjeevan et al., 2018) ranged from 32.61 to 96.64 mt of carbon (mt C yr-1) in SEAS, 24.43 to 43.36 mt C yr-1 in NEAS, 7.83 to 32.32 mt C yr-1 in SWBoB and 18.94 to 42.88 mt C yr-1 in NWBoB, with distinct variations between coastal and offshore regions. Corresponding SP varied from 5.79 to 23.12 mt C yr-1 in SEAS, 2.89 to 3.76 mt C yr-1 in NEAS, 0.31 to 1.97 mt C yr-1 in SWBoB, and 1.01 to 3.95 mt C yr-1 in NWBoB. The estimated trophic TE (PP to SP) showed strong spatial variability, ranging from 3.78% in SWBoB coastal waters to 24% in SEAS offshore waters, reflecting ecosystem-specific productivity and trophic structure.

Based on trophic transfer pathways and biomass conversion models, the revalidated potential fishery yield for the Indian EEZ (excluding island ecosystems) was estimated at 50.659 lakh tonnes per year (5.066 mt). Of this, the SEAS contributed the highest share (23.147 lakh tonnes; 45.7%), followed by NEAS (13.500 lakh tonnes; 26.6%), SWBoB (9.319 lakh tonnes; 18.4%), and NWBoB (4.693 lakh tonnes; 9.3%). Pelagic carnivores constituted the dominant component of the potential yield (22.202 lakh tonnes), followed by phytoplanktivores (7.888 lakh tonnes), pelagic planktivores (7.299 lakh tonnes), benthic scavengers (5.881 lakh tonnes), pelagic omnivores (3.441 lakh tonnes) and benthic carnivores (3.062 lakh tonnes) (Fig. 7.1). These results highlight the strong dependence of fishery potential on both plankton-driven and detritus-driven food webs in tropical Indian waters.

Notably, the trophodynamic revalidation indicates a substantial increase in potential yield of small pelagics, particularly oil sardine, linked to enhanced primary productivity during 2012-2017. The estimated PP increased by 20.6% in SEAS, 18.22% in SWBoB, and 8.87% in NWBoB compared to earlier assessments, resulting in higher MSY estimates for phytoplanktivorous stocks. In contrast, the NEAS coastal waters exhibited a 24% decline in PP, which was reflected in reduced trophic transfer and lower yield potential. Such spatially contrasting trends underscore the importance of region-specific management strategies rather than uniform exploitation policies across the Indian EEZ.

Overall, the trophodynamically based MSY assessment provides a scientifically defensible, ecosystem-based reference for sustainable fisheries development in India. By explicitly accounting for variations in energy flow, trophic structure and detrital pathways, this approach supports precautionary harvest strategies, spatial planning, and climate-resilient fisheries management. The framework also allows periodic revalidation using

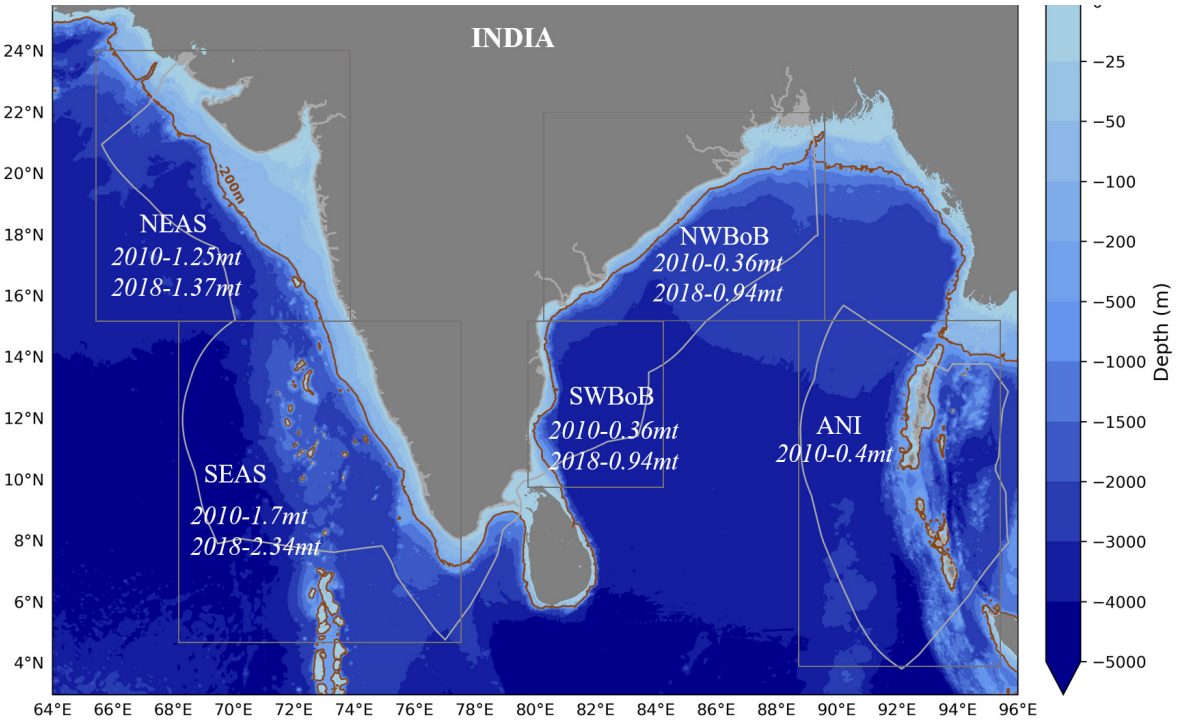



Fig. 7.1: The ecosystem-wise potential yield for the Indian waters during 2010 and 2018

updated satellite and in situ data, thereby enabling adaptive management in response to long-term changes in productivity, monsoonal forcing and oceanographic variability in the Indian Ocean.

## 7.3. Stock assessment of Deep-sea fishes

The rising global demand for seafood and the stock depletion of traditional fishing grounds have led to increased fishing activities in deeper waters (Gorelli et al., 2016; Sih, 2019). Deep-sea ecosystems are complex and often poorly understood (Ferrari et al., 2023), featuring unique biological and ecological traits that complicate traditional assessment methods. Many deep-sea fish species exhibit slow growth rates and delayed sexual maturity, rendering them particularly vulnerable to overexploitation (Santos et al., 2021). Their low resilience to fishing pressure emphasizes the need for innovative stock assessment methodologies to ensure long-term sustainability.

Stock assessment of deep-sea fishes is essential for understanding the sustainability, biomass, and exploration status of fishery resources, especially emerging non-conventional resources such as myctophids, which are gaining importance due to declining coastal fish stocks. The growing commercial utilization of puffer fishes along the southwest coast of India, once treated as trash fish and discards, highlights how underutilized resources can rapidly emerge as important food fisheries, emphasizing the need for timely scientific assessment and management (Saha, 2021). Traditional methods, such as virtual population analysis (VPA) and surplus production models, have limitations for deep-sea species due to data scarcity and assumptions of population homogeneity, which do not accurately reflect the complex life histories of these fish (Zhu et al., 2023). The high costs and logistical challenges of deep-sea surveys further complicate accurate assessments (Zhang et al., 2021; Mehanna & Samy-Kamal, 2024). To address these challenges, length-based methods such as the length-based spawning potential ratio (LBSPR) and length-based Bayesian biomass estimation (LBB) have been developed for data-poor contexts (Zhang et al., 2021; Lauden et al., 2024). These methods rely on length-frequency data, which can be easier to collect.

Technological advancements, such as acoustic surveys and underwater video systems, are also vital for

estimating the abundance and distribution of deep-sea fish (Watanabe et al., 2004). While acoustic surveys offer fisheries-independent biomass estimates, underwater video systems provide detailed species data but can be costly and labour-intensive. Genetic techniques help in understanding stock structure and connectivity among deep-sea populations (Mattiucci et al., 2015). By using genetic markers for population identification and assessing gene flow, these methods help to define management units. Integrating genetic analysis with other approaches can enhance the accuracy of stock assessments by addressing data limitations (Pulkkinen, 2015). Studies in the Northeast Atlantic illustrate the effectiveness of these advanced techniques in improving the understanding of deep-sea resources.

## 7.4. Challenges in Deep-Sea fishery potential estimation

The challenges facing India's marine fisheries sector in estimating fishery potential extend beyond infrastructure limitations, bycatch issues, and the lack of targeted fisheries. They encompass economic, technological, environmental, policy-related, and governance issues that collectively hinder the exploration and sustainable development of this vital food resource. To address these challenges, India needs to strengthen in fishery assessment and management strategies through advancements in acoustic technologies, integrated with ship-based, satellite, and autonomous observations, along with emerging tools such as eDNA and ecosystem modelling, provide a strong foundation for improved biomass estimation and ecosystem understanding. A shift towards ecosystem-based fisheries management, incorporating trophic interactions, habitat linkages, and climate signals, supported by precautionary approaches for underexplored resources like the mesopelagic, is essential. This must be complemented by science-based harvesting strategies, strengthened long-term monitoring and data systems, and marine spatial planning that balances conservation with Blue Economy goals. Enhancing national capacity, multi-institutional collaboration, and effective science policy integration will be critical. Overall, sustainable fisheries management depends on data-driven, adaptive, and ecosystem-based approaches supported by continuous observation and technological innovation.

### a) Limited infrastructure and biological data

The deep-sea fisheries research in India is constrained by inadequate infrastructure, including a lack of modern fisheries research vessels and advanced fishing gear (Sinha et al., 2017). The FORV *Sagar Sampada* has been a key asset for fisheries and oceanographic studies in India. However, she is now aged, with limited survey efficiency and insufficient operational capacity. As a country with a very long coastline and an extensive EEZ, employing a single FORV will not be sufficient to cover the vast area. The absence of modern research vessels equipped with cutting-edge hydroacoustic systems, multi-beam sonar, and autonomous sampling tools hampers comprehensive deep-sea stock assessments. Furthermore, there is a lack of long-term and accurate biological data on key species (Mohamed et al., 2014).

### b) Lack of targeted fisheries

The absence of targeted fishing practices will lead to the overexploitation of non-target species and underutilization of commercially viable deep-sea species (Norse et al., 2012; Sinha et al., 2017). Furthermore, insufficient investment and effort in research to develop targeted fishing technologies and practices exacerbate this issue, limiting the potential for sustainable exploitation of deep-sea resources.

### c) By-catch and resource wastage

The deep-sea fishing sector is plagued by high by-catch rates, wherein non-targeted, vulnerable and slow-growing deep-sea organisms are caught during trawling operations (Lively & McKenzie, 2023). This leads to significant ecological damage, including habitat destruction and the depletion of non-target stocks, worsening the problem of resource waste (Fig. 7.2). Moreover, bycatch poses a serious threat to biodiversity and undermines the sustainability of deep-sea fisheries (Gianni, 2004).

Juvenile fishing to support the aquaculture feed industry has increasingly become embedded within prevailing fishing practices, with significant implications for both ecosystem sustainability and




Fig. 7.2: Bycatch composition associated with deep-sea demersal trawl fisheries

the long-term viability of the fisheries sector. The capture of immature individuals undermines stock replenishment, as these juveniles would otherwise contribute substantially to biomass through growth and reproduction. Studies from Karnataka trawl fisheries have shown that low-value bycatch constitutes about 20-44% of total trawl landings, with juveniles forming a major component of the catch. Multiday trawlers alone landed 31,689-35,949 tonnes of low-value bycatch annually, of which nearly 46-47% by weight comprised juveniles of commercially important finfishes, highlighting the scale of the issue (Mahesh et al., 2017). This trend is closely associated with the widespread adoption of high-speed trawling, coupled with the use of smaller mesh sizes and diamond-shaped nets, which result

in indiscriminate catches of juveniles and non-target (trash) species. Such practices not only disrupt trophic structures and ecosystem balance but also pose a serious threat to the sustainability and productivity of marine fisheries.

## d) High operational costs

The financial burden of deep-sea fishing and research is substantial, driven by the costs of deploying and maintaining modern research vessels, fishing gear, and advanced technologies such as sonar and remote sensing equipment (Rajool Shanis et al., 2014; Sinha et al., 2017). These expenses are particularly challenging for developing nations, such as India, where funding for fisheries research and development is often limited. High operational costs limit the frequency and scope of deep-sea research, reducing overall capacity to explore and estimate fishery potential in India's vast EEZ.

## e) Illegal, Unreported, and Unregulated (IUU) fishing

IUU fishing is indeed an international issue that poses a serious problem, undermining sustainable fisheries, jeopardizing marine ecosystems, and negatively impacting coastal communities and food security (Fig. 7.3). Considering the nation's vast EEZ, the lack of a robust surveillance system makes it difficult to monitor and control IUU fishing activities (Valli, 2023). It challenges conservation efforts, skews stock assessments, and results in inaccurate estimates of fishery potential. Vessel Monitoring Systems (VMS) have emerged as critical tools in modern fisheries governance, offering real-time tracking of fishing vessels and promoting compliance with legal frameworks (Molenaar, 2007a). The integration of VMS with advanced remote sensing technologies and automated data analysis significantly enhances surveillance capacity, enabling the detection of suspicious activities across large and remote marine areas (Lee et al., 2010). Taking into consideration India's expanding distant water fishery, our efforts to tap a portion of the Antarctic fishery resources and the known IUU activities within the Indian EEZ, it is essential to set up a two-way communication system (VMS) in India.

## f) Insufficient policy framework and governance

Current fisheries policies in India primarily focus on nearshore fisheries, with minimal attention to deep-sea fisheries. The lack of comprehensive policies for deep-sea conservation, sustainable exploitation and ecosystem-based management leads to weak implementation and enforcement of regulations (Norse et al., 2012).



Fig. 7.3: Unreported night-time fishing operations documented during surveillance by FORV *Sagar Sampada*

## g) Technological gaps

Limited access to high-resolution data and inadequate sampling equipment hinders accurate assessments of species distribution and biomass. The absence of extensive monitoring systems and standardized long-term datasets further complicates reliable evaluation. Additionally, deep-sea expeditions demand sophisticated vessels, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), and unmanned underwater vehicles (UUVs), all of which contribute to high costs and logistical barriers (Xu et al., 2024).

## h) Lack of public and political awareness

Deep-sea fisheries often receive less public and policymaker attention than nearshore fisheries. As a result, insufficient resources are allocated to research, monitoring, and development in this area (Gatto et al., 2023). The lack of awareness and understanding of the significance of deep-sea ecosystems and fisheries to the national economy and food security limits political will to invest in this sector, further hindering sustainable development. In India, the challenges to the exploration and sustainable development of deep-sea fisheries arise from complex interactions among environmental, technological, governance, and economic factors. A comprehensive approach is necessary for India to unlock the full potential of its deep-sea fisheries while ensuring their long-term sustainability and ecological health.

# 7.5. Sustainability and conservation concerns

The depletion of coastal fisheries is driving a shift towards deep-sea fishing to ensure food security and export potential (Sendurpandian et al., 2025). The deep-sea environment, characterized by its unique biodiversity and slow-growing species, is particularly vulnerable to the impacts of fishing. Bottom trawling, a destructive fishing method that involves dragging heavy gear along the seafloor, threatens deep-sea benthic communities (Clark et al., 2016). This leads to biodiversity loss and decreased abundance, as the slow recovery of fauna can take decades to centuries. Studies worldwide confirm similar widespread damages, with research in the northwestern Mediterranean Sea reporting significant declines in organic matter, carbon turnover, biodiversity, and abundance in the trawled areas (Pusceddu et al., 2014).

Deep-sea fisheries often result in significant bycatch, which includes many vulnerable deep-sea faunas that are frequently overlooked in research and management due to their low commercial value. The bramble shark (*Echinorhinus cf. brucus*) serves as a prime example, suffering significant bycatch in southern India. This underscores the urgent need for improved monitoring programs to protect these species and ensure the sustainability of deep-sea fisheries (Akhilesh et al., 2020). The underreporting of bycatch and discards in global bottom trawling fisheries, potentially as high as 43% (Victorero et al., 2018), further emphasizes the need for enhanced data collection and reporting mechanisms. This lack of accurate data hinders effective management and conservation efforts.

The application of advanced technologies offers significant potential for improving the sustainability of deep-sea fisheries. These technologies can enhance monitoring, assessment, and management, leading to more informed decision-making. ROVs, Remotely Piloted Aircraft Systems (RPAS), and environmental DNA (eDNA) are emerging technologies with the potential to revolutionize deep-sea research and monitoring (Yang et al., 2024). These tools significantly expand the spatial scale of research without a proportional increase in survey efforts, and they enable non-destructive sampling methods (Schmunk et al., 2023). Their application in India can significantly improve stock assessments, habitat mapping, and the monitoring of fishing activities. AUVs and ROVs can be integrated with acoustic long-baseline localization systems to track fish movements (Fanelli et al., 2021), providing valuable data for effective conservation management strategies. Cloud-powered neural networks can further enhance data analysis by integrating diverse data sources, such as satellite images, weather patterns, and catch records, to predict fish stock dynamics and informed decision-making (Portela et al., 2012).

Species Distribution Modelling (SDM) are cost-effective for identifying potential deep-sea species habitats over large areas (Winship et al., 2020). By integrating data from visual sampling and broad-scale surveys (e.g., fisheries trawl surveys), SDMs provide key information for management and data collection (Akter et al., 2024). Multi-species models, using presence-absence and density data, enable more robust predictions and community-level inferences. In India, these models can enhance the identification of vulnerable marine ecosystems (VMEs) and inform the establishment of marine protected areas (MPAs). A Mediterranean study employed multi-criteria decision analysis (MCDA) and expert evaluation to identify important deep-sea areas for conservation (Fanelli et al., 2021), a method that could be adapted to the Indian scenario. Ecosystem-based management (EBM) is crucial for balancing fishing pressure and conservation in deep-sea fisheries (Durán-Muñoz et al., 2008; Clark & Dunn, 2012). Spatial management, including closed areas and MPAs, is vital for protecting VMEs and promoting sustainable fisheries. Integrating EBM with spatial planning helps to identify areas for protection while enabling sustainable fishing in other areas.

International agreements like the UN Convention on the Law of the Sea (UNCLOS) and its Fish Stocks Agreement provide a framework for managing high-seas fisheries (Takei, 2013; Diz, 2016), however, considerable gaps remain, especially for deep-sea fisheries and VMEs (Molenaar, 2007b). RFMOs implement these agreements, but their effectiveness varies (Kimball, 2004). Creating new RFMOs or strengthening existing ones is critical in areas lacking effective management frameworks. UN General Assembly resolutions call for better protection of VMEs (Portela et al., 2012), highlighting the need for improved implementation and international cooperation. National policies for sustainable deep-sea fisheries management should incorporate EBM, promote technological advancements, and address socio-economic needs. Strengthening enforcement mechanisms and integrating traditional knowledge with science will improve strategies closing regulatory gaps and promoting multi-stakeholder collaboration for effective management (Roberson, 2021). An FAO case study on the Code of Conduct for Responsible Fisheries highlights challenges with non-binding instruments and the need for legally binding agreements (Friedrich, 2008). A global database on VMEs is urgently needed to standardize their identification and protection.

# 8 Strategic Pathways for Sustainable Fisheries and Marine Ecosystem Management

Achieving sustainability in fisheries and marine ecosystems for India requires a strategic shift from conventional resource exploitation towards integrated, science based, and ecosystem-oriented management frameworks. In the context of increasing pressures from fishing, climate variability, and environmental change, particularly in deep-sea and distant-water domains, and corresponding to the vulnerable systems, there is a critical need to strengthen assessment methodologies, reduce uncertainties, and incorporate ecosystem dynamics into decision-making. The complexity of marine living resources, coupled with data limitations and emerging exploitation of underexplored resources such as the mesopelagic, necessitates precautionary and adaptive approaches that balance utilization with conservation.

This chapter outlines key pathways for advancing sustainable fisheries and marine ecosystem management, with an emphasis on leveraging technological advancements, such as acoustic observations, to enhance long-term monitoring systems and foster multi-institutional collaboration. It highlights the importance of ecosystem-based fisheries management, climate-resilient strategies, and effective policy integration to support informed and adaptive governance. By aligning scientific innovation with national priorities, including Blue Economy initiatives, this chapter presents a framework to ensure the sustainable use and conservation of marine resources within a rapidly changing ocean environment. This chapter also discusses the multi-factor strategies to be implemented towards effective and sustainable management of our resources.

## 8.1. Strengthening the scientific assessment framework

Sustainable management of MLR requires addressing growing pressures from fishing, climate variability, and habitat degradation amid significant uncertainties in data, species-specific assessments, and monitoring systems. Advancements in acoustic technologies, integrated with ship-based, satellite, and autonomous observations, along with emerging tools such as eDNA and ecosystem modelling, provide a strong foundation for improved biomass estimation and ecosystem understanding. A shift towards ecosystem-based fisheries management, incorporating trophic interactions, habitat linkages, and climate signals, supported by precautionary approaches for underexplored resources such as the mesopelagic, is essential. This must be complemented by science-based harvesting strategies, strengthened long-term monitoring and data systems, and marine spatial planning that balances conservation with blue economy goals (Fig. 8.1).

National efforts, including habitat mapping, Potential Fishery Zone (PFZ) advisories, and resource and fleet assessments, have significantly improved the scientific basis for management. Regulatory measures such as trawl bans, mesh size control, and protection of spawning grounds are critical to reduce juvenile fishing and support stock sustainability. At the same time, climate-driven changes, such as shifts in species distribution and reductions in size of key species, highlight the need for adaptive and climate-

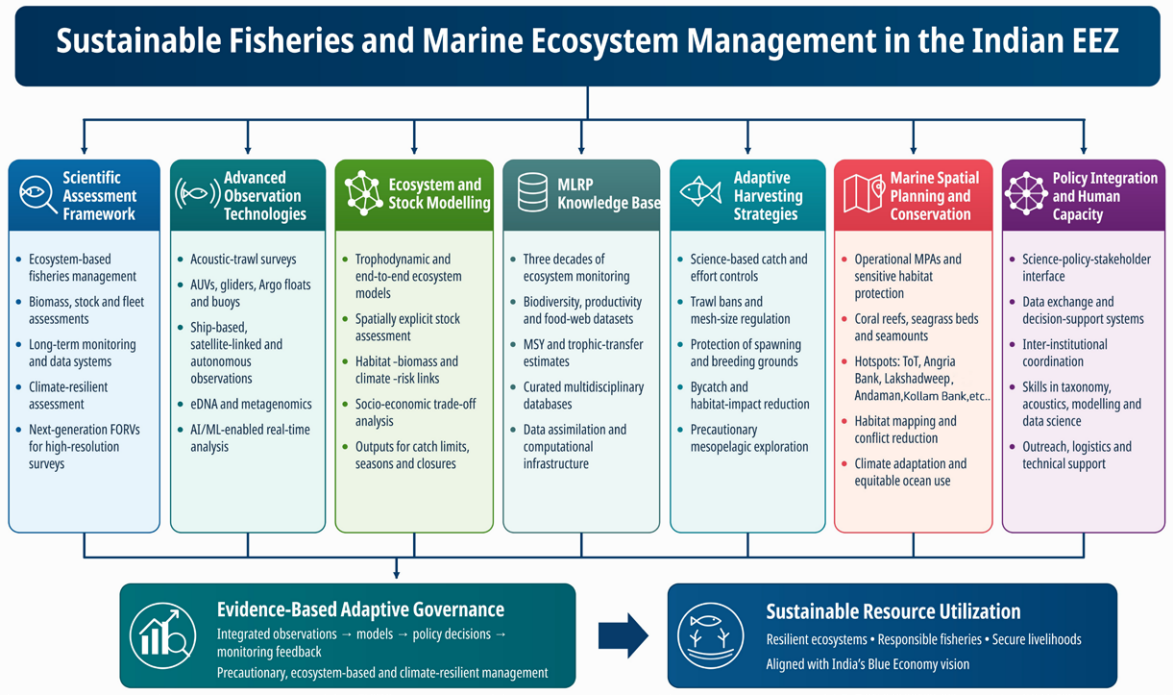



Fig. 8.1: Strategic framework for sustainable fisheries and marine ecosystem management in India's EEZ.

resilient strategies and continuous monitoring of these ecosystems for value addition in the scientific knowledge that addresses the multi-scale impacts in the fishery.

India possesses one of the largest EEZs globally, yet the existing research fleet, particularly ageing platforms such as FORV *Sagar Sampada*, is inadequate to comprehensively survey and monitor such an extensive and diverse marine domain. FORVs are central to assess fish stocks, monitoring ecosystem health, and generating the scientific evidence required for sustainable fisheries management. With increasing pressures from climate variability, expanding deep-sea exploration, and emerging resource use in distant-waters, the demand for technologically advanced, high-endurance platforms for *in situ* observations has become critical. Strengthening fleet capacity with next-generation FORVs is essential to enable systematic, high-resolution surveys across coastal, deep-sea, and high-seas regions.

Enhanced fleet capabilities will significantly improve India's ability to monitor marine biodiversity, detect ecosystem changes, and assess climate-driven impacts such as regime shifts and alterations in species distribution. This is vital for supporting national and international fisheries governance frameworks and ensuring sustainable and responsible resource utilization. Furthermore, as India continues to play an important role in global ocean research, including Arctic and Antarctic programmes, the availability of state-of-the-art research vessels is indispensable for participation in large-scale international expeditions and collaborations. Investment in multiple, technologically advanced FORVs, equipped with modern acoustic systems, satellite-linked observation platforms, AUVs, and real-time data acquisition capabilities, will not only strengthen national ocean observation systems but also reinforce India's leadership in marine science and its commitment to the sustainable management of ocean resources.

## 8.1.1. Technological Intervention (Acoustics, AUVs, eDNA, and AI/ML)

Studies of deep-sea fish in their natural environment using conventional techniques has proved challenging. These methods damages the samples, are time consuming not economically viable and are

also prone to error in species identification. There is a need for more effective, robust, non-invasive, and cost-friendly techniques for ecosystem assessment to improve the ecological data. Previously, researchers have addressed challenges by adopting non-visual approaches such as mark-recapture and fisheries-dependent sampling, as well as fisheries-independent sampling methods such as trawls and surveys. These strategies aid in mapping fish habitats, assessing distributions, and estimating their populations. Effectively understanding fish behaviours, locating and counting them across diverse environments and timeframes, necessitates leveraging alternative and advanced technologies.

## a) Integrated Acoustic-Trawl-Based assessment of fisheries in Indian waters

The way forward for the development of deep-sea and mesopelagic fisheries in Indian tropical waters requires a sustained, integrated approach that combines hydroacoustic surveys and biological sampling to generate reliable, ecosystem-level biomass estimates. Tropical oceanic systems within the Indian EEZ are characterised by high species diversity, overlapping acoustic scattering layers, and complex trophodynamic linkages, which demand the refinement of multi-frequency and broadband acoustic techniques supported by systematic, depth-stratified midwater trawling. Strengthening calibration protocols, improving target-strength libraries for dominant mesopelagic taxa, and developing region-specific acoustic classification algorithms will be essential to reduce uncertainty in biomass estimates and move towards species-resolved assessments.

Future efforts should prioritise the establishment of standardised, long-term acoustic monitoring transects across major biogeographic provinces of the Indian Ocean, coupled with seasonal and interannual biological validation through midwater trawl surveys. This will support the development of robust baseline datasets, reference points for stock assessment, and ecosystem indicators relevant to OMZ, thermal stratification, productivity gradients, and monsoon-driven variability. Integration of acoustic and trawl data with oceanographic and biogeochemical observations will further enhance understanding of habitat-biomass relationships and climate sensitivity of deep-sea fish communities.

In the management and policy context, the integrated acoustics-trawl framework provides a scientifically defensible basis for precautionary and ecosystem-based approaches to potential deep-sea and distant-water fisheries development in India. This approach enables the evaluation of sustainable harvest limits, spatial planning of fishing grounds, and assessment of ecological risks associated with the exploitation of mesopelagic resources. Strengthening institutional capacity, regional data-sharing mechanisms, and alignment with national initiatives such as the Blue Economy and Deep Ocean Mission (DOM) will be critical to ensure that any future deep-sea fisheries are developed in a sustainable, scientifically informed, and environmentally responsible manner.

## b) Autonomous Underwater Vehicles (AUVs)

AUVs are excellent platforms for fisheries surveys because they are small, independent, and unmanned, pre-programmed to operate without external control or communication systems. They significantly enhance fisheries and plankton investigations by using high-end optical and acoustic imaging sensors that can operate in deeper waters, enabling researchers to make precise, close-range observations of targets often overlooked during acoustic profiling (Watkins & Brierley, 1996). This capability provides new insights into the composition of DSLs (Magnusson, 1996) and ecologically important concentrations of zooplankton. While acoustic surveys are usually conducted with deep-towed vehicles, AUVs can collect higher-quality acoustic data, allowing research vessels to focus on validating fishing grounds.

## c) Environmental DNA (eDNA)

Environmental DNA (eDNA) is a groundbreaking method for studying biodiversity and ecology across ecosystems. Traditional approaches to fish stock assessment, such as visual surveys, trawls, seines, and tissue biopsies, are not only expensive

and time-consuming but also invasive and fraught with environmental risks. Consequently, the momentum behind the use of eDNA as a complementary tool to conventional taxonomic methods is growing in popularity (Jayasankar, 2017). By analysing genetic material in water and organic-rich sediments, eDNA empowers researchers and conservationists to effectively track biodiversity and identify alien or invasive species. Monitoring fish in their natural habitats poses substantial challenges, particularly as traditional methods often require electricity or fuel for capture and use extensive fishing gears. These traditional techniques can be costly, labour-intensive, and detrimental to the organisms being studied. In contrast, eDNA sampling offers a higher probability of successful detection than traditional methods, making it a superior choice (Jayasankar, 2017).

## d) Artificial intelligence (AI) and Machine learning (ML)

The integration of artificial intelligence (AI) and machine learning (ML) to explain marine ecology, particularly for monitoring and assessing deep-sea fish habitat, is redefining the landscape of fisheries research. These advanced technologies significantly enhance traditional methodologies, increasing both accuracy and efficiency through innovative techniques. By addressing persistent challenges such as occlusion, water turbidity, and operational noise, AI and ML significantly improve the reliability of biomass assessments (Zhang et al., 2024). Advancements in AI and ML with frequent refinement and value addition with *in situ* observations provide fisheries with the tools needed to make informed, impactful decisions about fish populations and conservation efforts. Moreover, automating these processes significantly reduces time and labour costs, streamlining operations and enhancing efficiency. The fusion of deep learning and imaging technologies further amplifies the efficiency of ecological studies. Automated systems enable real-time data collection, facilitating more frequent monitoring of fish populations (Jeong et al., 2013). This improved efficiency enables faster responses to ecosystem changes, ultimately shaping resource management strategies.

## 8.1.2.Ecological Modelling-Integrated Approach for Sustainable Fisheries Management

Effective management of fishery resources requires a comprehensive, integrated approach that links ecosystem processes with biological responses across multiple scales, from physical drivers and microbial dynamics to fish and higher trophic levels. To achieve this, a suite of classical and modern observation technologies must be employed, combining data from *in situ* ship-based surveys, satellite remote sensing, autonomous platforms (AUVs, Gliders, Argo floats, buoys), and experimental research. Crucially, these diverse data streams must be properly linked to ecosystem models to address complex research and management questions (Smitha et al., 2022).

## 8.1.3.Strengthening Fish Population Dynamics Modelling Frameworks

Despite several decades since the seminal work of Beverton and Holt on the Dynamics of Exploited Fish Populations (1957), many of the core challenges they identified remain unresolved (Pennino et al., 2023). Accurately estimating key biological and fishery parameters such as growth rates, natural mortality, recruitment, and gear selectivity continues to pose significant difficulties. Nonetheless, substantial progress has been made in other areas of fishery science, particularly in advancing integrative approaches and analytical frameworks. These developments have contributed meaningfully to the evolution and implementation of ecosystem-based fisheries management, offering more holistic and sustainable pathways for the stewardship of marine resources.

The significance of spatial and ecosystem heterogeneity has been emphasized across numerous studies and must be more effectively integrated into fisheries assessment and management frameworks. In particular, spatially explicit stock assessment models are critical for addressing management challenges in areas where spatial structure is relevant, such as in the planning and evaluation of MPAs or where decision-

makers require outputs at finer geographic scales. Enhancing the spatial resolution of assessments will support more targeted, adaptive, and region-specific management interventions, for example, the ToT, and other biological hotspots viz spawning breeding grounds, deep coralline ecosystems etc.

Fishery modelling offers a comprehensive and forward-looking approach to understanding, managing, and sustaining MLR, especially in the context of India's complex tropical marine ecosystems, where the fishery so far is open access. These models serve as virtual laboratories, allowing scientists and policymakers to simulate the dynamics of fish populations and ecosystems under various environmental and anthropogenic scenarios. It should integrate multiple dimensions of species biology, recruitment, natural mortality, fishing effort, gear selectivity, trophic interactions, and oceanographic conditions, within structured frameworks that range from empirical to mechanistic and individual-based modelling frameworks. In deep-sea ecosystems, where observational data are scarce and uncertainties high, modelling tools help overcome critical knowledge gaps by coupling available datasets (e.g., acoustic biomass estimates, satellite-derived productivity, and vessel movement data) with simulation capabilities to assess stock status, ecosystem health, and the impacts of fishing. Fish models can be integrated as a built-in, more efficient tool using data from various sources, such as acoustic surveys, trawl catch, satellite remote sensing, tagging studies, oceanographic models, and environmental DNA (eDNA). The results can guide policy decisions like setting catch limits, regulating fishing seasons, or implementing area closures.

The inclusion of socio-economic variables enables evaluation of trade-offs between conservation goals and livelihood outcomes, supporting balanced and inclusive policy decisions. For India, developing high-resolution, coupled-ecosystem, and climate-sensitive models is vital, given the spatial heterogeneity of our marine ecosystems and the strategic importance of the Indian Ocean to regional fisheries governance. With growing emphasis on ecosystem-based and climate-resilient fisheries management, fishery models also play a key role in integrating climate projections and variability patterns (El-Nino Southern Oscillation, ENSO, Indian Ocean Dipole, IOD, monsoon anomalies etc.) into resource forecasting and risk assessment.

## 8.2. Suggestions for ecosystem-based marine resource management

Since its inception in 1998, the MLRP has advanced an ecosystem-based approach to studying Indian waters, encompassing oceanographic processes, marine biodiversity, and targeted technology development.

Being one of the central pillars of the MLRP, the trophodynamic approach offers a robust framework for resource estimation. However, the complex and often chaotic nature of ecosystem interactions necessitate continuous value addition through *in situ* observation, controlled experimentation, and simulation studies. Enhancing our understanding of ecosystem dynamics requires ongoing, high-resolution monitoring and systematic strengthening of the national marine information domain. Future assessments of fisheries resources in the Indian EEZ should place trophodynamic processes at the core of biomass estimation and management frameworks. Strengthening the quantification of energy flow pathways, trophic transfer efficiencies, and production-to-biomass (P/B) ratios across pelagic, mesopelagic, and demersal compartments will be essential to improve estimates of ecosystem carrying capacity and sustainable yields. Integration of multi-frequency hydroacoustic backscatter with prey-field characterisation (zooplankton and micronekton biomass), stable isotope and fatty acid trophic markers, and refined diet-matrix information will enable a more accurate representation of trophic linkages, functional group interactions, and vertical carbon fluxes in tropical oceanic systems.

Going forward, the development of spatially explicit trophodynamic models, including Ecopath with Ecosim-type formulations and end-to-end ecosystem modelling frameworks, needs to be prioritised to link primary and secondary production to higher trophic-level biomass across varying oceanographic regimes. Particular emphasis is required to explicitly resolve mesopelagic pathways and the role of diel vertical migrators in energy transfer and carbon sequestration, especially in the context of strong monsoonal forcing

and expanding OMZ in the Indian Ocean. These advances will provide a scientifically robust basis for ecosystem-based fisheries management, enabling the derivation of trophodynamically informed harvest strategies, risk assessments, and adaptive management measures for sustainable exploitation of deep-sea and oceanic fishery resources.

Integrated effort on the application of advanced techniques, like implementation of acoustic network, eDNA database, ecosystem modelling, AI-driven pattern analysis, and machine learning-based forecasting, is imperative for better assessments and evaluation. These approaches demand access to well-curated, long-term, and multidisciplinary datasets on MLR, underscoring the importance of continued investment in MLRP-driven data systems, infrastructure, and capacity-building.

The way forward demands investment in multi-disciplinary research, computational infrastructure, data assimilation systems, and long-term ecosystem monitoring, alongside capacity-building in fisheries science, modelling, and data science. Institutionalizing fishery modelling within India's marine policy architecture will ensure informed, transparent, and adaptive governance, supporting long-term sustainability, international commitments, and the national blue economy vision. Strengthening national and multi-institutional collaboration is essential to address the complexity of marine resource assessment and management in India. Enhanced coordination among research institutes, academic institutions, and Grant-in-Aid (GIA) project networks will improve data coverage, scientific rigor, and operational efficiency. Promoting interdisciplinary and cross-sectoral collaboration, integrating oceanography, fisheries science, climate studies, and data analytics, will enable more holistic and ecosystem-based approaches. Establishing robust data-sharing and integration frameworks is critical to ensure timely access to information, reducing duplication of effort, and supporting informed, evidence-based decision-making.

## 8.3. Sustainable and adaptive harvesting strategies

Sustainable and adaptive harvesting strategies are essential for ensuring the long-term viability of Indian marine fisheries, which are characterized by multi-species, multi-gear, and spatially diverse fishing practices. Implementing science-based catch and effort regulations, informed by continuous resource assessments, is critical to prevent overexploitation and maintain stock health. Equally important are management measures such as the effective implementation of trawl bans, regulation of mesh sizes, and the protection of spawning and breeding grounds, which play a vital role in reducing juvenile fishing and supporting stock replenishment. Efforts to reduce bycatch and minimize habitat impacts, particularly in trawl fisheries, must be strengthened through appropriate gear modifications and regulatory enforcement.

Integrated multi-trophic ocean enhancement through offshore fish farming presents a promising pathway for augmenting fish production in India's deep- and distant-waters while ensuring ecological sustainability. By integrating fed species such as finfish (like cobia, pompano, tuna) with extractive species like bivalves and seaweeds, this approach enables efficient nutrient recycling and minimizes environmental impacts. Considering India's vast and underutilized EEZ, offshore mariculture systems can serve as productive hubs that complement capture fisheries, enhance resource availability, and support ecosystem-based management. Careful selection of suitable areas is critical, as such interventions are likely to be particularly effective in oligotrophic ecosystems, where nutrient enhancement can significantly improve the production. In addition to reducing pressure on coastal stocks, this offers opportunities for livelihood diversification and blue economy growth. Strategic implementation through pilot-scale initiatives, robust site selection, technological advancements, and supportive policy frameworks will be essential for realizing its full potential in Indian waters. At the same time, responsible and precautionary exploration of underutilized resources, such as those in the mesopelagic domain, offers opportunities to diversify fisheries while minimizing ecological risks. In the face of increasing climate variability influencing species distribution and productivity, adaptive management frameworks that are responsive to environmental changes are essential. Collectively, these approaches will support sustainable utilization, enhance ecosystem resilience, and secure fisheries-based livelihoods.

## 8.4.Marine Spatial Planning and Conservation

Marine spatial planning (MSP) and conservation are critical for balancing ecological sustainability with the growing demands on India's marine resources. Identifying and operationalizing MPAs, along with safeguarding ecologically sensitive and vulnerable habitats such as coral reefs, seagrass beds, and spawning grounds, are essential for maintaining biodiversity and supporting fisheries productivity. The area to be protected includes the already identified biodiversity hotspots in Indian waters, viz., the ToT, Angria Bank, a number of seamount ecosystems in the Lakshadweep and Andaman areas, etc. In the Indian context, where multiple sectors, including fisheries, shipping, offshore development, and Blue Economy initiatives, compete for ocean space, a coordinated spatial planning framework is necessary to minimize conflicts and optimize resource use. Integrating MSP into fisheries governance will enable informed decision-making by aligning conservation priorities with sustainable harvesting practices, while also incorporating scientific inputs from habitat mapping, ecosystem assessments, and long-term monitoring programmes. Such an approach will strengthen ecosystem resilience, support climate adaptation, and ensure the sustainable and equitable use of marine resources.

## 8.5.Policy integration and alliance

Effective policy integration and governance in the Indian marine fisheries sector require seamless sharing of knowledge, data, and scientific insights generated by key national institutions, including CMLRE, INCOIS, CMFRI, CIFT, FSI, MPEDA, etc. Strengthening the science-policy-stakeholder interface is essential to ensure that research outputs are translated into actionable advisories, management measures, and operational strategies. This includes improving coordination among agencies, enhancing data exchange mechanisms, and developing integrated decision-support systems. Equally important is fostering an efficient supply-demand chain by linking scientific assessments with market dynamics and stakeholder needs, including local and large-scale fishers, industry, and policymakers. Such an integrated and collaborative framework will support informed decision-making, promote sustainable resource utilization, and enhance the overall resilience and efficiency of the marine fisheries sector.

## 8.6.Capacity building and human resource development

A highly skilled, multidisciplinary workforce is essential for advancing deep-sea exploration and the sustainable management of MLR. Strengthening national capacity in key domains such as fishery biology, taxonomy, metagenomics, fisheries acoustics, ecosystem modelling, and data science is critical to support emerging scientific and technological requirements. Continuous investment in training, skill development, and knowledge transfer is necessary to enhance institutional capabilities at national and regional levels. To effectively address the scientific, technological, and operational demands, manpower requirements can be broadly categorized as follows:

**Research and Exploration:** This includes marine biologists, oceanographers, and fisheries scientists engaged in biodiversity assessment, ecosystem dynamics, and resource evaluation, including mesopelagic and deep-sea systems. Expertise in ecosystem modelling is essential for integrating environmental and biological parameters to support non-invasive and ecosystem-based assessments. Collaboration with geoscience institutions (e.g., NCPOR, NIOT, NCESS) is important for seabed characterization and habitat mapping.

**Technology and Operations:** Specialized personnel are required for operating advanced observational systems, including acoustic survey specialists for fisheries acoustics and multibeam mapping, remote sensing analysts for satellite data interpretation, experts in eDNA, bioinformatics and engineers for maintaining oceanographic instruments and autonomous platforms (ROVs/AUVs). Skilled vessel crew are essential for safe and efficient execution of research cruises.

**Data Analysis and Management:** Data scientists, modellers, and GIS specialists are required to process and interpret large, multi-source datasets for resource assessment, habitat mapping, and predictive modelling. Bioinformatics expertise is increasingly important for genetic and molecular analyses supporting species identification and population studies.

**Policy and Outreach:** Environmental economists and policy analysts are needed to integrate scientific outputs with socio-economic considerations and policy frameworks, including blue economy initiatives. Outreach and extension personnel play a key role in stakeholder engagement, awareness generation, and dissemination of scientific advisories.

**Administrative and Technical Support:** Efficient programme implementation requires project managers, technical assistants, and financial and administrative staff to ensure effective planning, logistics, and resource management.

To address current and future manpower requirements, a strategic focus on capacity building is essential. This includes establishing dedicated training programmes in advanced oceanographic techniques, fisheries acoustics, deep-sea exploration, metagenomics, taxonomy, and data analytics. Strengthening national and international collaboration among premier institutions will enhance knowledge exchange and optimize resource utilization. Engagement with academic institutions to develop specialized courses in marine sciences, underwater technologies, and ecosystem modelling is critical to build a skilled workforce. Additionally, structured internship, fellowship, and training programmes should be promoted to attract and nurture young talent.

A sustained investment in human resource development will enable the country to build a robust scientific and technical workforce capable of addressing emerging challenges in marine ecosystems. This will not only strengthen national capabilities in ocean observation and resource assessment but also support informed decision-making and the long-term sustainable management of marine resources.

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# Annexure 1a

## Technology, Methods, and Practices

Deep-sea fishery research in India was mainly based on scientific expeditions conducted onboard the FORV *Sagar Sampada.* The vessel spans 72.5 m in length, with a gross tonnage of approximately 2,600 tonnes, a cruising speed of around 12 knots, and an operational endurance of up to 30 days at sea. It is equipped with advanced acoustic systems, including multi-frequency SIMRAD split-beam Echosounders EK-60 and EK-80, a hull-mounted broadband Acoustic Doppler Current Profiler (ADCP) operating at 75 kHz, and an Integrated Trawl Instrumentation (ITI) system that incorporates remote-sensing transducers such as the SIMRAD FR500 Trawl Eye System. FORV *Sagar Sampada* supports deep-sea trawling operations using High-Speed Demersal Trawls (HSDT), High-Opening Trawls (HOT), and Expo-model Fish trawls, in addition to specialized midwater trawls such as the Isaacs-Kidd Midwater Trawl (IKMT) and Modified Midwater Trawl (MMT). Oceanographic tools onboard include the Sea-Bird SBE 911 Plus CTD profiler and bathymetric mapping systems. In addition to demersal and pelagic sampling, FORV *Sagar Sampada* is equipped with Multi-Plankton Nets (MPN), Bongo Nets, Continuous Underway Fish Egg Sampler (CUFES), and Smith-McIntyre grabs for benthic sample collection. The vessel also features onboard laboratories for real-time biological sampling, taxonomic studies, and chemical analysis.

FORV *Sagar Sampada* has so far covered 420 scientific expeditions to support the MLR program. This has provided essential insights into the distribution, abundance, and dynamics of marine species, especially those belonging to the 200-1500 m depth zone, ultimately supporting sustainable fisheries management and conservation efforts. Over the span of various Five-Year Plans (FYP) periods, a total of 38 dedicated fishery cruises with 237 trawls were meticulously conducted along the continental slope of the EEZ. To provide a clear overview, intricate specifics about the fishery cruises and the exact survey locations are detailed in Table 1a and illustrated in Fig. 1a.1, respectively.

The mesopelagic studies within the Indian EEZ were carried out through multiple phases from 1989 to 2025. The investigations spanned the Arabian Sea (AS) (22°N 65°E to 6°N 76°E), Bay of Bengal (BoB) (11°N 80°E to 19°N 89°E), and Andaman Sea (8°N 90-95°E to 13°N 92-95°E) (Fig. 1a.2). The sampling sites represent

Table 1a: Details of the fishery cruises and stations conducted along the Indian EEZ

| Area surveyed | REIS (2017-2020) | 12th Plan (2012-2017) | 11th plan (2007-2012) | 10th Plan (2003-2007) |
|---|---|---|---|---|
| Arabian Sea | 8 | 10 | 3 | 2 |
| Bay of Bengal | 1 | 2 | 2 | 1 |
| Andaman waters | 3 | 4 | 3 | 0 |
| Total Cruises | 11 | 16 | 8 | 3 |
| Total stations | 40 | 88 | 55 | 54 |

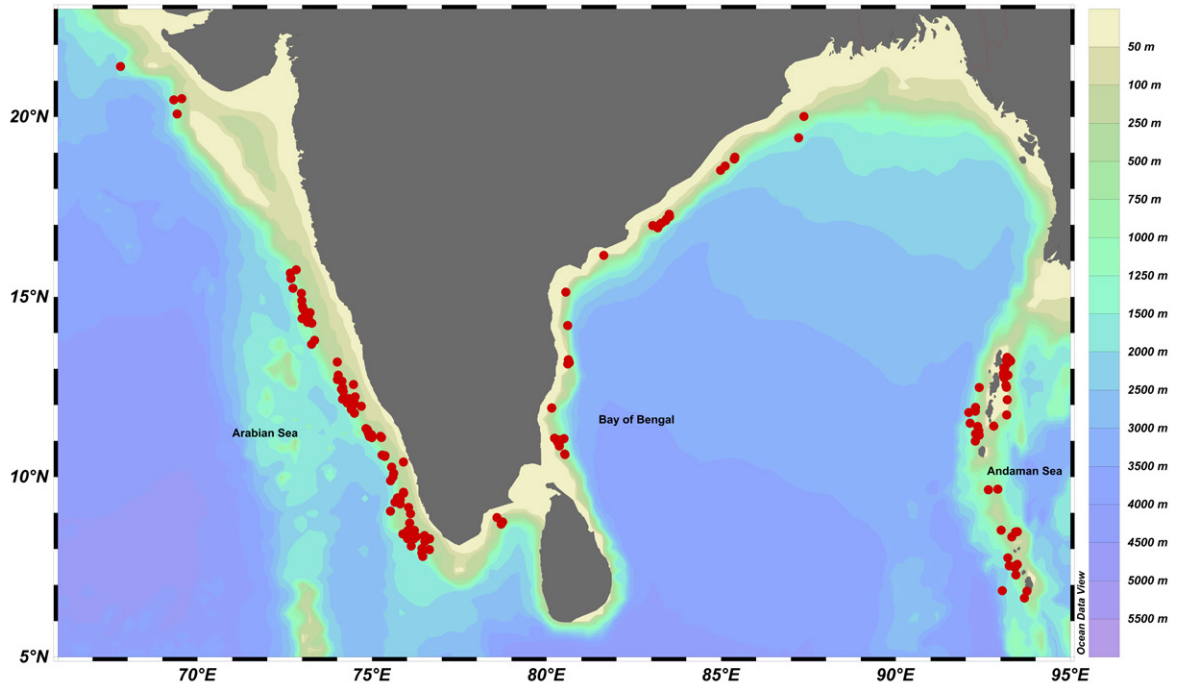



Fig 1a.1: Details of bottom trawl location along the Indian EEZ.

301 stations across the Indian EEZ and the primary objective was to assess the occurrence, distribution, abundance, and composition of mesopelagic fauna, particularly in the DSL, and to explore their potential as a food source for commercially valuable species or for direct exploitation.

During the 9th to 12th plan periods (2008-2017) and 2022-2025, CMLRE conducted surveys exclusively to determine myctophid distribution and abundance. The study area was defined as the North Eastern Arabian Sea (NEAS- 22-16°N and 65-70°E), the South Eastern Arabian Sea (SEAS- 16-6°N and 67-76°E), and the

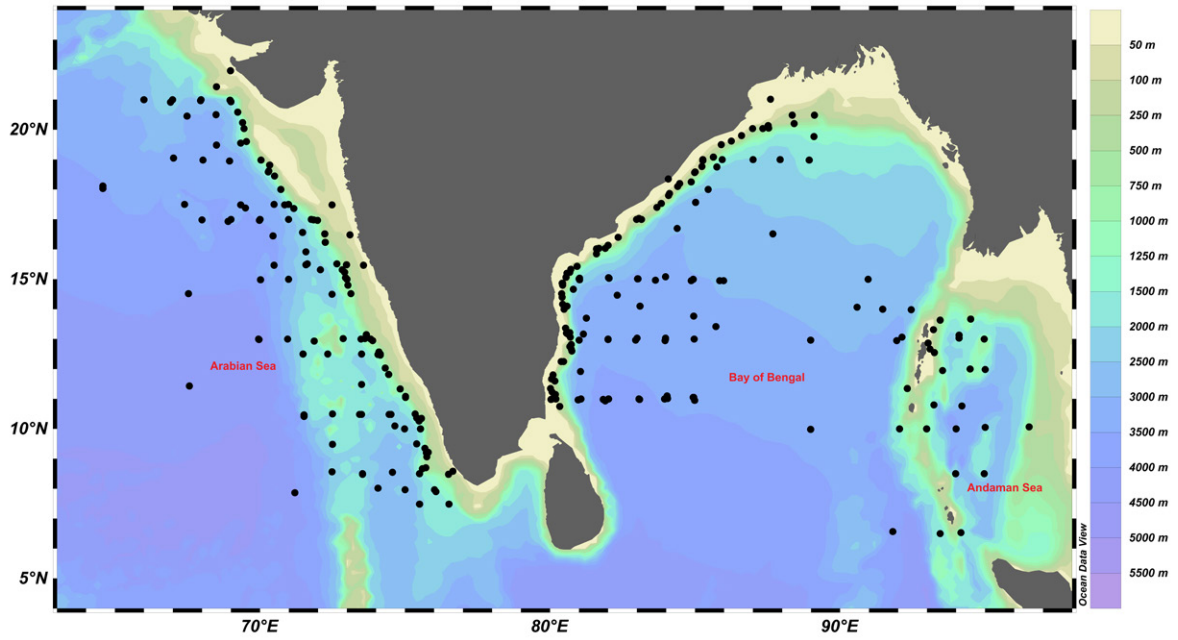



Fig 1a.2: Study Area DSL and Mesopelagic Nekton within the Indian EEZ

Western Equatorial Indian Ocean (WEIO- 6°N-16°S, 60-70°E). The sampling sites represent 94 stations across the NEAS, SEAS, and WEIO open ocean, with spatial and depth variability depending on the thickness and day- and night-time migration of DSL (Fig. 1a.3).

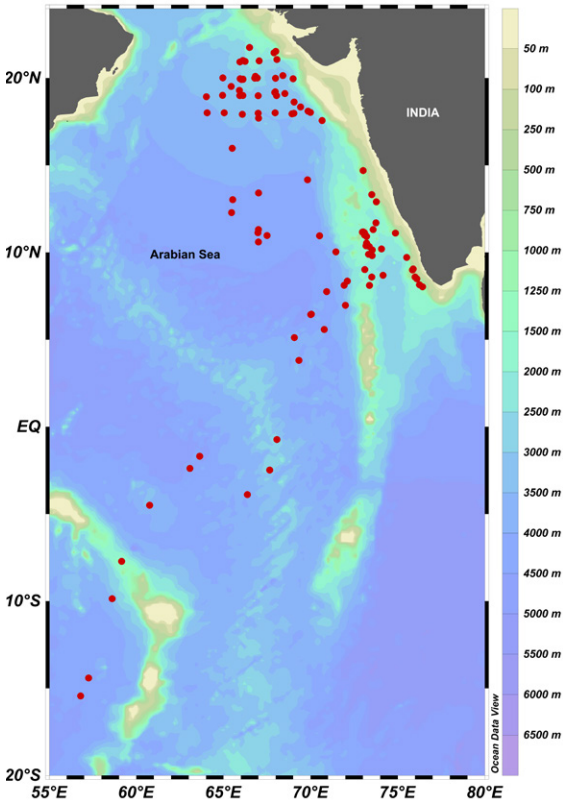



Fig. 1a.3: Study area of Myctophid resources exploration.

# Sampling Gears and Protocols

Prior to initiating the trawling operations, suitable fishing grounds were meticulously identified through acoustic surveys conducted in parallel with bathymetric contours. A multi-frequency split-beam echosounder (SIMRAD EK 60) operating at 38, 120, and 200 kHz was used to assess the depth of the DSL layer and the bottom nature. The duration of trawling operations was 1 hour; however, it varied depending on factors such as bottom type and water currents.

Three distinct types of bottom trawl nets were utilized for sampling: the HSDT II CV, the EXPO-Model trawl, and the HOT-I. The HSDT is a twin-otter bottom trawl net spanning 58.6 m in total length, with a head rope length of 38 m, a foot rope of 44.5 m, and a cod-end featuring a stretch mesh size that transitions from 30 mm to 130 mm in the front trawl sections. The EXPO-Model trawl, spanning 79.4 m in total length, boasts a head rope length of 45.6 m, a foot rope of 55.8 m, and a cod-end with a stretch mesh size that increases from 30 mm to 400 mm in the belly and wing sections. The HOT I, with dimensions of 50 m for the headline and 57 m for the foot rope, was also occasionally employed for operations. Detailed specifications of the sampling gear are shown in Fig. 1a.4.

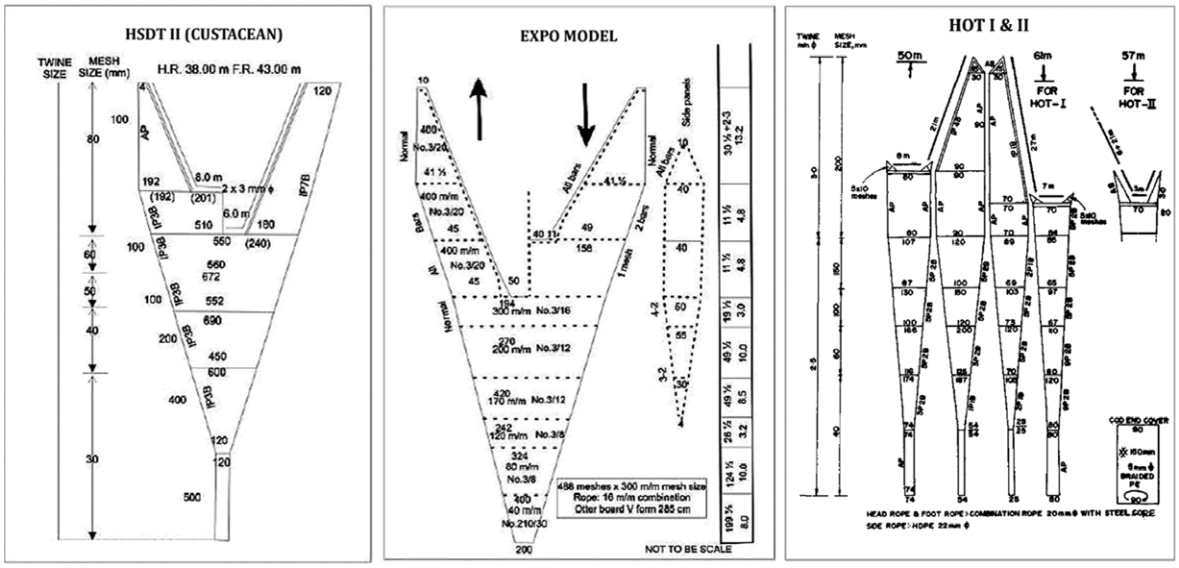



Fig. 1a.4: Schematic representation of sampling gears, HSDT CV, EXPO, HOT

During all operations, V-shaped otter boards (Perfect Economy Model, Denmark) measuring approximately 285x126 cm and weighing approximately 2,800 kg/set were affixed to the net mouth using a 50 m wire rope. Trawling operations were carried out at ship speeds ranging from 2-3 knots, dependent on factors like depth and water currents. The wire paid-out (warp-out) ratio was approximately 1:3 (depth: wire rope released). Notably, all trawl operations were conducted during daylight hours. The Surfer-11 & 20, and Ocean Data View 6 softwares were used to create distributional maps and bathymetric vizualizations of the study region..

For mesopelagic sampling, the IKMT was deployed during the surveys 1989-1990, 1998-2002. The trawl, constructed from nylon webbing, featured four sections with varying mesh sizes (25 mm, 16 mm, 11 mm, and 5 mm) and lengths (500 mm, 500 mm, 8,250 mm, and 1,750 mm, respectively), totaling 10 m. The mouth opening tapered from 2,500 mm to 750 mm at the cod end. A 2.5 m long, 25 kg aluminum depressor was used to maintain an optimal net opening of 4 m. Trawling was conducted at a towing speed of 3 knots, with warp paid out at 25 m/min and retrieved at 12-14 m/min. The net was equipped with a 5-litre bucket at the cod end to collect samples. To locate the DSL, SIMRAD echo sounders operating at 38 kHz and 120 kHz were used continuously. Echograms were recorded every two hours to determine behavioural, migratory, and spatial distribution patterns of the DSL. Trawling depths were adjusted based on echograms, and the net was lowered to the depth of the DSL as observed on the trawl sonde recorder. Stratified sampling was conducted across various bathymetric layers during both day and night to investigate DVM patterns.

During the 9th to 12th plan periods additional sampling technologies were introduced, including, CIFT-designed 45 m and 28.4 m 4 equal panel myctophid trawl net featuring four equal panels and designed for depths of 100-1000 m. These trawls had mesh sizes ranging from 120 mm at the

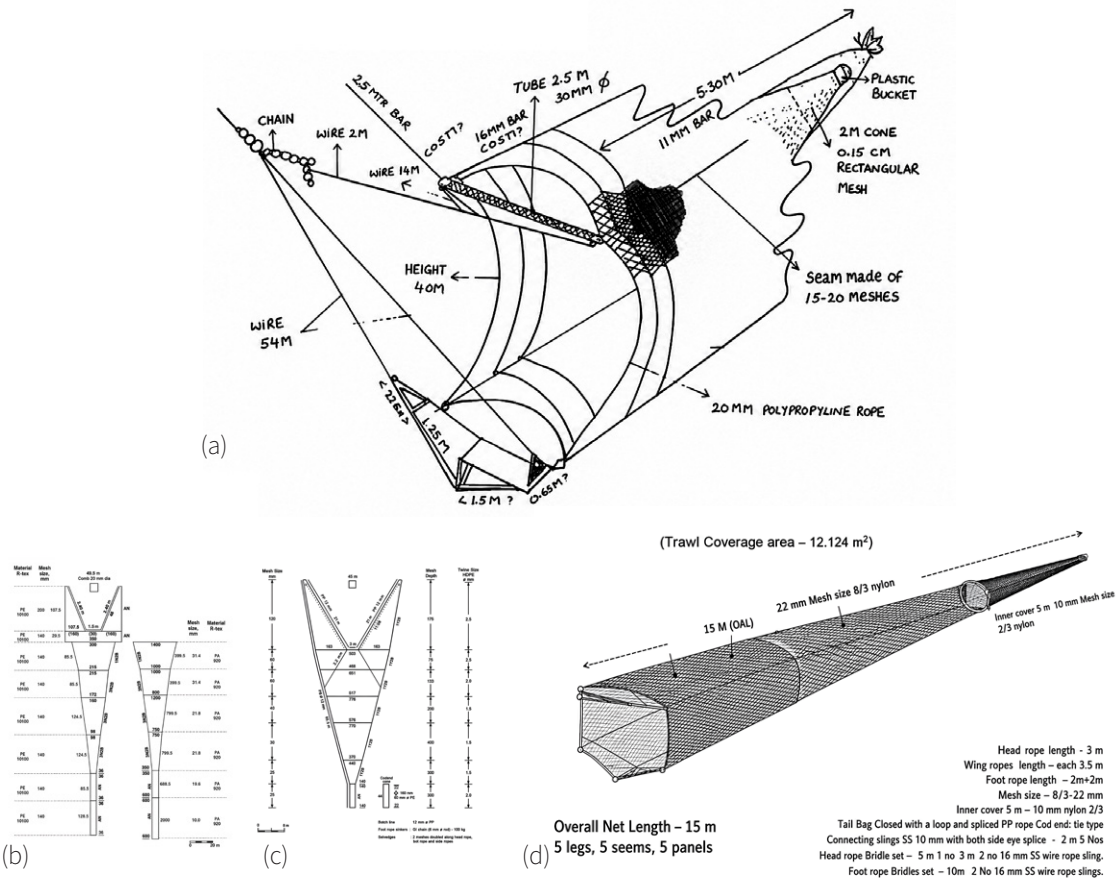



Fig. 1a.5: Trawl design of–(a) Issac Kid Midwater Trawl, (b) Cosmos Trawl, (c) 45m 4 equal panel myctophid trawl, (d) Modified Issac Kid Mid Water Trawl

mouth to 25 mm at the cod end (Boopendranath et al., 2012d) (Fig. 1a.5). Operations utilized 40 floats (270 mm diameter) and 100 kg iron link chains along the footrope. COSMOS 49.5 m experimental krill midwater trawl, is another modified net used for mesopelagic resource assessments (Fig.1a.6). A Modified IKMT was also employed, which is a 10 m trawl with a uniform 10 mm mesh during the 2022-2025 surveys (Fig.1a.7). Historical surveys and gear efficiency studies (Gjosaeter, 1984; FAO, 2001; Menon, 2002; Boopendranath et al., 2009) contributed to the design and operation of the trawling gear. Upon retrieval, nets were thoroughly washed to ensure all samples were collected into the cod-end. Half of the samples were frozen, and the remaining were preserved in 5% formaldehyde and transferred to the laboratory for further analysis. The species were sorted and identified to the lowest taxonomic level using standard keys (Fig. 1a.8).

## Biomass Estimation

The determination of the numerical abundance and biomass of each fish species within individual stations was carried out using a structured methodology. The process involved the enumeration of the number of fish (Cn) present at each station, thereby quantifying its numerical abundance. Additionally, the catch in weight (Cw) for each station and the weight of specific species groups were recorded using a marine balance,



Fig 1a.6: Cosmos Trawl from *FORV Sagar Sampada*



Fig 1a.7: Modified Issac Kid Mid Water Trawl from *FORV Sagar Sampada*




Fig. 1a.8: Mesopelagic catch from midwater trawl

with a precision of 0.1 g. Biomass was estimated using the methodology outlined by Sparre & Venema (1998), and the results were expressed in kg/km$^2$.

The calculation of numerical abundance (n) was conducted as follows:

Numerical abundance (n) = Cn / a

Where:

Cn = the number of individuals in the catch (Individuals)

a = the swept area (km$^2$)

Similarly, the estimation of biomass (b) was performed according to the formula:

Biomass (b) = Cw / a

Where:

Cw = the catch in weight (kg)

a = the swept area (km$^2$)

The concept of "swept area" or "effective path swept" is pivotal to these calculations, encompassing the length of the path multiplied by the width of the trawl. The computation of swept area (a) is as follows:

a = D × hr × X2

Where:

D = the distance covered by the trawl (converted to km from nautical miles)

hr = the head-rope length, with values of 38 m for HSDT, 45.6 m for EXPO, and 50 m for HOT

X2 = is a fraction of the head-rope length (hr), representing the width of the path swept by the trawl

The distance covered by the trawl (D) was computed in nautical miles (nm) and can be calculated using the formula:

$$D=60\times\sqrt{(Lat1-Lat2)^2 + (Lon1-Lon2)^2 \times \cos2\,(0.5\,(Lat1+Lat2))}$$

Here, the variables denote:

Lat1: latitude at the start of the haul (in degrees)
Lat2: latitude at the end of the haul (in degrees)
Lon1: longitude at the start of the haul (in degrees)
Lon2: longitude at the end of the haul (in degrees)

Moreover, the fraction of head-rope length, X2, is set as 0.5, as suggested by Pauly (1984) for tropical waters, to represent the effective horizontal trawl opening, also known as "wing spread." This value accounts for factors such as hauling speed, weather conditions, and current velocity and direction.

Biomass estimates of mesopelagic fishes were calculated using the swept-area method for 2° × 2° grid cells (120 nm × 120 nm). Gridded biomass data were used to create spatial distribution maps highlighting high- and low-biomass regions in the NEAS and SEAS. These regions were further analyzed to assess spatial and depth variability influenced by DSL thickness and diel migration patterns.

# Quantitative Analysis of the Diversity

In the analysis of quantitative diversity, the study area was divided into depth zones. A combination of diversity indices and multivariate approaches was employed to provide insights into the ecological characteristics and community structure across these zones

## Margalef's Species Richness Index (d) (Margalef, 1973):

Species richness is the total number of species in an environment/sample. This index was used to evaluate community structure and to compare the diversity of different ecosystems, with higher values indicating greater species richness.

$$d = \frac{S-1}{\ln N}$$

Where S = the number of species within a population.

N = the total count of individuals across all S species.

## Shannon and Weiner Diversity Index (H') (Shannon, 1948):

It is a metric used to assess biodiversity within an ecosystem. This index of biodiversity encompasses both the variety of species present (species richness) and the equitable distribution of individuals among those species (species evenness).

$$H' = -\sum_{i=1}^{s}(pi\ \ln pi)$$

Where S = total number of species
i = counts denoting the $i^{th}$ species, ranging from 1 to S.

*pi* = proportion of individuals represented by the ith species within the total population of individuals across the entire area.

## Pielou's Evenness Index (J') (Pielou, 1966):

This index is a measure used in ecology to quantify the equitability of species abundance distribution within a community. The calculation involves dividing H' by the natural logarithm of the total number of species (S) found within the community.

$$J' = \frac{H'}{H'max}$$

Where H' = Shannon diversity index
H' max = maximum value of H' = $-\sum_{i=1}^{s}(\frac{1}{S}\ln\frac{1}{S})S = \ln S$

## Simpson's dominance index (λ) (Simpson, 1949):

This index measures the probability that two individuals randomly selected from a sample belong to the same species, thereby reflecting the community's dominance structure.

$$\lambda = \frac{\sum n_i(n_i-1)}{N(N-1)}$$

Where, $n_i$ = number of individuals of the i-th species. N = total number of individuals of all species.

K-dominance curves (Lambshead et al., 1983): To examine cumulative dominance patterns of species across different depth zones. Species were ranked in descending order of abundance, and cumulative percentage abundance was plotted against species rank. These curves provide a graphical representation of community structure, where steeper curves indicate high dominance by a few species and consequently lower diversity, whereas flatter curves reflect a more even distribution of species and higher community diversity.

## Similarity Percentage Analysis (SIMPER) (Clarke, 1993):

This method identifies species contributing to similarities or dissimilarities within or between depth groups.

## Non-metric Multi-Dimensional Scaling (nMDS) (Clarke, 1993):

nMDS utilizes the Bray-Curtis coefficient to visualize similarities among samples in a lower-dimensional space. It aids in understanding species assemblages. The combination of these methods allows for a comprehensive assessment of the diversity and distribution patterns of demersal fishes within the studied deep-sea ecosystems.

# Biodiversity and Community Structure

Species diversity was quantified using the number of species per sample. To evaluate sampling sufficiency and richness, species-area (accumulation) curves were plotted (Clarke & Warwick, 2001). Based on the sampling sufficieny curve using species accumulation plot, species predictors such as Chaos-2, Jacknife estimators (1 & 2) were used to estimate the number of species which could be encountered in the study area when sampling approached to infinity (Burnham & Overton, 1978; Chao, 1984; Colwell & Coddington, 1994; Heltshe & Forrester, 1983).

These estimators provided minimum richness estimates and accounted for rare species distributions. The Chao's (1984) estimators are based on the numbers of rare species, of which Chao-2 is modified for use with presence-absence data (Colwell & Coddington, 1994).

$$S_{Chaos2} = S_{Obs} + Q1^2/2Q_2$$

Where $S_{obs}$ indicates the number of observed species, Q1 is the number of species that occur only in one sample, and Q2 is the number of species that occur in exactly two samples. Jackknife estimators also estimate species richness from presence-absence data and place greater emphasis on rare species. The first order estimator (Jacknife-1) employs the number of species that occur only in one sample, while the second order estimator (Jacknife-2) also takes into account species that occur in exactly two samples (Burnham & Overton, 1978; Heltshe and Forrester, 1983).

$S_{Jack}1 = S_{obs} + Q1\ (m-1/m)$

$S_{Jack}1 = S_{obs} + [Q1\ (2m-3)/m - Q2\ (m-2)^2/m\ (m-1)]$

Where $S_{obs}$ indicates the number of species observed, Q1 is the number of species that occur only in one sample, Q2 is the number of species that occur in exactly two samples, and *m* is the total number of samples.

# Annexure- 2a

Table 2a.1: Summarizing the research vessel information of MoES

| Organization | Vessel (LOA) | Commissioning Year | Research details | Present Status |
|---|---|---|---|---|
| CMLRE | FORV *Sagar Sampada* (72.5m) | 1984 | Multidisciplinary research, dedicated to marine ecosystem studies, including deep-sea and distant-water fisheries, physical, chemical, and biological oceanography. | Active but due for a replacement |
| NIOT | ORV *Sagar Nidhi* (104 m) | 2008 | Multidisciplinary research, technology demonstration, deep-sea mining, ROSUB, AUV, gas hydrate exploration, meteorological, and geological research. | Active |
| | ORV *Sagar Manjusha* (59.9 m) | 2006 | Data buoy deployment, scientific activities, and ocean observations. | Active |
| | CRV *Sagar Tara* (43 m) | 2018 | Oceanographic data collection, environmental indexing, shallow water testing, Sea Water Quality Monitoring (SWQM), and bathymetry surveys. | Active |
| | CRV *Sagar Anveshika* (43.06 m) | 2019 | Oceanographic data collection, environmental indexing, shallow water testing, SWQM, and bathymetry surveys. | Active |
| NCPOR | ORV *Sagar Kanya* (100.34 m) | 1983 | Coastal and deep-sea surveys, oceanographic observations, and environmental monitoring. | Active but due for a replacement |

Table 2a.2: Information on other National Institute Vessels in Ocean Research

| Organization | Vessel (LOA) | Commissioning Year | Research details | Present Status |
|---|---|---|---|---|
| CMFRI | R.V. *Cadalmin-I* (13.5 m) | 1980 | Support various research activities, including sampling water, sediment, and plankton, and are also equipped for bottom trawling | Active |
| | FV *Silver Pompano* (19.75 m) | 2013 | Trawl fishing and collecting oceanographic data and marine samples, | Active |
| CIFNET | M.V. *Prashikshan I* (34.19 m) | 1980 | Provide onboard practical training for students in fishing operations. | Active |
| | M.V. *Tharangini* (24 m) | NS | Support training programs in fisheries and nautical engineering. | Active |

| Organization | Vessel (LOA) | Commissioning Year | Research details | Present Status |
|---|---|---|---|---|
| CIFT | F.V. *Sagar Harita* (19.75 m) | 2006 | Conduct fishing operations, research, and introduce modern fishing techniques. | Active |
| | M.V. *Matsya Kumari II* (18 m) | NS | Provide onboard practical training and support for fishery research. | Active |
| NIO | RV *Sindhu Sadhana* (80 m) | 2013 | Full ocean-depth, all-weather, multi-disciplinary oceanographic research vessel. | Active |
| | RV *Sindhu Sankalp* (53.6 m) | 2008 | Modified Japanese vessel for oceanographic research. | Active |
| | CRV *Sagar Sukti* (23.5 m) | 1990 | Converted from a fishing trawler for coastal research. | Decommissioned |
| | RV *Gaveshani* | | Converted/Modified for Oceanographic research | Inactive |
| FSI | MFV *Matsya Nireekshani* (40.5 m) | 1978 | Used for various fishing operations, including trawling and other fish capture methods. | Inactive |
| | MFV *Yellow Fin* (36 m) | 1989 | Dedicated to tuna longlining, focusing on catching the tuna species. | Inactive |
| | MFV *Matsya Vrushti* (37.5 m) | 2005 | Used for commercial fishing operations, including trawling and longlining. | Active |
| | MFV *Sagarika* (28.8 m) | 1994 | Used for various fishing operations, including trawling and net fishing. | Active |
| | MFV *Matsya Varshini* (36.5 m) | 1980 | A trawler-cum-purse-seiner vessel used for large-scale commercial fishing. | Active |
| | MFV *Lavanika* (24 m) | 1995 | A stern trawler used in commercial fishing operations. | Inactive |
| | MFV *Matsya Drushti* (37.5 m) | 2005 | Dedicated to fishing operations similar to other FSI vessels. | Active |
| | MFV *Samudrika* (28.8 m) | 1994 | A stern trawler for fishing, mainly in coastal areas for various fish species. | Active |
| | MFV *Blue Marlin* (35.76 m) | 1989 | Used for oceanic tuna surveys, longlining, and marine mammal assessments. | Active |
| | MFV *Matsya Darshini* (36.50 m) | 1980 | Demersal resource surveys, trawling, purse seining, and fishing ground identification | Active |
| | MFV *Matsya Shikari* (39.50 m) | 1979 | Marine mammal tracking, deep-sea exploratory trawling, and monitoring. | Inactive |
| GSI | RV *Samudra Ratnakar* (103.6 m) | 2013 | An oceanographic research vessel used for seabed exploration, mapping, and studying underwater terrain. | Active |
| | RV *Samudra Kaustubh* (35.07 m) | 1984 | Used for various oceanographic research, such as water quality and marine ecosystem studies. | Active |
| | RV *Samudra Shaudhikama* (35.07 m) | 1984 | Used for environmental and marine research, especially focused on deep-sea studies. | Active |

# Annexure- 2b

## Onboard Ship Infrastructure Requirements

New FORVs should be equipped with advanced facilities to support multidisciplinary research, as listed below:

### a. Navigation and Survey Systems

- *Multibeam Echo Sounders (MBES):* For detailed bathymetric mapping and habitat characterization.
- *Dynamic Positioning Systems:* To maintain vessel stability during precise operations.
- *Split-Beam Echo Sounders:* For fisheries acoustics and DSL studies.
- *Side scan sonars:* To identify and track fish shoals.
- *Acoustic Doppler Current Profilers (ADCP):* To measure water column currents.
- *Automatic Weather Stations:* For continuous meteorological data collection.

### b. Sampling Equipment

- *Deep-Sea Trawls and Nets:* For Deep and distant-water fisheries, including pelagic, mesopelagic, and demersal fishing.
- *Sediment Corers and Grabs:* For sampling seabed sediments.
- *Water Samplers (CTD-Rosette):* To collect water at various depths for chemical and biological analysis.
- *Plankton Nets:* For collecting plankton samples for biomass and diversity studies.
- *Improved Hull Design:* Reduce noise and vibrations, especially for acoustic surveys, ensuring high-quality data collection.
- *Ice-Class Rating:* Enables operations in polar regions if necessary.
- *Hybrid Propulsion Systems:* Incorporate energy-efficient propulsion (e.g., diesel-electric systems) to reduce fuel consumption and minimize emissions.

### c. Underwater Exploration Tools

- *Remotely Operated Vehicles (ROVs):* For video surveys and precise sampling at great depths.
- *Autonomous Underwater Vehicles (AUVs):* For seabed mapping, oceanographic data collection, and exploratory missions.
- *Deep-Towed Camera Systems:* For visual documentation of the deep-sea biodiversity and environment.

### d. Onboard Laboratories

- *Wet Laboratory:* For initial processing of biological samples, sorting, and identification.
- *Dry Laboratory:* For data analysis, using instruments like spectrophotometers, fluorometers, and salinometers.
- *Cold Storage Facilities:* For preserving biological samples at sub-zero temperatures.
- *Molecular Biology Lab:* Equipped with PCR machines, centrifuges, and gel electrophoresis systems for genetic analysis.

### e. Data Analysis and Communication

- *High-Performance Computing (HPC) and storage Systems:* For processing and archiving large datasets.
- *Real-Time Data Transmission Systems:* For sharing data with onshore teams.
- *GIS Workstations:* For mapping and spatial analysis.

## 8.3 Onshore Laboratory Infrastructure

Land-based laboratories must complement onboard research capabilities with advanced facilities, such as those given below:

### a. Marine biodiversity and taxonomy laboratory

- Microscopes with imaging systems for taxonomy.
- Barcode and bioinformatics tools for species identification.
- Databases for biodiversity records and genetic repositories.

### b. Fish biology laboratory

- Length-weight analysis tools and otolith analysis equipment for growth studies.
- Stable isotope and fatty acid analysis setups for studying trophic relationships.
- Automated stomach content analysers for diet studies.

### c. Chemical and biogeochemical analysis laboratory

- Gas Chromatography-Mass Spectrometry (GC-MS) for studying trace elements and organic compounds.
- Nutrient auto-analysers for measuring dissolved nitrogen, phosphorus, and silica.
- Carbon and nitrogen analysers for studying elemental cycles.

### d. Geological and Sediment Analysis Laboratory

- X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF) systems for sediment and mineral analysis.
- Core logging systems for detailed stratigraphic studies.
- Grain size analysers and geotechnical equipment for sediment characterization.

### e. Bioinformatics and Data Processing Centre

- High-capacity servers for managing genetic, acoustic, and oceanographic datasets.
- Specialized software for modelling, simulation, and GIS-based mapping.
- Collaboration platforms for multidisciplinary data integration.

### f. Cold Storage and Sample Repositories

- Cryogenic storage systems for long-term preservation of biological and genetic samples.
- Sediment and water sample repositories with controlled conditions.
- Training and innovation facilities

### g. Training Centres:

- For capacity building in modern sampling, instrumentation, and analytical techniques.

# Annexure- 3a

## Zooplankton groups in the DSL

The DSL macrozooplankton comprises various taxa and has a wide distribution, with euphausiids among the major groups. They contribute approximately 4.1% to the total macrozooplankton biomass of DSL in the Indian EEZ. On the west coast, euphausiids contributed 16.2% in daytime hauls, with 45% during the night. On the east coast, their share was 21% by day and 56% at night. In the Andaman waters, they accounted for 23% by day and 37% at night. At night, euphausiids from the deep-sea make rapid ascents and are concentrated in three layers: 0-100 m (596 nos./haul), 150-200 m (544 nos./haul), and 450-500 m (696 nos./haul) at the sampled depths using the IKMT operated from FORV *Sagar Sampada*. During the day, they descend to depths exceeding 500 m, with maximum concentrations recorded at 300-350 m (552 nos./haul), followed by 100-150 m (401 nos./haul) and 450 m and below (207 nos./haul). There are a few studies of MLR showing that even euphausiids living below 500 m during the day make rapid upward migrations to join the major DSL at night. Larvae of crabs (zoea and megalopa) frequently appear in the DSL, accounting for 3.2% of the planktonic catch in both day and night. They are more abundant during the day at depths of 0-250 m, while at night they concentrate in the 0-100 m depth range. Amphipods constitute less than 3% of the zooplankton biomass in DSL. They belong to 13 families, distributed from the coast to deep oceanic waters during both day and night, with higher densities especially at night. The frequently occurring families in the DSL are Oxycephalidae, Phronimidae, Platyscelidae, and Phrosinidae.

Copepods contribute less than 2% to the macrozooplankton biomass in the DSL in the Indian EEZ, comprising approximately 90 species across 26 families. They are commonly found in shelf waters during the day and slope waters during the night, with consistently sufficient biomass. Chaetognaths made up to 1% at night and 3% during the day in the DSL of the Indian EEZ. They are present at all depths, up to 500 m, but are particularly abundant in the 0-50 m depth range, both during the day and night. Salps have a wide distribution in neritic and oceanic realms, and their vertical ascent during the night is particularly pronounced in oceanic waters up to 1000 m depth. In the west and east coasts, salps comprised 56% during the day and 53% during the night, and 18% during the day and 9% during the night in the DSL. In Andaman waters, its biomass was 18%, which is similar in both the day and night. Lucifer is a common component of the DSL, contributing to less than 1% during the day and 9% during the night on the west coast. Although lucifers occur throughout neritic and oceanic waters, they are most abundant in neritic zones. On the east coast and in the Andamans, it contributes less than 1% to the total zooplankton biomass, both during the day and at night. The abundance of lucifers progressively diminishes from the surface to depths up to 500 m in daytime hauls, while at night they ascend to surface waters (0-100 m). However, some species remain at 450-500 m even during the night (102 nos./haul).

# Annexure- 3b

## Mesopelagic Fishes

The Indian Ocean has a rich mesopelagic fauna in terms of both numbers and biomass (Gjosaeter & Kawaguchi, 1980), with myctophids accounting for >60% of the total biomass (Shilat & Valinassab, 1998). They occur in large concentrations in the Indian Ocean, particularly in the northern AS, including the Gulf of Aden and the Gulf of Oman, as well as the Pakistani coast (Gjosaeter, 1984; Shilat & Valinassab, 1998; Jayabalan, 2011). They typically ascend into shallow (<100 m) or near-surface (<5 m) waters at night and return to depths of ≈250 to >1000 m by day (Shotton, 1997). Myctophids accounted for 28-31% of total fish biomass in the DSL, with their abundance highest in NEAS compared to SEAS.

The most important component of mesopelagic fishes other than myctophids is Stomiidae, which inhabit the mesopelagic to bathypelagic realms and display DVM in AS. Other important groups comprising the catches were Leptocephali and Phosichthyidae, both of which were widely distributed throughout the surveyed areas. Bregmacerotidae was recorded from several stations and was represented by only a single genus, *Bregmaceros*. In addition to these groups, a diverse range of miscellaneous mesopelagic and bathypelagic fishes were found inhabiting the DSL, displaying characteristic vertical ascents and descents throughout the area.

In the total nekton population, fish accounted for 32%, while crabs and cephalopods accounted for 2% and 3%, respectively. The geographic abundance of fish biomass in the DSL during day hauls was highest off Tamil Nadu. In night collections abundance varied at different locations, and the most abundant was off Lakshadweep. The night catches consistently exceeded daytime catches in all seasons. The highest catch rate was recorded in October and November. The data were categorized into three seasons: pre-monsoon, monsoon, and post-monsoon. The post-monsoon season showed the highest values at night, and the monsoon season showed the highest values during the day. According to a depth-wise analysis of fish catches in the DSL, the resource was abundant in the slope during night hauls. The highest fish catch was recorded in the 75 m depth range during the night. The data indicated that fish ascended more slowly at night than they descended during the day. In the intermediate depths (50-200 m), night catches were much higher than day catches, while the deeper layers of the DSL (200-500 m) showed a relatively better catch rate during the day. These diel differences in catch were most pronounced in the mid-depths. A more or less conclusive understanding of this phenomenon requires quantitative sampling throughout the entire vertical range of the animals, including the depths to which they migrate during the day, using opening- and closing-midwater trawl nets.

## Myctophids of the Indian Ocean

Myctophids formed 31% of the total fish biomass of the DSL in the EAS. Peak myctophid abundance occurred along the west coast of India. Off the north-west coast, myctophids accounted for ≈53.4% of DSL fish biomass, with local dominance near Ratnagiri-Mormugoa, off Bombay, and in the northern Arabian waters. Off the south-west coast, myctophids comprised ≈46% of the DSL fish biomass, with maximum densities found in continental slope waters near Mangalore and off Cochin. From the FORV *Sagar Sampada* study between 1998-2002, myctophid

larvae were found within the upper open ocean layers in the AS. *Diaphus arabicus* formed 80% of larvae, *Benthosema pterotum* 15%, and *B. fibulatum* 5%. The study recorded a total of 27 species (1998-2002) in the AS with a maximum daytime abundance between 19° and 20°. Higher species diversity (≥10 species) was observed at Lakshadweep waters. A total of 137 myctophid species belonging to 28 genera have been reported from the Indian Ocean (Bolin, 1946; Bradbury et al., 1971; Kawaguchi & Aioi, 1972; Gjosaeter, 1977; Nafpaktitis, 1984; Hulley, 1986a, b; Raman & James, 1990; Dalpadado & Gjosaeter, 1993; Kinzer et al., 1993; Jayaprakash, 1996; Menon, 2002; Valinassab, 2005; Karuppasamy et al., 2006b; Valinassab et al., 2007; Muhlinga et al., 2007; Karuppasamy et al., 2010; Vipin et al., 2012). Surveys conducted onboard FORV *Sagar Sampada* during the 2012-2017 and 2024-2025 periods recorded 59 myctophid species, including six new records (Meera, 2018). By incorporating these findings alongside secondary data (97 species reported by Nafpaktitis, 1982), the total number of myctophid species in the WIO is revalidated at 158.

# Annexure- 3c

## Ecological Indices for Myctophids in WIO

### Species accumulation and sampling sufficiency

The species accumulation curves for the NEAS, SEAS, and WEIO did not reach an asymptote, indicating that the sampling effort did not fully capture the total species richness in these regions. Richness estimators predicted up to 21, 64, and 66 species in NEAS, SEAS, and WEIO, respectively, whereas the present study (2013- 2017, 2024) recorded 16, 45, and 55 species, representing approximately 76-86% of the estimated richness. These findings suggest that, despite considerable sampling effort, additional surveys are likely to reveal further species diversity within each region (Meera, 2018).

The species accumulation curve for NEAS (Fig. 3c.1) predicted the occurrence of up to 21 species in this region (Chao's 2 estimator: 20 ± 5.29; Jacknife 1 estimator: 19; and Jacknife 2 estimator: 21 species). The study (2013- 2017, 2024-2025) collected only 16 species from 35 stations representing 76.2-84.2% of the highest estimated diversity. From the secondary data species such as *Bolinichthys indicus, Diaphus aliciae, D. fulgens, D. hudsoni, Diogenichthys panurgus* and *Myctophum aurolaternatum* were reported from NEAS but were not obtained in the present study. When added to the list of species from NEAS, the total tally of species was 22, which is one species higher than the highest predicted value.

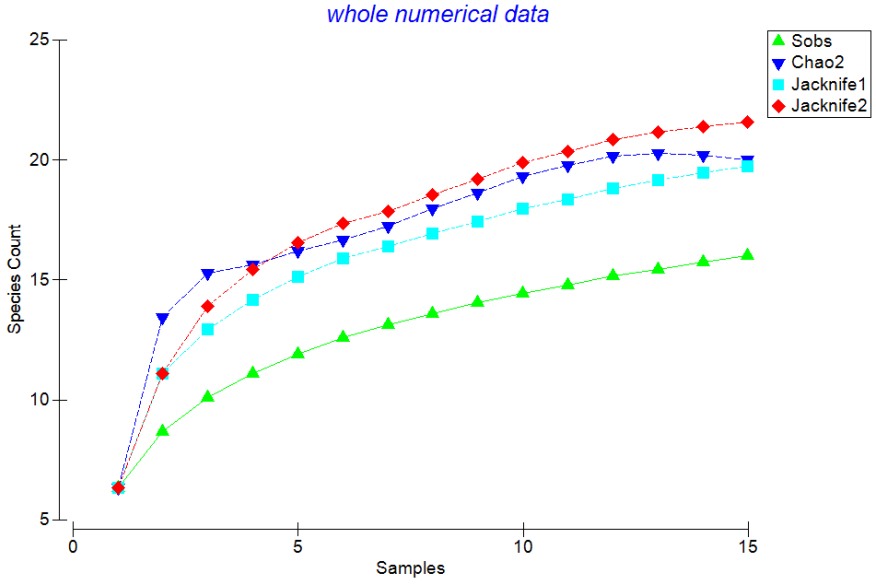



Fig.3c.1: Species accumulation curves for Myctophids in NEAS

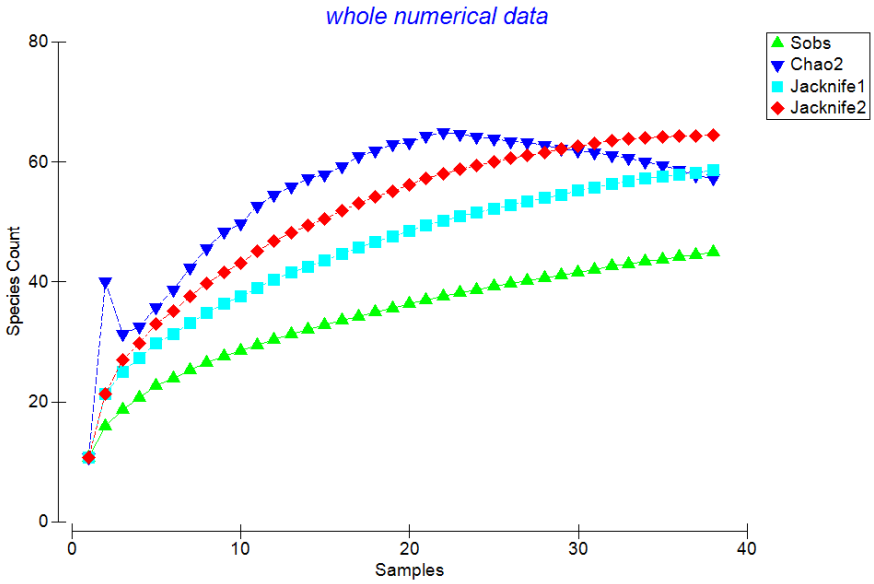



Fig. 3c.2: Species accumulation curves for Myctophids in SEAS

The species accumulation curve for the SEAS (Fig. 3c.2) did not reach the upper asymptote. Estimators predicted the occurrence of up to 64 species in this region (Chao's 2: 57 ± 8.59; Jacknife 1: 58; and Jacknife 2: 64 species). However, only 45 species across 37 sites were obtained (Sobs), representing 70.3% of the estimated highest diversity. With the inclusion of species reported from SEAS by others (*Bolinichthys indicus, Dasyscopelus seleneops, Diaphus dumerilii, D. hudsoni, D. luetkeni, D. malayanus, D. phillipsi, Diogenichthys panurgus, Hygophum reinhardtii, Lampanyctus pusillus,* and *Myctophum fissunovi*), the total number of myctophid species in SEAS reached 56, which is very close (87.5%) to the value predicted by the estimators.

The species accumulation curve for the WEIO (Fig. 3c.3) predicted the occurrence of up to 66 species

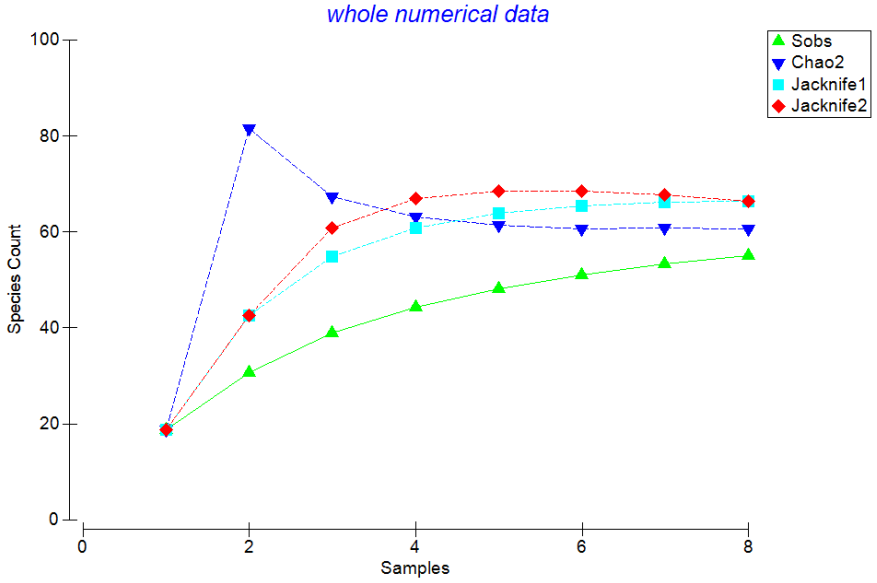



Fig. 3c.3: Species accumulation curves for Myctophids in WEIO

in this region (Chao's 2: 60 ± 4.1; Jacknife 1: 63; and Jacknife 2: 66 species). The study collected 55 species from 9 stations, representing 86.4% of the estimated highest diversity. The WEIO extends from 6°S to 6°N and 40°E to 80°E, and the species accumulation curve represents the maximum possible number of species within the study area.

The cumulative dominance curves indicate distinct differences in species abundance distribution across eco-regions. Sampling sufficiency varied across regions, with the WEIO showing the highest coverage (86%), followed by the SEAS (70%) and the NEAS (55%) (Fig. 3c.4). The present study documented 16 species from NEAS (15 trawl surveys), 45 species from SEAS (23 surveys), and 55 species from WEIO (23 surveys). These records represent approximately 70-90% of the estimated species richness, indicating that the sampling effort effectively captured the majority of species contributing to community structure, as reflected in the K-dominance patterns.

The highest species diversity (H′ = 4.33) was observed in the WEIO, followed by the SEAS (H′ = 3.506) and the NEAS (H′ = 2.66). This gradient indicates a progressive increase in diversity from the northeastern to the western equatorial region. Both species richness (*d*) and species evenness (*J′*) were higher in the WEIO (*d* = 9.43; *J′* = 0.75) compared to the SEAS (*d* = 6.006; *J′* = 0.638) and NEAS (*d* = 1.793; *J′* = 0.665) (Table 3c.1), suggesting that the WEIO not only harbours a greater number of species but also maintains a more balanced distribution among them. The observed spatial variation in diversity indices is attributed to differences in hydrological conditions, primary productivity, and habitat heterogeneity across these regions, with the WEIO benefiting from greater oceanic mixing and nutrient availability that support higher biodiversity.

The differences and affinities among the regions of WIO were more clearly established using an nMDS plot based on Kulcsynski's resemblance of species incidence data. These latitudinal trends in species distribution were evident within the 50-600 m depth zones for all three regions. The nMDS plot demarcated the study area into three distinct regions, at 63% similarity, based on diversity and species composition between the regions (Fig. 3c.5). The results of the SIMPER analysis quantified the contribution of each

Table 3c.1: Diversity Indices of three regions of Western Indian Ocean (WIO)

| Area | Species richness(d) | Species evenness(J¢) | Species diversity(H¢) |
|---|---|---|---|
| NEAS | 1.793 | 0.665 | 2.66 |
| SEAS | 6.006 | 0.6384 | 3.506 |
| WEIO | 9.43 | 0.75 | 4.33 |

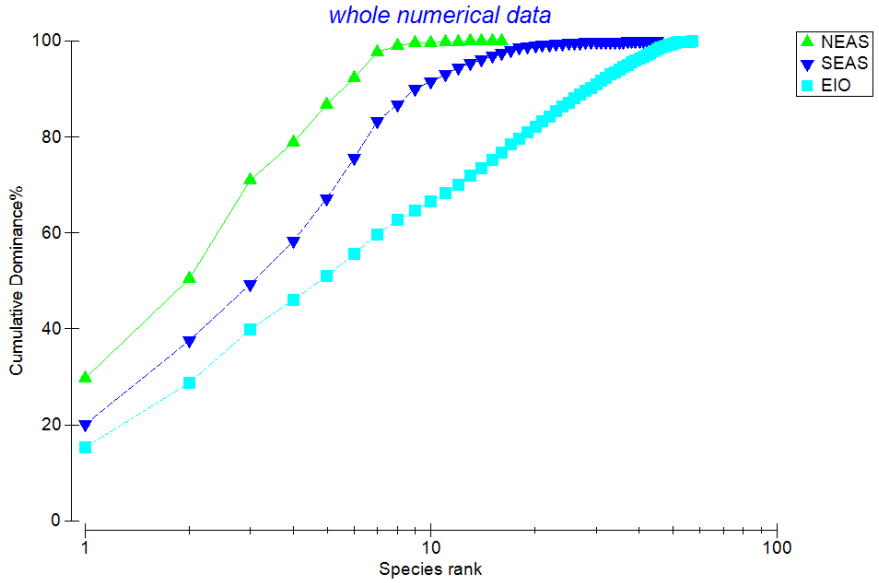



Fig. 3c. 4: Sector-wise Diversity of myctophids

species to the observed similarity (or dissimilarity) between regions based on the differences between actual distances and their predicted values are given in Table 3c.2.

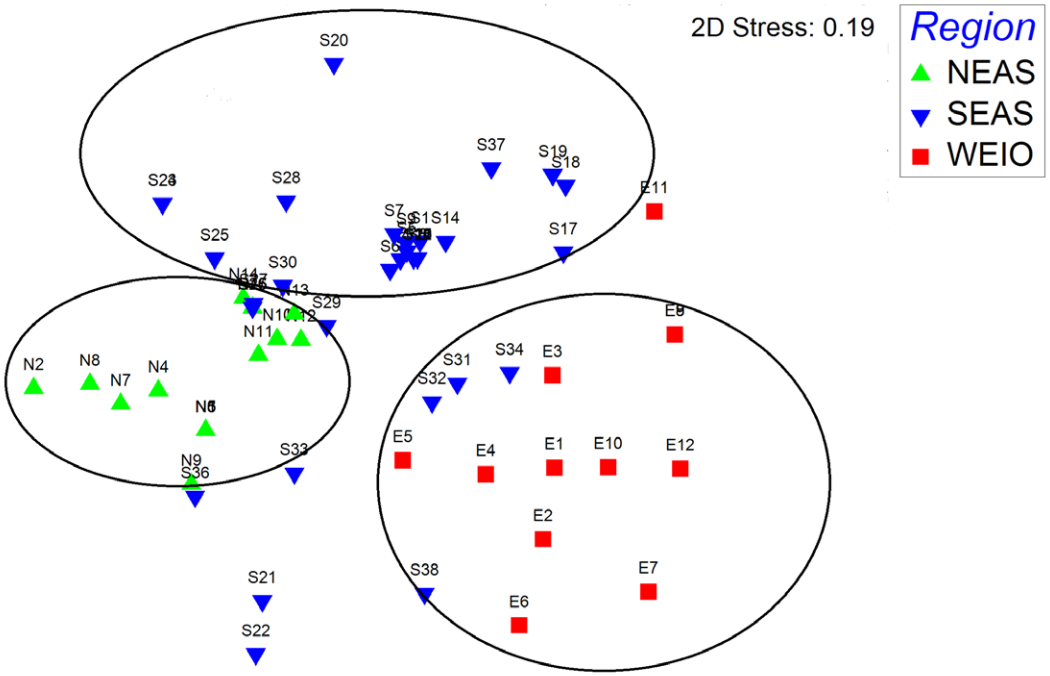



Fig. 3c.5: Three distinct assemblages correspond to NEAS, SEAS, and WEIO eco-regions.

Table 3c.2: Summary of SIMPER Analysis and Species Distribution Patterns Across Indian Ocean Eco-Regions

| Category | Description / Interpretation | Representative Species | Remarks |
|---|---|---|---|
| Total species recorded | 59 species identified from the Western Indian Ocean | | |
| Widespread species (across NEAS, SEAS, WEIO) | 16 species occurring in all three eco-regions | *Benthosema fibulatum*, *B. pterotum*, *Bolinichthys longipes*, *Ceratoscopelus warmingii*, *Dasyscopelus spinosus*, *Diaphus aliciae*, *D. arabicus*, *D. garmani*, *D. jenseni*, *D. lucidus*, *D. signatus*, *D. thiollierei*, *Hygophum proximum*, *Lampanyctus turneri*, *Symbolophorus evermanni*, *S. rufinus* | Widespread distribution indicates broader environmental tolerance |
| Species restricted to SEAS & WEIO | 25 species restricted to southern and western regions | *Taaningichthys minimus*, *Bolinichthys pyrsobolus*, *B. indicus*, *Dasyscopelus asper*, *D. obtusirostris*, *Diaphus brachycephalus*, *D. coeruleus*, *D. diadematus*, *D. diademophilus*, *D. effulgens*, *D. fulgens*, *D. lobatus*, *D. mollis*, *D. parri*, *D. perspicillatus*, *D. problematicus*, *D. splendidus*, *D. taaningi*, *D. aliciae*, *Hygophum hanseni*, *Lampanyctus intricarius*, *L. nobilis*, *Lampadena luminosa*, *L. urophaos*, *L. anomala*, *M. aurolaternatum*, *M. nitidulum* | Indicates narrower environmental tolerance; 13 of 25 species belong to *Diaphus* |

| Category | Description / Interpretation | Representative Species | Remarks |
|---|---|---|---|
| Species with narrow range | 16 species with restricted occurrence | Exclusive to WEIO (14 spp.) *Bolinichthys supralateralis*, *B. nikolayi*, *Diaphus antonbruuni*, *D. luetkeni*, *D. theta*, *Electrona risso*, *Lampadena anomala*, *L. luminosa*, *Lampanyctus achirus, L. atrum, L. crocodilus, L. macdonaldi, L. photonotus, L. tenuiformis*, Exclusive to SEAS (2 spp.): *Diaphus similis, D. watasei* | Reflects regional endemism and environmental specialization |
| Average dissimilarity (NEAS-SEAS) | 64.58% | 19 species explain 91.27% of this dissimilarity | Moderate regional differentiation |
| Average dissimilarity (NEAS-WEIO) | 84.52% | 43 species account for 90% of dissimilarity | High dissimilarity; distinct faunal assemblages |
| Average dissimilarity (SEAS-WEIO) | 75.57% | 45 species explain 90.6% of dissimilarity | Substantial overlap but still distinct patterns |

# Annexure- 3d

## Vertical Migration Strategies of Myctophid Fishes

During the daytime myctophid fish species occupy the depths of an extremely low oxygen layer (<0.1 ml/L) whereas in the night they forage in the oxygen-rich surface layer (Kinzer et al., 1993; GLOBEC, 1993; Shilat & Valinassab, 1998; Nair et al., 1999) (Fig. 3d.1). The vertical migration rate of myctophids varied with body size, with smaller species ascending or descending at rates of 10-170 m/hr, while larger taxa exhibited higher displacement rates of 100-200 m/hr. Myctophid larvae remain in the epipelagic zone (<200 m) and then move to deeper depths to adapt to their later adult life in the mesopelagic zone, after which most species begin their migration (Sassa et al., 2004). They are also capable of crossing density gradients such as thermocline and halocline (Nafpaktitis & Nafpaktitis, 1969).

The epipelagic zone shapes myctophid development, as they carry out most of their activities, such as feeding and reproduction, in this area (Gartner, 1991). Daily migration is linked to the exchange of nutrients and energy between lower and higher trophic levels

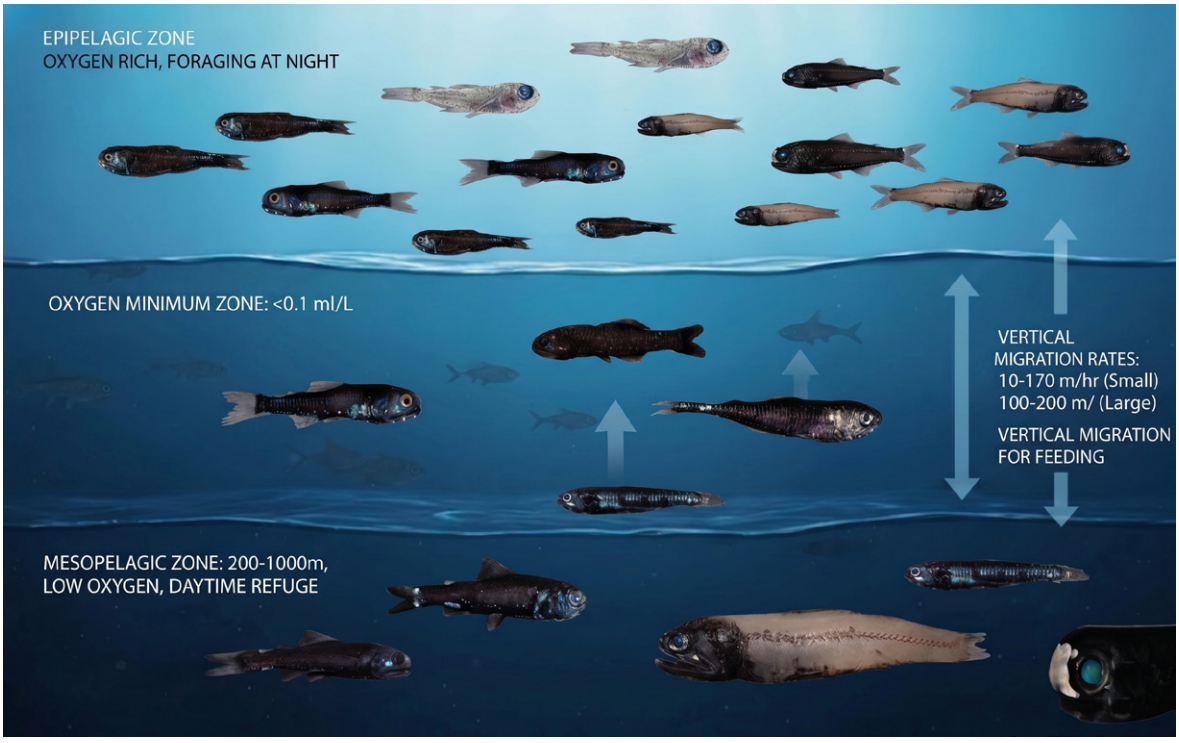



Fig. 3d.1: Vertical Migration of Myctophid Fishes

(Tsarin, 1997). Adaptation to low-oxygen conditions makes the OMZ a safe niche for myctophids, as it limits the entry of predatory fishes into this layer (Levin, 2003). Myctophid studies carried out by CMLRE (2009-2017) noticed that species that prefer highly oxygenated waters with relatively low temperature, and high salinity and density (WEIO waters) include *Bolinichthys pyrsobolus, Diaphus aliciae, D. coeruleus, D. diadematus, D. effulgens, D. fragilis, D. jenseni, D. luetkeni, D. splendidus* and *Symbolophorus rufinus*. The species associated with intermediate levels of oxygen, temperature, salinity and density (SEAS) are *Benthosema pterotum, Bolinichthys indicus, Dasycopelus spinosus, Diaphus garmani, D. perspicillatus, D.luetkeni, D. problematicus, D. similis, D. lobatus, D. lucidus, D. thiollierei, Lampanyctus turneri* and *Symbolophorus evermanni.* The species that can thrive in low-oxygenated waters with relatively high temperatures and salinity (NEAS) are represented by *Benthosema fibulatum, Bolinichthys longipes, Dasyscopelus asper, Ceratoscopelus warmingii, D. signatus, D. arabicus* and *Hygophum proximum.*

# Annexure- 3e

## Feeding and Reproductive Biology of Myctophids

Despite extreme hypoxia, the AS sustains one of the world's largest mesopelagic fish biomasses (Garcia-Seoane et al., 2025). The feeding habits of myctophids have been mainly studied in adult and juvenile life stages by Tyler & Pearcy (1975); Hopkins & Baird (1973); Young & Blaber (1986); Rissik & Suthers (2000), and Watanabe et al. (2002). Most myctophids are opportunistic feeders that filter water with well-developed gill rakers and feed on copepods, ostracods, euphausiids, hyperiid amphipods, chaetognaths, pteropods, fish eggs and larvae (Hulley, 1985; Dalpadado & Gjosaeter, 1988; Kinzer et al., 1993; Pakhomov et al., 1996). The feeding habits of 11 myctophid species during MLR, belonging to the genera *Benthosema*, *Bolinichthys*, *Ceratoscopelus*, *Diaphus*, *Lampanyctus*, and *Symbolophorus*, showed that all are carnivorous.

Myctophids are characterized by rapid growth, early sexual maturity, external fertilization, a lifespan of 1-5 years, and high mortality rates (Childress *et al.,* 1980; Gjosaeter & Kawaguchi, 1980; Karuppasamy et

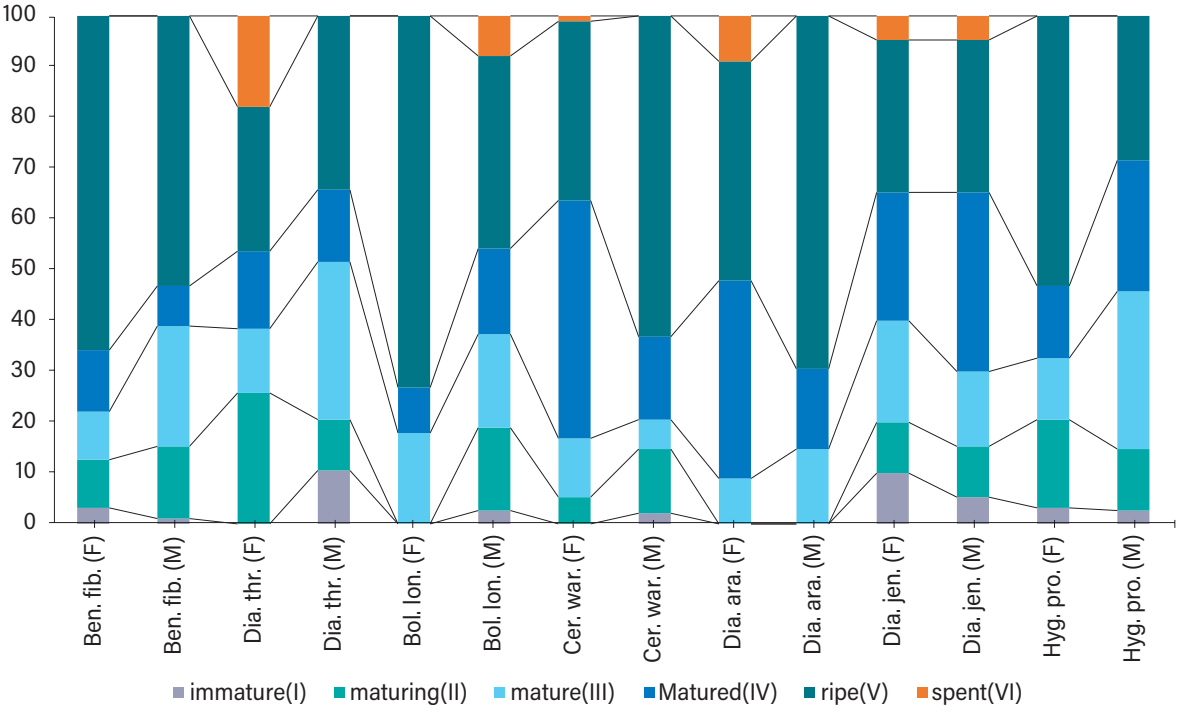



Fig. 3e.1: Reproductive stages of Myctophids from CMLRE studies (2013-2016, FORV *Sagar Sampada*)

al., 2008a, b). Females are oviparous, and both sexes are non-guarding pelagic spawners. The tiny eggs (ranging between 0.70-0.90 mm in diameter, with a segmented yolk, a moderately perivitelline space, a single oil globule, and a delicate chorion) are buoyant due to lipid droplets. The hatched larvae (≈2.0 mm) drift with the currents until they develop. Spawning may continue year-round, but in some species has been reported to peak during the winter early spring season (Balu & Menon, 2006). Only little information is available on the reproductive biology of myctophid fishes from the Indian Ocean. A detailed study on the gonad development, size, age at maturity, and fecundity of *Benthosema pterotum* from the Indian Ocean was provided by Dalpadado (1983), Gjosaeter (1981b, 1984), Hussain & Khan (1987), and Hussain (1992). The studies indicate that this species reaches maturity at approximately 6 months of age and exhibits batch fecundity, varying from about 200 to 3000 eggs.

The sex ratios of a few myctophids were analysed based on FORV *Sagar Sampada* cruises and found that *Benthosema fibulatum* (1:0.3), *Bolinichthys longipes* (1:0.3), *Diaphus arabicus* (1:0.5), *D. jenseni* (1:0.2), and *Hygophum proximum* (1:0.4) deviates significantly from the normal 1:1 ratio towards male dominance (Meera, 2018). While in case of *Ceratoscopelus warmingii* (1:1.7), the females dominate over the males ($p < 0.05$). For *D. thiollierei* (1:1.04) *p*-values of the Chi-Square test ($p > 0.05$) suggest that the differences in the sex ratio are not significant and therefore, the species follows the 1:1 ratio. The most abundant of all the six stages observed in the specimens was the ripe stage, followed by the mature and maturing stages and the least observed were the spent stage and the immature stage. Rare occurrences of spawned fishes in the specimens collected may indicate that these fishes spawn just once, die soon afterward, and sink out of the sampled depth layers after spawning, or that spawners recover extremely rapidly and leave no trace of previous spawning, indicating they could be continuous spawners (Fig. 3e.1).

# Annexure- 3f

## Biochemical Composition of Selected Myctophids from the Arabian Sea

The myctophids provide a well-balanced nutritional composition with moderate protein and variable lipid reserves, as detailed in Annexure Tables 3f.1 and 3f.2, which captures these species-level differences in a clear and comparable manner.

Table 3f.1: Proximate composition of a few selected myctophid fishes

| Species | Moisture (%) | Protein (%) | Fat (%) | Ash (%) |
|---|---|---|---|---|
| *Benthosema fibulatum* | 78.18 | 14.27 | 1.67 | 4.78 |
| *Dasyscopelus obtusirostris* | 77.09 ± 2.09 | 16.70 ± 3.78 | 5.32 ± 2.19 | 2.19 ± 1.32 |
| *Diaphus effulgens* | 78.06 | 16.54 | 4.86 | 0.54 |
| *Diaphus hudsoni* | 74.12 | 14.45 | 7.73 | 3.63 |
| *Diaphus luetkeni* | 74.71 ± 4.85 | 16.49 ± 2.01 | 5.73 ± 3.78 | 3.03 ± 1.20 |
| *Diaphus watasei* | 65.99 ± 2.83 | 18.11 ± 4.62 | 14.50 ± 1.25 | 1.13 ± 0.04 |

Table 3f.2: Combined Nutritional Profile, Fatty Acid Composition, of Myctophids and Common Food Fishes

| Species | Protein (%) | Lipid (%) | Moisture (%) | Ash (%) | SFA (%) | MUFA (%) | PUFA (%) | n-3 PUFA (%) | EPA (%) | DHA (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Dasyscopelus obtusirostris* | 22.64 | - | - | - | - | - | - | - | - | - |
| *Diaphus effulgens* | 16.54 | 4.68 | 77.21 | 1.57 | 35.04 | 23.78 | 41.18 | 27.88 | 6.25 | 17.42 |
| *Diaphus hudsoni* | 14.45 | 4.12 | 79.08 | 1.49 | 34.12 | 22.45 | 43.43 | 28.47 | 6.97 | 18.14 |
| *Diaphus watasei* | 15.62 | 11.71 | - | - | 33.30 | 36.70 | 25.50 | - | 3.83 | 9.33 |
| *Mugil cephalus* | 18.34 | 6.45 | 72.80 | 1.20 | 41.11 | 25.34 | 33.55 | 20.32 | 4.38 | 12.87 |

| Species | Protein (%) | Lipid (%) | Moisture (%) | Ash (%) | SFA (%) | MUFA (%) | PUFA (%) | n-3 PUFA (%) | EPA (%) | DHA (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| *Rastrelliger kanagurta* | 20.12 | 9.56 | 68.35 | 1.28 | 38.75 | 22.47 | 38.78 | 23.69 | 5.43 | 14.94 |
| *Sardinella longiceps* | 19.21 | 8.97 | 70.47 | 1.35 | 39.68 | 21.52 | 38.80 | 24.78 | 5.64 | 15.23 |

The present table supports that myctophids contain a balanced mix of essential amino acids, with particularly strong contributions from leucine, valine, and lysine. When viewed alongside conventional food fishes, the amino acid profile of myctophids remains competitive and nutritionally valuable. This is clearly illustrated in Annexure Table 3f.3, where the relative proportions of essential amino acids across species are presented in a straightforward manner.

Table 3f.3: Essential Amino Acids Composition (%) of Myctophids and Selected Food Fishes (Fernandez et al., 2014)

| Amino Acids | *Diaphus effulgens* | *Diaphus hudsoni* | *Mugil cephalus* | *Rastrelliger kanagurta* | *Sardinella longiceps* |
|---|---|---|---|---|---|
| Valine | 9.04 | 8.31 | 5.83 | 6.35 | 6.41 |
| Methionine | 0.55 | 0.84 | 1.16 | 1.38 | 1.25 |
| Isoleucine | 6.6 | 5.7 | 4.06 | 4.3 | 4.37 |
| Leucine | 8.71 | 8.82 | 4.23 | 4.21 | 4.43 |
| Tyrosine | 0.9 | 0.65 | 0.86 | 0.81 | 0.33 |
| Phenylalanine | 3.85 | 3.86 | 6.81 | 5.89 | 6.08 |
| Histidine | 8.32 | 3.57 | 10.59 | 15.39 | 11.32 |
| Lysine | 6.74 | 3.48 | 16.54 | 15.62 | 16.12 |
| Threonine | 6.16 | 5.48 | 4.26 | 4.67 | 4.59 |
| Tryptophan | 1.16 | 1.23 | 0.83 | 0.92 | 0.95 |
| Total | 52.03 | 41.94 | 55.17 | 59.54 | 55.85 |

# Annexure- 3g

These spatial and seasonal patterns, summarized in Table 3g, underline the ecological importance of shrimps in the DSL and their consistent availability across regions, particularly during favorable seasons.

Table 3g: Seasonal Variations of shrimps in DSL in Indian EEZ

| Region | Season | Average Density (Individuals/Haul/1000 $m^3$) | Remarks |
|---|---|---|---|
| Southwest Coast | Pre-monsoon (Feb-May) | 563 (Night) / ≈130 (Day) | Highest abundance at night; peak off the Kochi coast |
| | Monsoon (Jun-Sep) | Moderate to High | Sustained abundance; active DVM observed |
| | Post-monsoon (Oct-Jan) | Low to Moderate | Slight decline |
| Northwest Coast | Pre-monsoon | 632 (Neritic) / 219 (Oceanic) | Very high off Bombay–Ratnagiri; dominated by *Acetes* |
| East Coast (BoB) | July-May | Max 7,500 (Oct, Andhra coast) | Patchy distribution; peak in October |
| Lakshadweep Region | Pre-monsoon | High | Large swarms of *Sergestes* |
| | Monsoon/post-monsoon | Moderate | Abundance persisted |
| Andaman Sea | Pre-monsoon | 50-100 | Highest near the Middle and Little Andaman Islands |
| | Monsoon/post-monsoon | Moderate | Stable abundance; diel increase of ≈36% at night |

# Annexure- 4a

## Deep-Sea Demersal Fish Diversity in the Continental Margin along the West Coast of India (Arabian Sea)

The study area in the AS was categorised into two depth zones based on trawling: 200-800 m and 800-1500 m. A total of 188 fish species were documented, belonging to 76 families and 25 orders. Among the orders, Perciformes exhibited the highest number of species, followed by Anguilliformes and Ophidiiformes (Fig. 4a.1). The estimation of biomass using the swept-area method revealed a wide range of values, from 17 to 21,179 kg/km$^2$, with an average of 2,220 kg/km$^2$. The highest biomass of 21,179 kg/km$^2$ was recorded at 12.04° N, 74.46° E, at a depth of 200 m, largely due to high catches of *Acropoma* sp. (1,100 kg) and *Priacanthus* sp. (510 kg). Another exceptionally high biomass of 19,668 kg/km$^2$ was observed at 1,043 m depth (8.5°N,

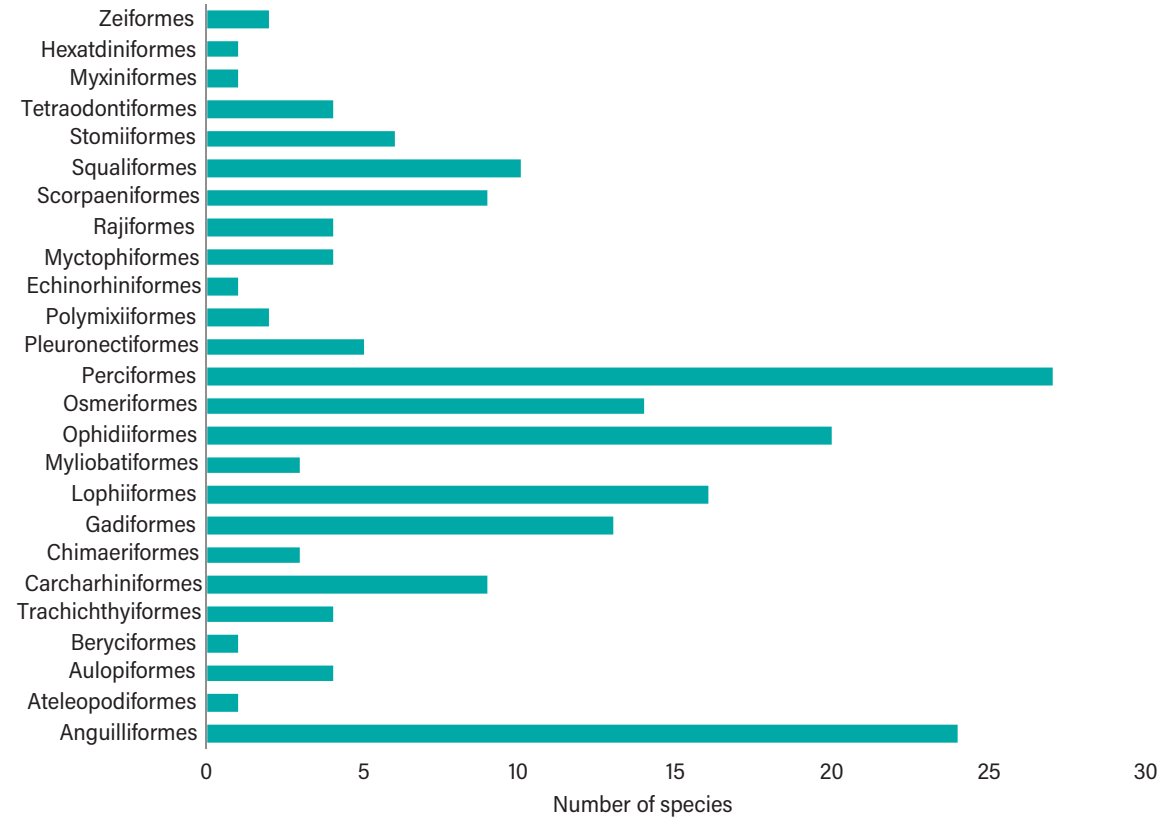



Fig. 4a.1: Number of deep-sea fish species recorded in different orders from the Arabian Sea.

76.0°E), where a single species, *Lamprogrammus niger*), contributed 1,024 kg. Biomass distribution patterns indicated consistently higher values between 7°-13°N at depths of 200-1240 m. When analysed by depth strata, the 800-1500 m zone showed the highest average biomass (2,696 kg/km$^2$), followed by the 200-800 m zone (1,986 kg/km$^2$). These findings underscore substantial spatial variability in biomass across stations, depths, and latitudes, reflecting the heterogeneous nature of fish distribution in the AS. Understanding these patterns enhances our knowledge of the complex dynamics of marine ecosystems in this region and can inform the development of effective fisheries management strategies.

## Diversity of deep-sea demersal fishes

Margalef richness index (*d*) values ranged from 0.23 to 7.34, with an average of 2.71 across all stations. In the 200-800 m depth zone, *d* values ranged from 0.23 to 5.86 (average 2.19), whereas in the 800-1500 m zone, the values varied from 0.49 to 7.34 (average 3.79). This depth-associated variation indicates an increase in species richness as observed in the 800-1500 m depth zone. Pielou's evenness index (*J'*), which reflects the equitability of species abundance distributions in a community, ranged from 0.33 to 0.99 (average 0.89). In the 200-800 m zone, *J'* ranged from 0.33 to 0.99 (average 0.88), while in the 800-1500 m zone, values ranged from 0.81 to 0.99 (average 0.93), suggesting a more evenly distributed community at deeper depths. Shannon index (*H'*) values ranged from 0.23 to 3.63 (average, 2.22) across all stations. The 200-800 m zone exhibited values from 0.23 to 3.16 (average 2.06), while the 800-1500 m zone showed a range from 1.03 to 3.63 (average 2.64). Simpson's Index of Dominance (λ) values ranged from 0.03 to 0.88 (average 0.16) for all stations. Within the 200-800 m zone, λ values ranged from 0.05 to 0.88 (average 0.19), whereas in the 800-1500 m zone, they ranged from 0.03 to 0.36 (average 0.11), indicating less dominance and more balanced species distributions in deeper waters (Fig. 4a.2).

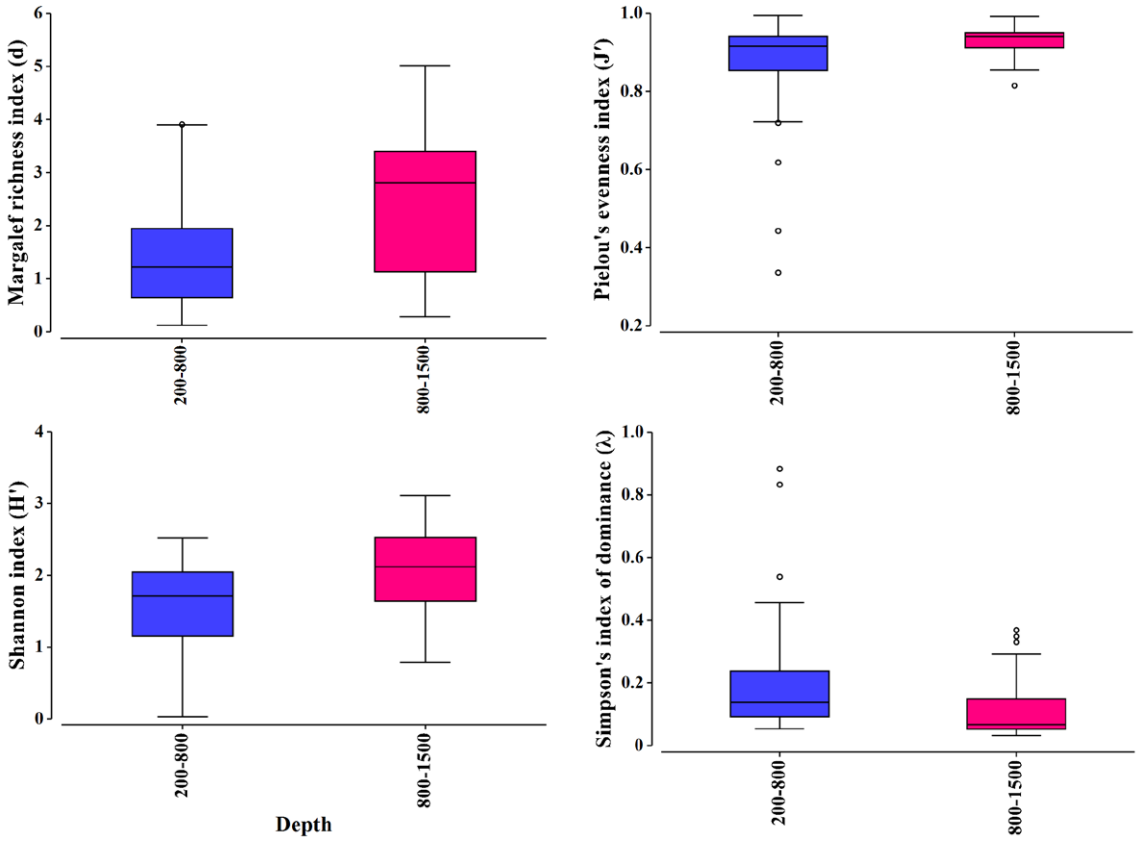



Fig. 4a.2: Diversity indices of the deep-sea fish community at two depth ranges (200-800 m and 800-1500 m) in the Arabian Sea.

These findings reveal clear bathymetric patterns in deep-sea fish biodiversity, with the 800-1500 m zone consistently exhibiting higher species richness, greater evenness, increased overall diversity, and lower dominance. These trends likely reflect the influence of environmental stability, reduced anthropogenic pressures, and niche diversification in deeper benthic ecosystems of the AS.

The K-dominance plot (Fig. 4a.3) illustrates cumulative dominance patterns of deep-sea fish communities across two depth zones, 200-800 m and 800-1500 m. The curve corresponding to the 200-800 m depth zone (blue line) rises more steeply at lower species ranks compared to the 800-1500 m zone (pink line), indicating a higher dominance by fewer species in the shallower depth range. In contrast, the curve for the 800-1500 m zone shows a more gradual slope, signifying a more even distribution of species and reduced dominance. In the 200-800 m depth zone, one species was responsible for 18% of the total abundance, while 17 species collectively accounted for 80% of the total abundance. Within the 800-1500 m depth zone, a single species contributed 20% of the total abundance, and nearly 30 species were collectively responsible for 80% of the total abundance.

Cluster analysis and nMDS ordination based on Bray-Curtis similarity revealed clear depth-related patterns in the community structure of deep-sea fish assemblages across the surveyed depth zones. The dendrogram shows distinct groupings of stations, with deeper stations (800-1500 m, pink inverted triangles) clustering separately from shallower stations (200-800 m, blue triangles), particularly at similarity above 60% (Fig. 4a.4). Several well-defined and statistically coherent clusters were observed, indicating a high degree of within-zone similarity and suggesting that depth plays a key role in structuring species assemblages. The nMDS ordination, with a 3D stress of 0.15, provides a fair representation of the multivariate data in reduced-dimensional space, suitable for ecological interpretation (Fig. 4a.5). Interestingly, some overlap was observed between stations from the two depth zones, indicating partial similarity in species composition across bathymetric strata. This pattern suggests the presence of certain eurybathic species capable of occupying a broad depth range, contributing to faunal continuity across the continental slope. These findings underscore the ecological significance of depth in structuring community composition while also highlighting zones of transition where species distributions converge across depth gradients.

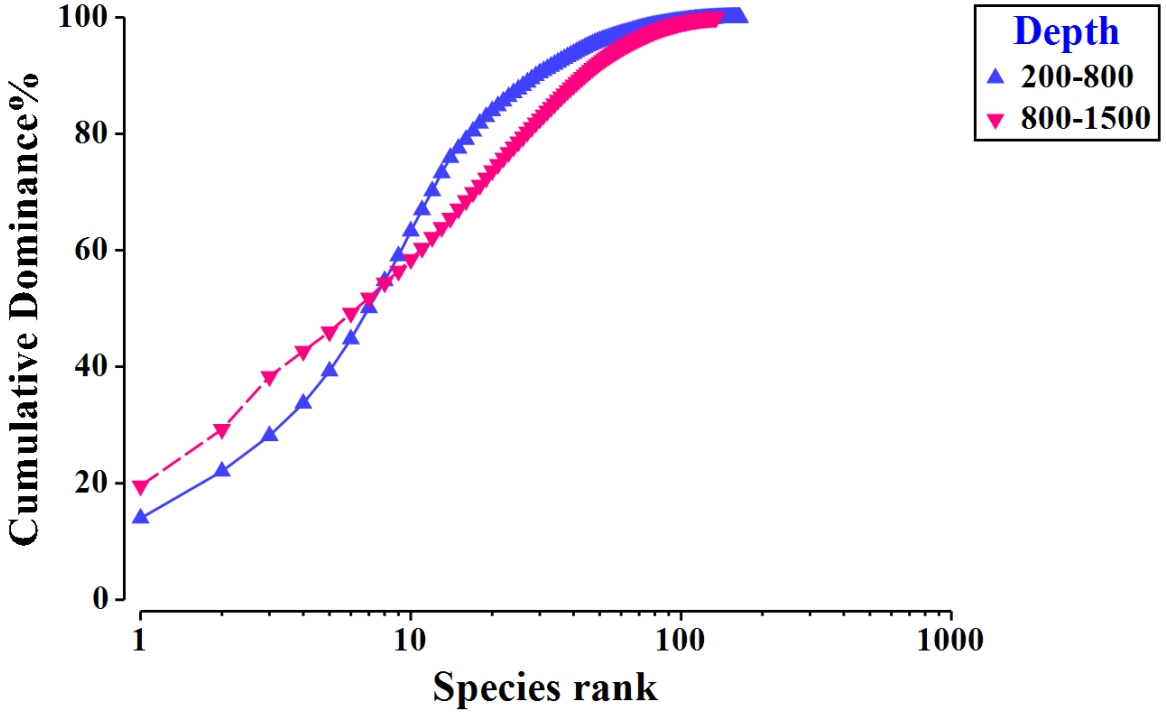



Fig. 4a.3: K-dominance plot showing species rank distribution at two depth ranges (200-800 m and 800-1500 m) in the Arabian Sea.

SIMPER analysis (Table 4a) revealed clear depth-related differences in community structure. The 800-1500 m depth zone exhibited greater within-group similarity than the 200-800 m zone, indicating a more homogeneous assemblage in deeper waters. Key species contributing to similarity within

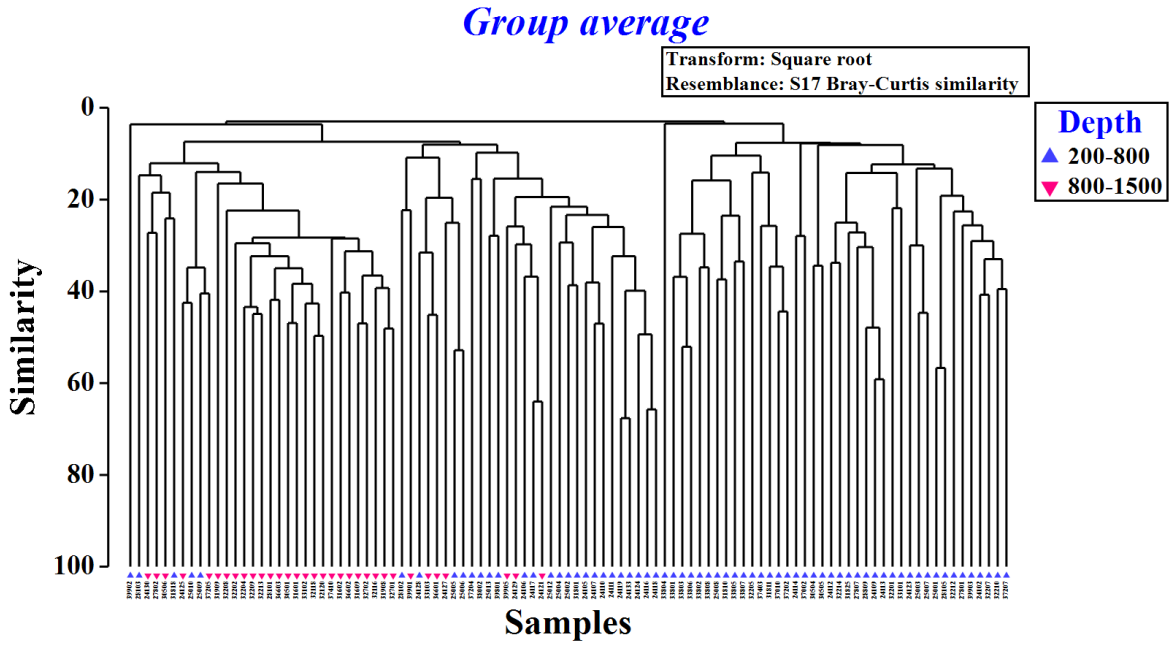



Fig. 4a.4: Cluster analysis (group average linkage) based on Bray-Curtis similarity of deep-sea fish communities at two depth ranges (200-800 m and 800-1500 m) in the Arabian Sea.

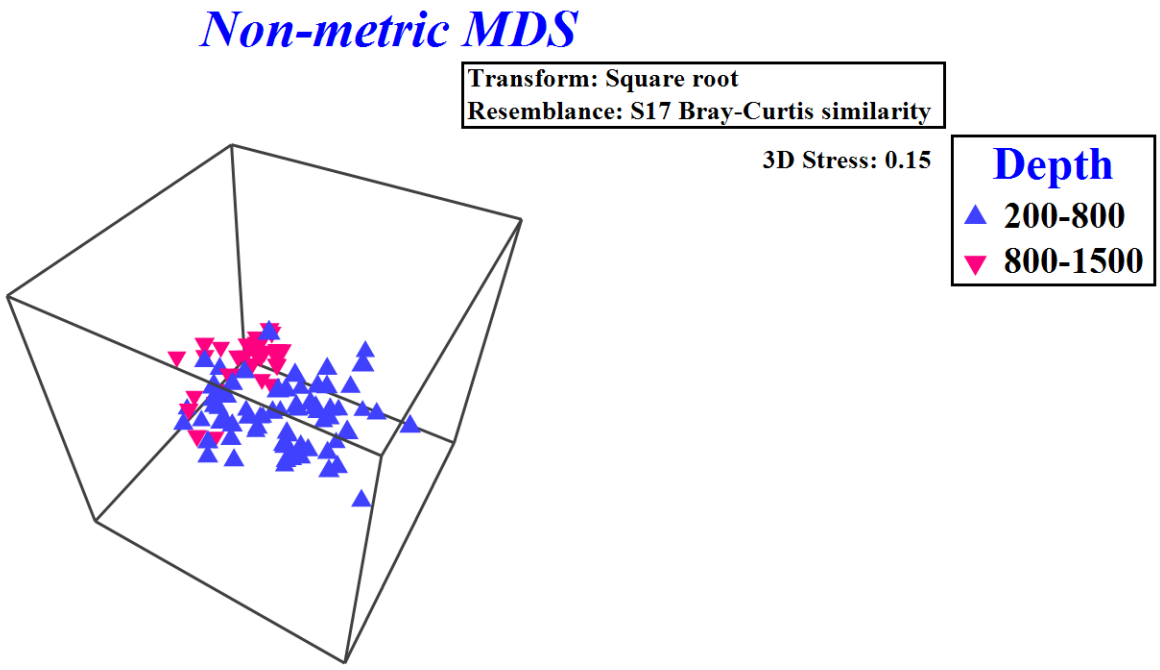



Fig. 4a.5: nMDS ordination based on Bray-Curtis similarity of deep-sea fish communities at two depth ranges (200-800 m and 800-1500 m) in the Arabian Sea.

each depth range were distinct, reflecting depth-stratified faunal composition. Notably, the high dissimilarity between zones (95.41%) highlights pronounced species turnover along the bathymetric gradient, with a few taxa contributing substantially to this separation. These results underscore depth as a primary structuring factor for deep-sea fish communities in the AS.

Table 4a: The results of the SIMPER analysis showing species contributing to similarity or dissimilarity within and between depth zones.

| **Depth Zone (m)** | **Average Similarity (%)** | **Cumulative contribution (%)** | **No. species contributing** | **Main taxa contribution** |
|---|---|---|---|---|
| 200-800 | 8.37 | 90% | 33 | *Gavialiceps taeniola* (13.03%), *Eridacnis radcliffei* (12.89%), *Psenopsis cyanea* (8.17%), *Neoepinnula orientalis* (5.98%), *Bembrops caudimacula* (4.72%) |
| 800-1500 | 17.65 | 90% | 33 | *Bathyuroconger vicinus* (14.47%), *Lamprogrammus niger* (12.42%), *Coryphaenoides hextii* (10.23%), *Bathycongrus guttulatus* (4.23%), *Coryphaenoides macrolophus* (4.05%) |
| Depth zone (m) | Average dissimilarity (%) | Cumulative contribution (%) | No. species contributing | Main taxa contribution |
| 200-800 & 800-1500 | 95.41 | 90% | 105 | *Coryphaenoides hextii* (3.63%), *Bathyuroconger vicinus* (3.48%), *Lamprogrammus niger* (3.46%), *Gavialiceps taeniola* (3.02%), *Psenopsis cyanea* (2.39%) |

# Annexure- 4b

## Deep-Sea Demersal Fish Diversity in the Continental Margin of the Andaman and Nicobar

The Andaman-Nicobar group of islands is located between 6° and 14° N latitude and 92° and 94° E longitude in the Bay of Bengal. It is recognized for its ecological significance and high species richness. It supports a remarkable diversity of fish species, representative of the broader Indo-Pacific biodiversity (Randall, 1998). Both the marine and terrestrial ecosystems in this region make substantial contributions to India's overall biodiversity and play a crucial role in the global marine environment. The area's diverse habitats, complex oceanography, and distinctive geological history have fostered the evolution of numerous

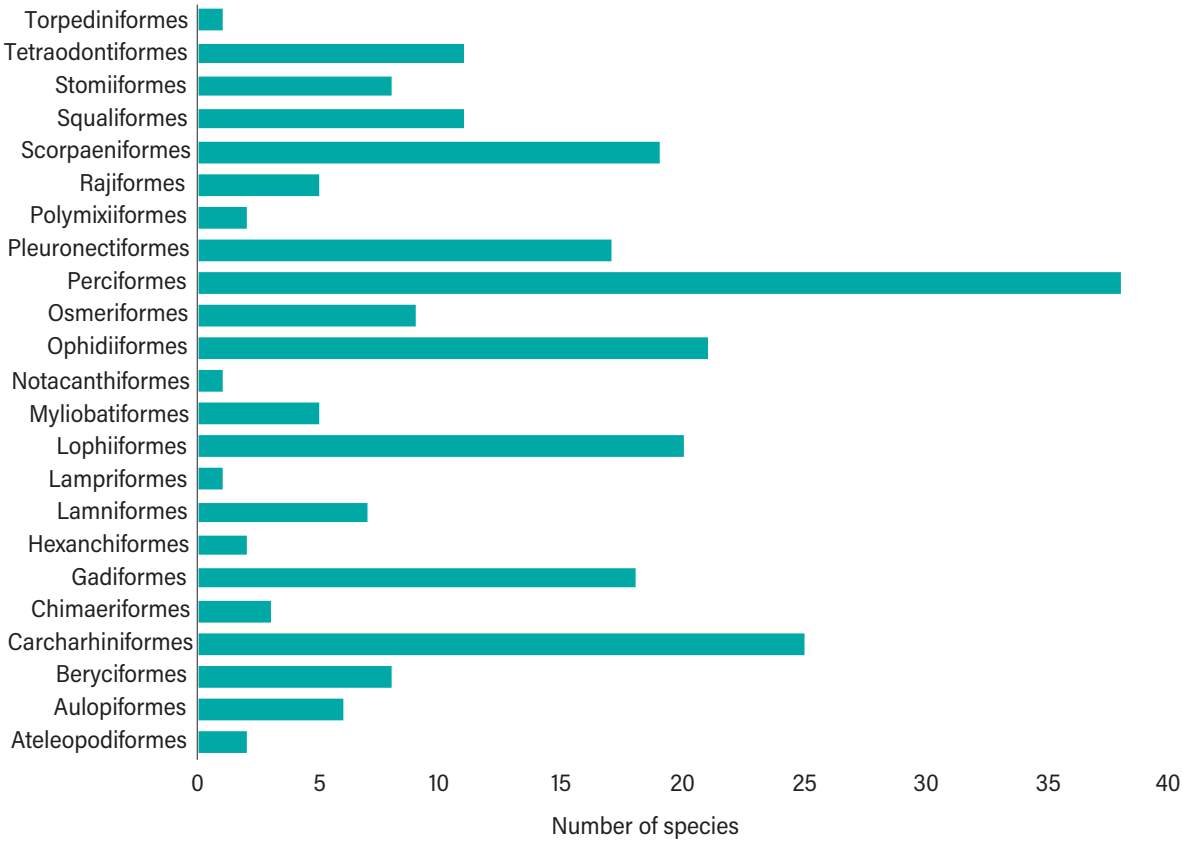



Fig. 4b.1: Number of deep-sea fish species represented in each order from the Andaman and Nicobar waters

endemic species, making it a vital hotspot for scientific research and conservation.

Deep-sea biodiversity surveys onboard FORV *Sagar Sampada*, focusing on the continental slope of the Andaman and Nicobar Islands, were conducted between 2007 and 2017. Bottom trawling was conducted at depths of 278-907 m, collecting comprehensive data on species composition and distribution. A total of 270 species, belonging to 89 families and 25 orders, were recorded from this region. The order Perciformes was found to be the most diverse, followed by Anguilliformes, Carcharhiniformes, Ophidiiformes, and Lophiiformes (Fig. 4b.1). Given the historically limited knowledge of the region's deep-sea fauna, the surveys addressed a critical gap by providing detailed taxonomic and distributional data. The comprehensive checklist developed as part of our research serves as a valuable reference for deep-water fish biodiversity in the Andaman and Nicobar region. Biomass values ranged from 7.75 to 7,943 kg/km$^2$, with an average of 1,222 kg/km$^2$. The stations located at approximately 10-13°N latitude and 92-93°E at depths of 200-600 m (Andaman Islands) exhibited relatively high biomass values (>3,000 kg/km$^2$).

# Diversity of deep-sea demersal fishes

The Margalef richness index (*d*) varied from 0.77 to 5.92, with an average of 3.92, indicating a high species richness. Pielou's Evenness Index (*J'*) varied from 0.74 to 0.98, with an average of 0.94, suggesting a fairly even distribution of individuals among species. The Shannon index (*H'*) exhibited values ranging from 1.36 to 3.36, with an average of 2.69, signifying a moderate to high level of species diversity (Fig. 4b.2). Simpson's Index of Dominance (λ) values ranged from 0.04 to 0.26, with an average of 0.09, indicating low dominance. Biodiversity indices of deep-sea fish populations showed distinct depth-related variation. The richness index (*d*) and diversity index (*H'*) were higher in the 200-600 m depth range,

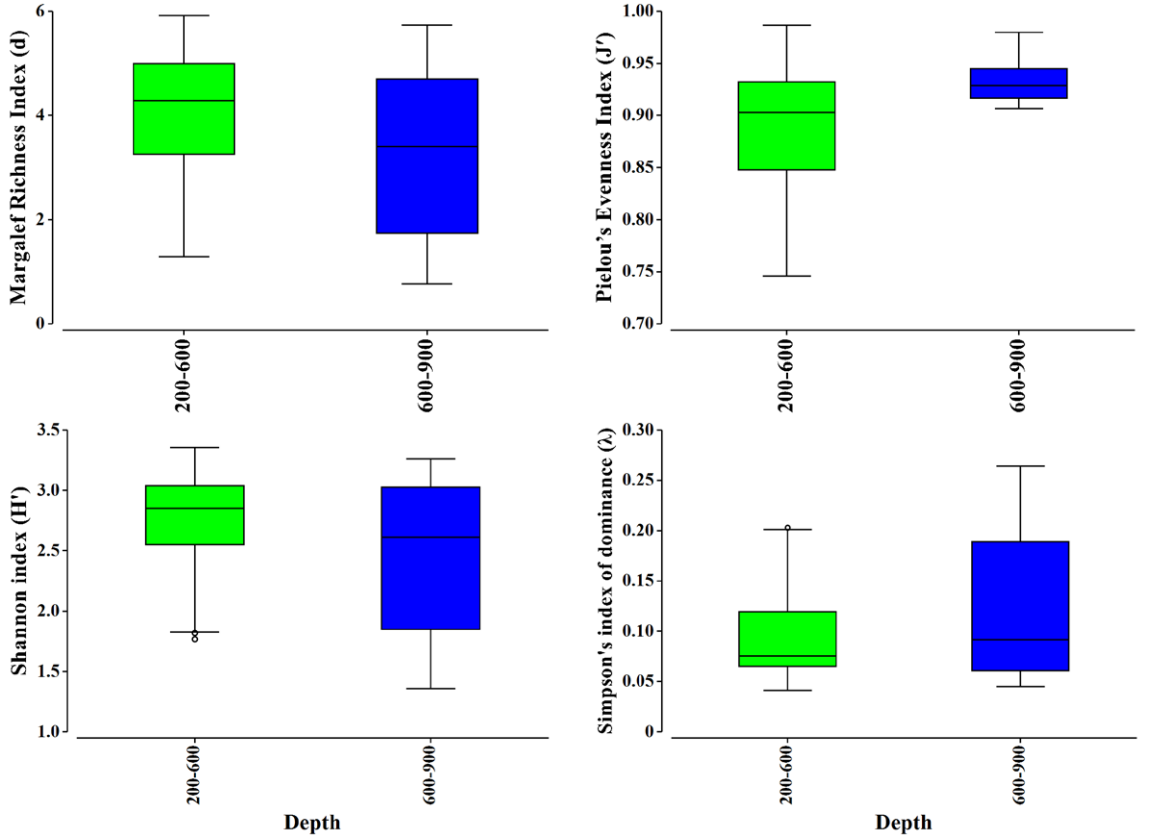



Fig. 4b.2: Box plots of biodiversity indices across two depth zones (200-600 m and 600-900 m) in the Andaman and Nicobar waters.

while the evenness index (J') remained consistently high across both depth ranges, though slightly higher at 600-900 m. The dominance index (λ) was low overall but higher at 600-900 m, suggesting that deeper stations were more influenced by fewer species than shallower depths.

The K-dominance curves were plotted for two different depth zones: 200-600 m and 600-900 m (Fig. 4b.3). In the depth zone of 600-900 m, species ranks 5-30 show a steeper increase in cumulative dominance, suggesting that fewer species account for a larger proportion of cumulative abundance. This indicates a higher degree of species dominance and lower evenness in deeper waters. In contrast, the shallower zone (200-600 m) exhibits a more gradual increase beyond species rank 30, suggesting a broader representation of less dominant taxa and a more even distribution of species abundance.

The hierarchical cluster dendrogram based on Bray-Curtis similarity revealed a clear separation of samples between the two depth zones. The shallower depths (200-600 m) clustered more closely together, indicating greater similarity within this zone, whereas the deeper samples (600-900 m) formed a distinct cluster, reflecting differences in species composition between depth ranges (Fig.4b.4). The nMDS ordination further supported this depth-related structuring, with shallow-water samples clustering separately from those in deeper waters (Fig. 4b.5). The moderate 3D stress value (0.17) indicates that the ordination provides a reliable representation of community similarity. Together, these analyses demonstrate that depth strongly influences species composition, with distinct assemblages in the shallower and deeper zones of the Andaman and Nicobar waters.

SIMPER analysis helps in understanding which species are responsible for the observed patterns of similarity and dissimilarity in fish assemblages (Table 4b). Distinct patterns in species composition were observed between the two depth zones. Within the 200-600 m depth zone, community similarity averaged 10.91%, driven by a diverse assemblage of 53 species, including *Cubiceps baxteri, Priacanthus hamrur,* and *Chlorophthalmus nigromarginatus*. In contrast, the 600-900 m zone exhibited slightly higher within-

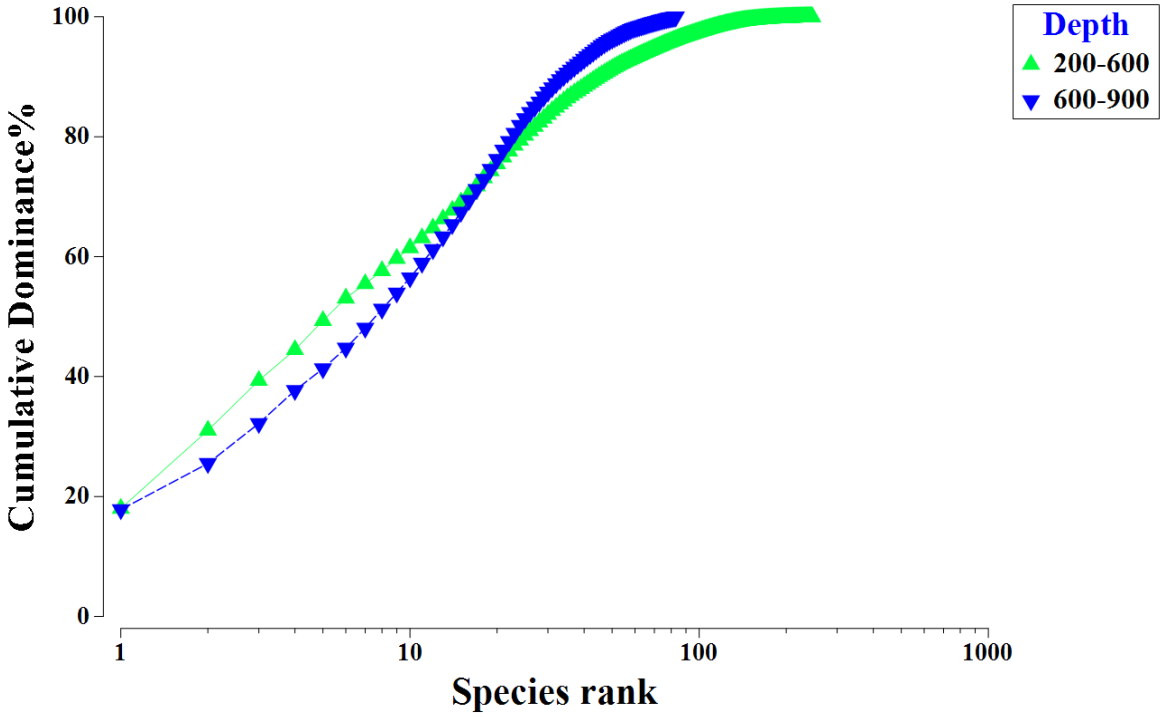



Fig. 4b.3: K-dominance curves illustrating cumulative species dominance (%) across two depth zones (200-600 m and 600-900 m) in the Andaman and Nicobar waters.

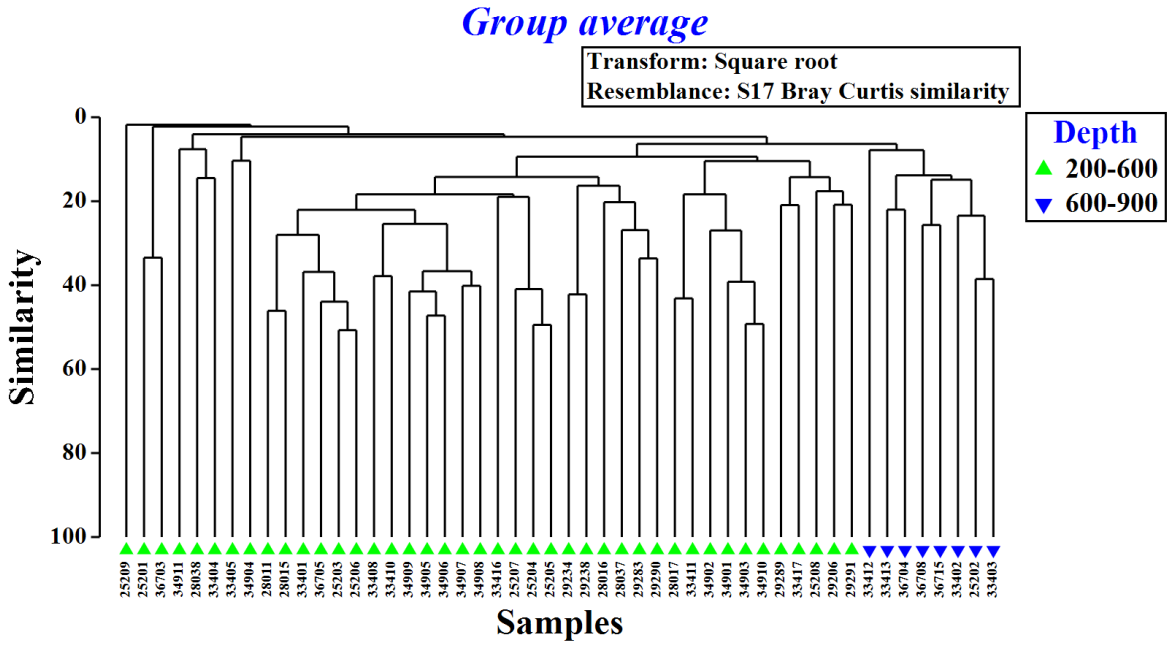



Fig. 4b.4: Hierarchical cluster dendrogram (group-average linking) based on Bray-Curtis similarity showing deep-sea fish community structure across two depth zones (200-600 m and 600-900 m) in the Andaman and Nicobar waters.

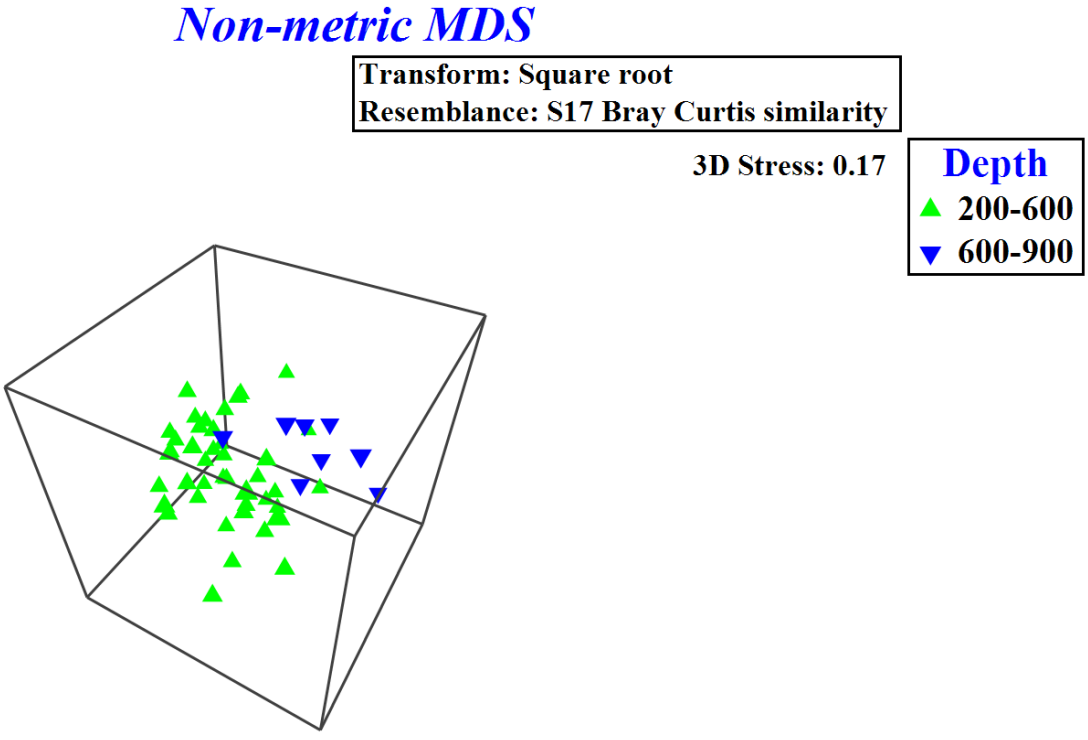



Fig. 4b.5: nMDS ordination based on Bray-Curtis similarity illustrating deep-sea fish community structure across two depth zones (200-600 m and 600-900 m) in the Andaman and Nicobar waters.

group similarity (14.84%) but with fewer contributing species (17), primarily *Gavialiceps taeniola, Setarches guentheri,* and *Alepocephalus bicolor.* Between the two depth zones, an average dissimilarity of 94.30% was recorded, with 127 species contributing to this distinction. Key taxa responsible for the dissimilarity included species from both zones, such as *Cubiceps baxteri, Gavialiceps taeniola, Setarches guentheri,* and *Chlorophthalmus corniger*. This information helps identify the key ecological and biological factors that differentiate fish communities at varying depths in the Andaman Sea.

Table 4b: The results of SIMPER analysis showing species contributing to similarity or dissimilarity within and between different depth zones.

| Depth Zone (m) | Average Similarity (%) | Cumulative contribution (%) | No. species contributing | Main taxa contributing |
|---|---|---|---|---|
| 200-600 | 10.91 | 90.24 | 53 | *Cubiceps baxteri, Priacanthus hamrur, Chlorophthalmus nigromarginatus, Neoepinnula orientalis, Ateleopus indicus* |
| 600-900 | 14.84 | 91.27 | 17 | *Gavialiceps taeniola, Setarches guentheri, Alepocephalus bicolor, Xenomystax trucidans, Lamprogrammus niger, Chaunax multilepis* |
| **Depth zone (m)** | **Average dissimilarity (%)** | **Cumulative contribution (%)** | **No. species contributing** | **Main taxa contributing** |
| 200-600 & 600-900 | 94.30 | 90 | 127 | *Cubiceps baxteri, Priacanthus hamrur, Gavialiceps taeniola, Cubiceps whiteleggii, Chlorophthalmus nigromarginatus,* |

# Annexure- 4c

## Deep-Sea Demersal Fish Diversity in the Continental Margin along the East Coast of India (Bay Of Bengal)

Deep-sea exploration surveys were conducted exclusively onboard FORV *Sagar Sampada* along the continental slope of the BoB between 2006 and 2020. The survey extended to depths of 200-1100 m. A total of 124 deep-sea fish species were recorded, representing 57 families and 21 orders. The order Ophidiiformes was the most diverse, followed by Perciformes, Gadiformes, and Anguilliformes (Fig. 4c.1). Given the scarcity of comprehensive records from this region, an updated checklist of deep-sea fishes has been prepared for these surveys. Biomass estimates ranged from 7 to 7,883 kg/km$^2$, with an average of 1,744 kg/km$^2$. The maximum biomass

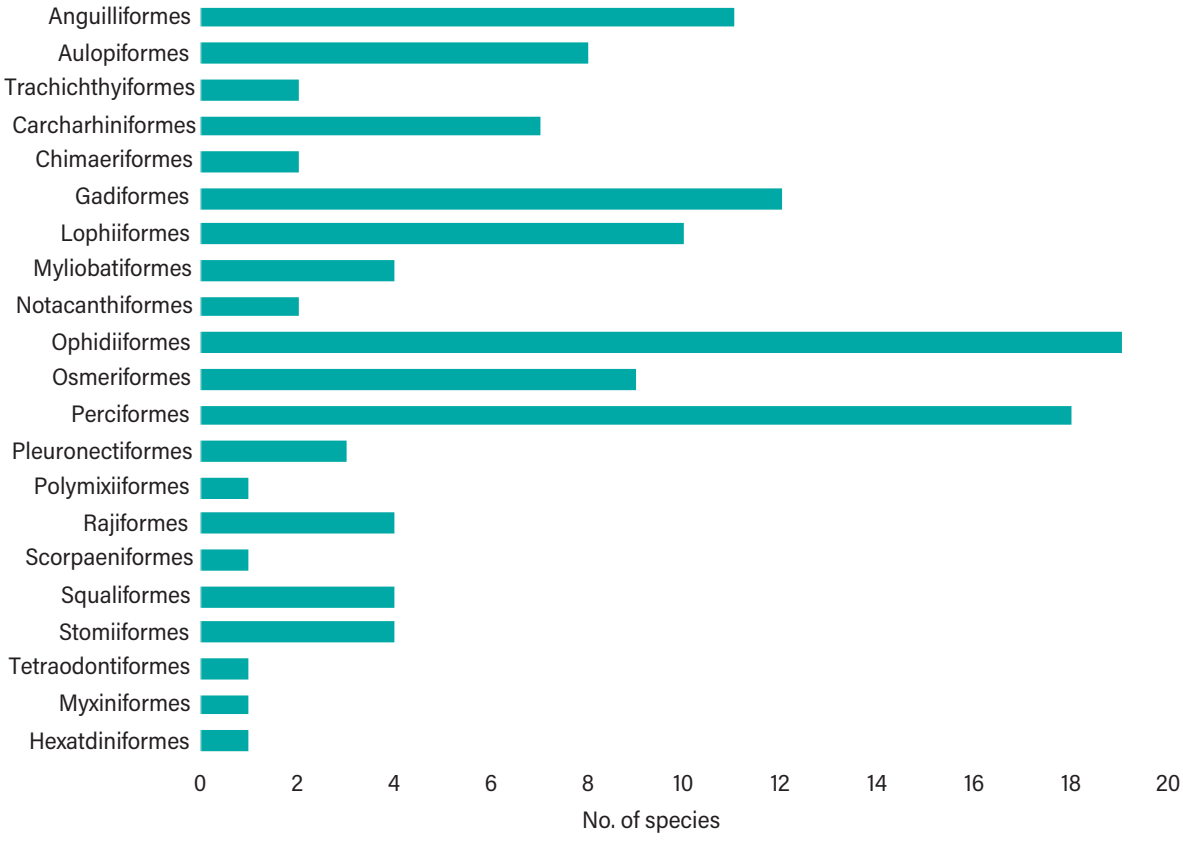



Fig. 4c.1: Number of species across different fish orders recorded from the Bay of Bengal

(7,833 kg/km$^2$) was observed at 13.2°N, 80.56°E, at a depth of 307 m. Depth-specific analysis indicated the highest average biomass in the 200-600 m zone compared to the 600-1100 m zone.

# Diversity of deep-sea demersal fishes

The species richness index (*d*) ranged from 0.52 to 5.81, with a mean value of 2.61. In the 200-600 m depth range, *d* values ranged from 0.52 to 3.80 (average 2.19), while in the 600-1100 m zone, *d* values varied from 0.79 to 5.80 (average 3.08), indicating higher species richness in deeper waters. The species evenness index (*J'*) values ranged from 0.23 to 0.99 (average 0.81). The 200-600 m zone exhibited *J'* values of 0.23, 0.99, and 0.81 for minimum, maximum, and average, respectively. In the 600-1100 m depth zone, the value was 0.63, 0.93, and 0.81, respectively. The similar average values suggest a comparable balance of community structure between the two depths, despite differences in species composition. The species diversity index (*H'*) varied from 0.25 to 2.92, with an average of 1.83. In the depth zone of 200-600 m, *H'* varied from 0.25 to 2.62, with an average of 1.69. In the 600-1100 m depth zone, *H'* ranged from 0.64 to 2.92, with an average of 2.01. These findings confirm that diversity tends to increase with depth in the BoB region. The index of dominance (λ) values ranged from 0.06 to 0.89, with an average of 0.25. In the depth zone 200-600 m, values ranged from 0.09 to 0.88 (average 0.28). In the 600-1100 m depth zone, the values ranged from 0.06 to 0.58 (average 0.23). Compared to the 600-1100 m depth zones, higher dominance was observed in the 200-600 m zone. This inverse pattern of diversity and dominance further supports the conclusion that deeper habitats support more evenly distributed and diverse assemblages. Overall, the analysis reveals a clear depth-related trend in species diversity, with higher richness (*d*) and diversity (H') and lower dominance (λ) observed in the deeper depth zone compared to the shallower zone (Fig. 4c.2).

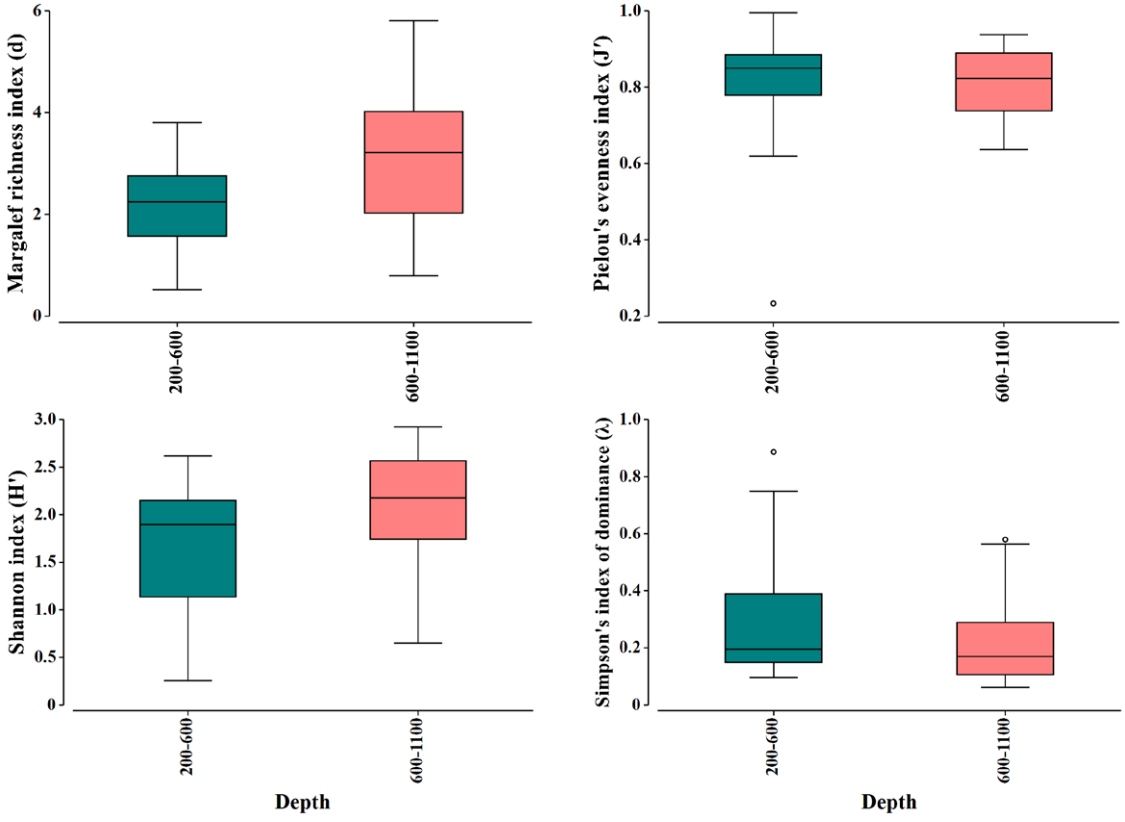



Fig. 4c.2: Diversity indices of deep-sea fish assemblages in the Bay of Bengal at two depth zones (200-600 m and 600-1100 m)

The K-dominance plot shows that in the 200-600 m zone, a single species accounted for 8% of the total abundance, while 11 species contributed to 55% of the cumulative abundance, reflecting a relatively even community structure (Fig. 4c.3). However, at 600-1100 m, a single species contributed 10% and 10 species accounted for 45% of the total abundance, indicating higher dominance by fewer species. At lower species ranks, the 600-1100 m zone exhibited greater cumulative dominance than the 200-600 m zone, demonstrating that deeper waters were more strongly influenced by a few dominant species. However, as species rank increased, the curves converged, showing similar cumulative dominance values at higher richness levels. Overall, these results suggest that the 200-600 m depth zone supports greater evenness and a more equitable distribution of species, while the 600-1100 m zone is characterised by stronger dominance and lower evenness.

Cluster analysis and nMDS ordination highlight variations and similarities in community structure across two depth ranges, providing insights into ecological dynamics and depth-related biodiversity patterns. Although some overlap occurred, samples tended to form clusters largely according to depth, indicating depth-related structuring of fish communities, which may be attributed to the depth tolerance of certain species. For instance, species such as *Alepocephalus bicolor, A. blanfordii, Bathyuroconger vicinus, Lamprogrammus brunswigi, L. exutus,* and *L. niger* are distributed across depths of 200-600 m and 600-1100 m (Fig. 4c.4). The nMDS ordination further supported this separation, with a relatively low stress value (0.08), indicating a reliable and robust representation of community patterns (Fig. 4c.5).

The SIMPER analysis revealed that the 200-600 m depth zone had a community similarity of 6.1%, driven by a diverse assemblage of 8 species (Table 4c). However, the 600-1100 m zone exhibited slightly higher within-group similarity (13.25%) but with fewer contributing species (7), primarily *Gavialiceps taeniola, Lamprogrammus brunswigi, Benthobatis moresbyi,* and *Bathyuroconger vicinus.* Between the two depth zones, an average dissimilarity of 83.72% was recorded, with 30 species. Key taxa responsible for the dissimilarity included species from both zones, such as *Lamprogrammus brunswigi, Gavialiceps taeniola, Bathyuroconger vicinus,* and *Neoharriotta pinnata*.

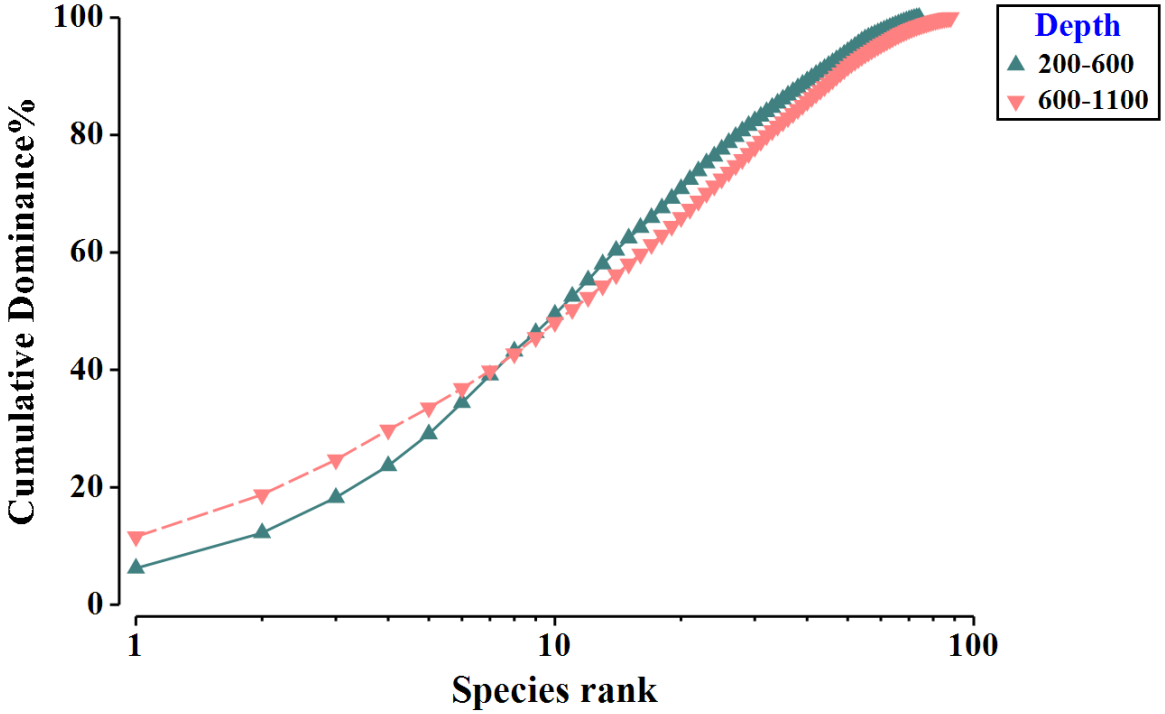



Fig. 4c.3: K-dominance plots for deep-sea fish assemblages at two depth zones (200-600 m and 600-1100 m) in the Bay of Bengal.

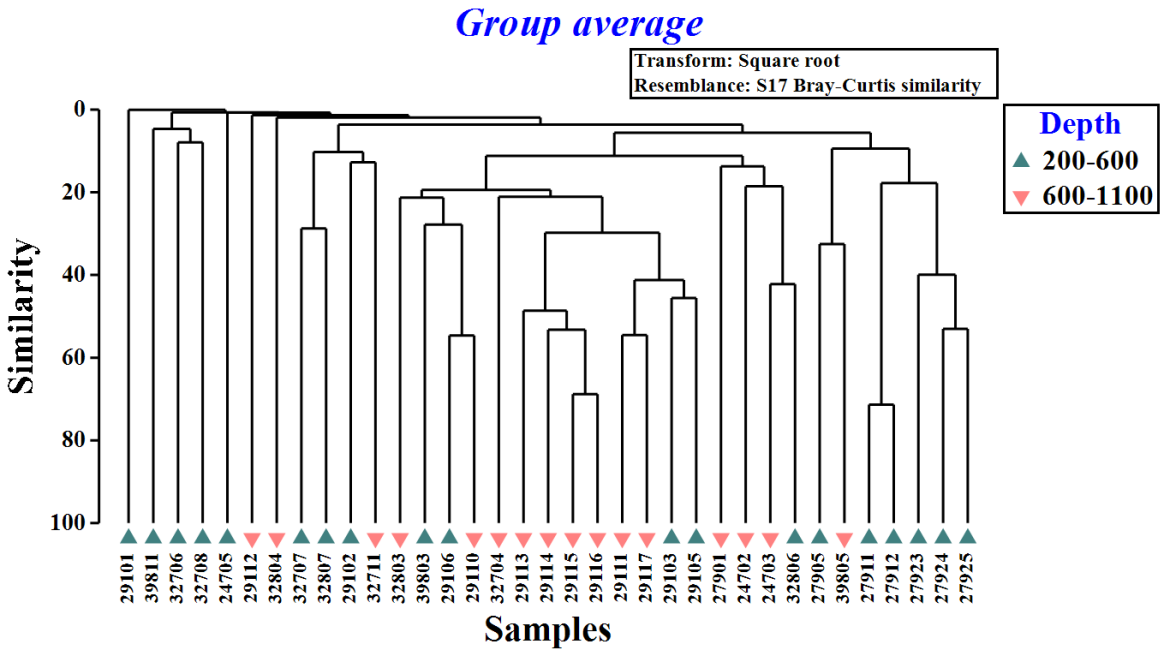



Fig. 4c.4: Cluster analysis showing depth-related grouping patterns of deep-sea fish assemblages from two depth zones (200-600 m and 600-1100 m) in the Bay of Bengal.

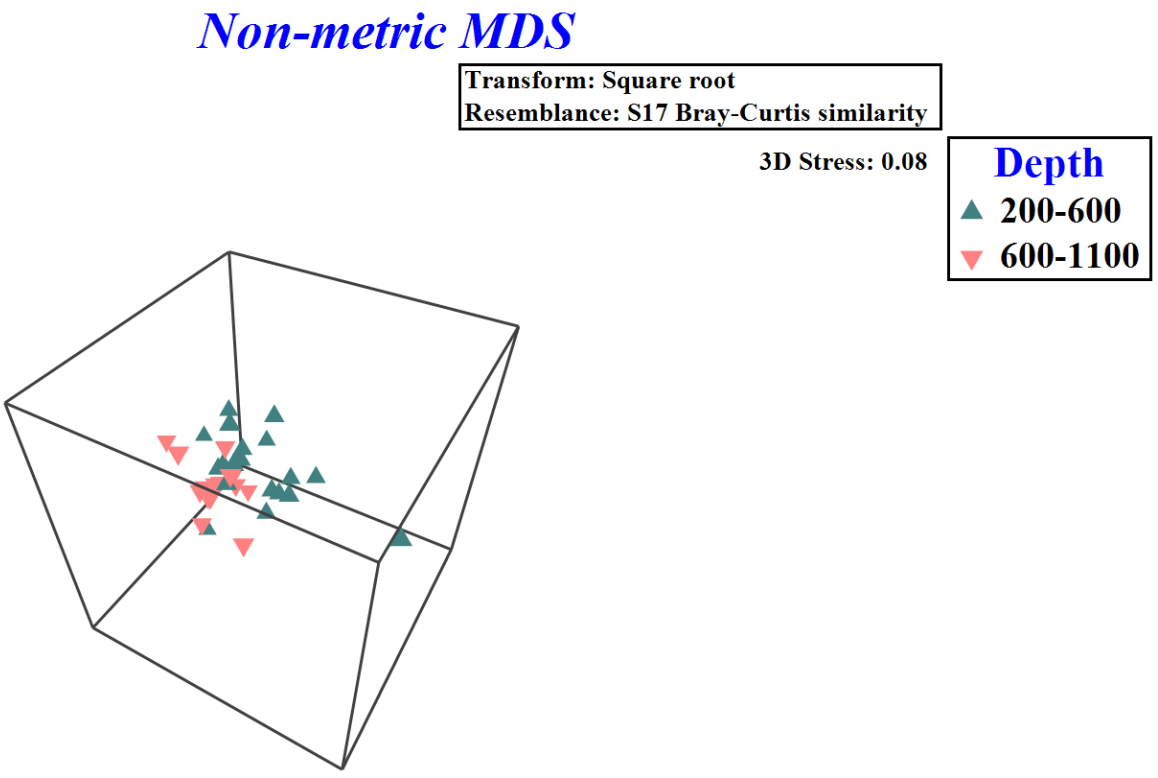



Fig. 4c.5: nMDS ordination based on Bray-Curtis similarity of deep-sea fish assemblages across two depth zones (200-600 m and 600-1100 m) in the Bay of Bengal (3D stress = 0.08)

Table 4c: SIMPER analysis showing species contributing to similarity or dissimilarity within and between depth zones of the Bay of Bengal.

| Depth Zone (m) | Average Similarity (%) | Cumulative contribution (%) | No. species contributing | Main taxa contribution |
|---|---|---|---|---|
| 200-600 | 6.10 | 71.10% | 8 | *Gavialiceps taeniola* (17.88%), *Congresox* sp. (13.67%), *Dicrolene multifilis* (12.65%), *Neoharriotta pinnata* (7.64%), *Bythaelurus lutarius* (6.06%) |
| 600-1100 | 13.25 | 73.13% | 7 | *Gavialiceps taeniola* (18.05%), *Lamprogrammus brunswigi* (17.61%), *Benthobatis* moresbyi (11.52%), *Bathyuroconger vicinus* (11.26%), *Coryphaenoides* sp. (5.75%) |
| **Depth zone (m)** | **Average dissimilarity (%)** | **Cumulative contribution (%)** | **No. species contributing** | **Main taxa contribution** |
| 200-600 & 600-1100 | 83.72 | 70.35% | 30 | *Lamprogrammus brunswigi* (8.27%), *Gavialiceps taeniola* (7.27%), *Bathyuroconger vicinus* (3.77%), *Neoharriotta pinnata* (3.57%), *Dicrolene multifilis* (3.55%) |

# Annexure- 5a

Table 5a: Annotated checklist of myctophid species from Western Indian Ocean (Meera, 2024). Species recorded in the present study are represented in bold letters, new records are represented as * with their scientific name, and cross-referred items in green (present) and red (absent) circle.

| SL NO | Species Name | WIO | AS | BOB | AN |
|---|---|---|---|---|---|
| 1 | *Benthosema fibulatum* (Gilbert & Cramer, 1897) | 🟢 | 🟢 | 🟢 | 🟢 |
| 2 | *Benthosema pterotum* (Alcock, 1890) | 🟢 | 🟢 | 🔴 | 🟢 |
| 3 | *Benthosema suborbitale* (Gilbert, 1913) | 🟢 | 🟢 | 🟢 | 🔴 |
| 4 | *Bolinichthys nikolkai* Becker, 1978* | 🟢 | 🔴 | 🔴 | 🔴 |
| 5 | *Bolinichthys indicus* (Nafpaktitis & Nafpaktitis, 1969) | 🟢 | 🟢 | 🟢 | 🔴 |
| 6 | *Bolinichthys longipes* (Brauer, 1906) | 🟢 | 🟢 | 🔴 | 🟢 |
| 7 | *Bolinichthys photothorax* (Parr, 1928) | 🟢 | 🟢 | 🟢 | 🔴 |
| 8 | *Bolinichthys pyrsobolus* (Alcock, 1890) | 🟢 | 🟢 | 🔴 | 🟢 |
| 9 | *Bolinichthys supralateralis* (Parr, 1928) | 🟢 | 🟢 | 🔴 | 🔴 |
| 10 | *Centrobranchus andreae* (Lütken, 1892) | 🟢 | 🔴 | 🔴 | 🔴 |
| 11 | *Centrobranchus nigroocellatus* (Günther, 1873) | 🟢 | 🔴 | 🔴 | 🔴 |
| 12 | *Ceratoscopelus warmingii* (Lütken, 1892) | 🟢 | 🟢 | 🔴 | 🟢 |
| 13 | *Ctenoscopelus phengodes* (Lütken, 1892) | 🟢 | 🔴 | 🔴 | 🔴 |
| 14 | *Dasyscopelus asper* Richardson, 1845 | 🟢 | 🟢 | 🔴 | 🔴 |
| 15 | *Dasyscopelus brachygnathos* (Bleeker, 1856) | 🟢 | 🟢 | 🔴 | 🟢 |
| 16 | *Dasyscopelus lunatus* Becker & Borodulina, 1978 | 🟢 | 🟢 | 🔴 | 🔴 |
| 17 | *Dasyscopelus lychnobius* Bolin, 1946 | 🟢 | 🔴 | 🔴 | 🔴 |
| 18 | *Dasyscopelus obtusirostris* Tåning, 1928 | 🟢 | 🟢 | 🔴 | 🔴 |
| 19 | *Dasyscopelus ovcharovi* Tsarin, 1993 | 🟢 | 🔴 | 🔴 | 🔴 |
| 20 | *Dasyscopelus selenops* Tåning, 1928 | 🟢 | 🟢 | 🟢 | 🔴 |
| 21 | *Dasyscopelus spinosus* (Steindachner, 1867) | 🟢 | 🟢 | 🟢 | 🟢 |
| 22 | *Diaphus aliciae* Fowler, 1934 | 🟢 | 🟢 | 🔴 | 🟢 |
| 23 | *Diaphus anderseni* Tåning, 1932 | 🟢 | 🔴 | 🔴 | 🔴 |
| 24 | *Diaphus antonbruuni* Nafpaktitis, 1978 | 🟢 | 🔴 | 🔴 | 🔴 |

| SL NO | Species Name | WIO | AS | BOB | AN |
|---|---|---|---|---|---|
| 25 | *Diaphus arabicus* Nafpaktitis, 1978 | ● | ● | ● | ● |
| 26 | *Diaphus basileusi* Becker & Prut'ko, 1984 | ● | ● | ● | ● |
| 27 | *Diaphus bertelseni* Nafpaktitis, 1966 | ● | ● | ● | ● |
| 28 | *Diaphus brachycephalus* Tåning, 1928 | ● | ● | ● | ● |
| 29 | *Diaphus coeruleus* (Klunzinger, 1871) | ● | ● | ● | ● |
| 30 | *Diaphus danae* Tåning, 1932 | ● | ● | ● | ● |
| 31 | *Diaphus dilidematus* Tåning, 1932 | ● | ● | ● | ● |
| 32 | *Diaphus diademophilus* Nafpaktitis, 1978 | ● | ● | ● | ● |
| 33 | *Diaphus drachmanni* Tåning, 1932 | ● | ● | ● | ● |
| 34 | *Diaphus dumerilii* (Bleeker, 1856) | ● | ● | ● | ● |
| 35 | *Diaphus effulgens* (Goode & Bean, 1896) | ● | ● | ● | ● |
| 36 | *Diaphus fragilis* Tåning, 1928 | ● | ● | ● | ● |
| 37 | *Diaphus fulgens* (Brauer, 1904) | ● | ● | ● | ● |
| 38 | *Diaphus garmani* Gilbert, 1906 | ● | ● | ● | ● |
| 39 | *Diaphus holti* Tåning, 1918 | ● | ● | ● | ● |
| 40 | *Diaphus hudsoni* Zurbrigg & Scott, 1976 | ● | ● | ● | ● |
| 41 | *Diaphus impostor* Nafpaktitis, Robertson & Paxton, 1995 | ● | ● | ● | ● |
| 42 | *Diaphus jenseni* Tåning, 1932 | ● | ● | ● | ● |
| 43 | *Diaphus knappi* Nafpaktitis, 1978 | ● | ● | ● | ● |
| 44 | *Diaphus lobatus* Nafpaktitis, 1978 | ● | ● | ● | ● |
| 45 | *Diaphus lucidus* (Goode & Bean, 1896) | ● | ● | ● | ● |
| 46 | *Diaphus luetkeni* (Brauer, 1904) | ● | ● | ● | ● |
| 47 | *Diaphus malayanus* Weber, 1913 | ● | ● | ● | ● |
| 48 | *Diaphus mascarensis* Becker, 1990 | ● | ● | ● | ● |
| 49 | *Diaphus meadi* Nafpaktitis, 1978 | ● | ● | ● | ● |
| 50 | *Diaphus megalops* Nafpaktitis, 1978 | ● | ● | ● | ● |
| 51 | *Diaphus metopoclampus* (Cocco, 1829) | ● | ● | ● | ● |
| 52 | *Diaphus mollis* Tåning, 1928 | ● | ● | ● | ● |
| 53 | *Diaphus nielseni* Nafpaktitis, 1978 | ● | ● | ● | ● |
| 54 | *Diaphus ostenfeldi* Tåning, 1932 | ● | ● | ● | ● |
| 55 | *Diaphus pallidus* Gjøsaeter, 1989 | ● | ● | ● | ● |
| 56 | *Diaphus parri* Tåning, 1932 | ● | ● | ● | ● |
| 57 | *Diaphus perspicillatus* (Ogilby, 1898) | ● | ● | ● | ● |
| 58 | *Diaphus phillipsi* Fowler, 1934 | ● | ● | ● | ● |
| 59 | *Diaphus problematicus* Parr, 1928 | ● | ● | ● | ● |

| SL NO | Species Name | WIO | AS | BOB | AN |
|---|---|---|---|---|---|
| 60 | *Diaphus rafinesquii* (Cocco, 1838) | ● | ● | ● | ● |
| 61 | *Diaphus regani* Tåning, 1932 | ● | ● | ● | ● |
| 62 | *Diaphus richardsoni* Tåning, 1932 | ● | ● | ● | ● |
| 63 | *Diaphus signatus* Gilbert, 1908 | ● | ● | ● | ● |
| 64 | *Diaphus similis* Wisner, 1974 * | ● | ● | ● | ● |
| 65 | *Diaphus splendidus* (Brauer, 1904) | ● | ● | ● | ● |
| 66 | *Diaphus suborbitalis* Weber, 1913 | ● | ● | ● | ● |
| 67 | *Diaphus subtilis* Nafpaktitis, 1968 | ● | ● | ● | ● |
| 68 | *Diaphus taaningi* Norman, 1930 | ● | ● | ● | ● |
| 69 | *Diaphus termophilus* Tåning, 1928 | ● | ● | ● | ● |
| 70 | *Diaphus theta* Eigenmann & Eigenmann, 1890* | ● | ● | ● | ● |
| 71 | *Diaphus thiollierei* Fowler, 1934 | ● | ● | ● | ● |
| 72 | *Diaphus watasei* Jordan & Starks, 1904 | ● | ● | ● | ● |
| 73 | *Diogenichthys atlanticus* (Tåning, 1928) | ● | ● | ● | ● |
| 74 | *Diogenichthys panurgus* Bolin, 1946 | ● | ● | ● | ● |
| 75 | *Electrona antarctica* (Günther, 1878) | ● | ● | ● | ● |
| 76 | *Electrona carlsbergi* (Tåning, 1932) | ● | ● | ● | ● |
| 77 | *Electrona paucirastra* Bolin, 1962 | ● | ● | ● | ● |
| 78 | *Electrona risso* (Cocco, 1829) | ● | ● | ● | ● |
| 79 | *Electrona subaspera* (Günther, 1864) | ● | ● | ● | ● |
| 80 | *Gonichthys barnesi* Whitley, 1943 | ● | ● | ● | ● |
| 81 | *Gymnoscopelus bolini* Andriashev, 1962 | ● | ● | ● | ● |
| 82 | *Gymnoscopelus braueri* (Lönnberg, 1905) | ● | ● | ● | ● |
| 83 | *Gymnoscopelus fraseri* (Fraser-Brunner, 1931) | ● | ● | ● | ● |
| 84 | *Gymnoscopelus microlampas* Hulley, 1981 | ● | ● | ● | ● |
| 85 | *Gymnoscopelus nicholsi* (Gilbert, 1911) | ● | ● | ● | ● |
| 86 | *Gymnoscopelus opisthopterus* Fraser-Brunner, 1949 | ● | ● | ● | ● |
| 87 | *Gymnoscopelus piabilis* (Whitley, 1931) | ● | ● | ● | ● |
| 88 | *Hintonia candens* Fraser-Brunner, 1949 | ● | ● | ● | ● |
| 89 | *Hygophum hanseni* (Tåning, 1932) | ● | ● | ● | ● |
| 90 | *Hygophum hygomii* (Lütken, 1892) | ● | ● | ● | ● |
| 91 | *Hygophum proximum* Becker, 1965 | ● | ● | ● | ● |
| 92 | *Hygophum reinhardtii* (Lütken, 1892) | ● | ● | ● | ● |
| 93 | *Idiolychnus urolampus* (Gilbert & Cramer, 1897) | ● | ● | ● | ● |
| 94 | *Krefftichthys anderssoni* (Lönnberg, 1905) | ● | ● | ● | ● |

| SL NO | Species Name | WIO | AS | BOB | AN |
|---|---|---|---|---|---|
| 95 | *Lampadena anomala* Parr, 1928 | ● | ● | ● | ● |
| 96 | *Lampadena chavesi* Collett, 1905 | ● | ● | ● | ● |
| 97 | *Lampadena dea* Fraser-Brunner, 1949 | ● | ● | ● | ● |
| 98 | *Lampadena luminosa* (Garman, 1899) | ● | ● | ● | ● |
| 99 | *Lampadena notialis* Nafpaktitis & Paxton, 1968 | ● | ● | ● | ● |
| 100 | *Lampadena pontifex* Krefft, 1970 | ● | ● | ● | ● |
| 101 | *Lampadena speculigera* Goode & Bean, 1896 | ● | ● | ● | ● |
| 102 | *Lampadena urophaos* Paxton, 1963* | ● | ● | ● | ● |
| 103 | *Lampanyctodes hectoris* (Günther, 1876) | ● | ● | ● | ● |
| 104 | *Lampanyctus achirus* Andriashev, 1962 | ● | ● | ● | ● |
| 105 | *Lampanyctus alatus* Goode & Bean, 1896 | ● | ● | ● | ● |
| 106 | *Lampanyctus atrum* Tåning, 1928 | ● | ● | ● | ● |
| 107 | *Lampanyctus australis* Tåning, 1932 | ● | ● | ● | ● |
| 108 | *Lampanyctus crocodilus* (Risso, 1810) * | ● | ● | ● | ● |
| 109 | *Lampanyctus cuprarius* Tåning, 1928 | ● | ● | ● | ● |
| 110 | *Lampanyctus festivus* Tåning, 1928 | ● | ● | ● | ● |
| 111 | *Lampanyctus indicum* (Zahuranec, 2000) | ● | ● | ● | ● |
| 112 | *Lampanyctus intricarius* Tåning, 1928 | ● | ● | ● | ● |
| 113 | *Lampanyctus lepidolychnus* Becker, 1967 | ● | ● | ● | ● |
| 114 | *Lampanyctus lineatum* Tåning, 1928 | ● | ● | ● | ● |
| 115 | *Lampanyctus lineatus* Tåning, 1928 | ● | ● | ● | ● |
| 116 | *Lampanyctus macdonaldi* (Goode & Bean, 1896) * | ● | ● | ● | ● |
| 117 | *Lampanyctus macropterus* (Brauer, 1904) | ● | ● | ● | ● |
| 118 | *Lampanyctus niger* (Günther, 1887) | ● | ● | ● | ● |
| 119 | *Lampanyctus nobilis* Tåning, 1928 | ● | ● | ● | ● |
| 120 | *Lampanyctus photonotus* Parr, 1928 | ● | ● | ● | ● |
| 121 | *Lampanyctus pusillus* (Johnson, 1890) | ● | ● | ● | ● |
| 122 | *Lampanyctus sp. A* | ● | ● | ● | ● |
| 123 | *Lampanyctus sp. B* | ● | ● | ● | ● |
| 124 | *Lampanyctus steinbecki* Bolin, 1939 | ● | ● | ● | ● |
| 125 | *Lampanyctus tenuiformis* (Brauer, 1906) | ● | ● | ● | ● |
| 126 | *Lampanyctus turneri* (Fowler, 1934) | ● | ● | ● | ● |
| 127 | *Lampanyctus wisneri* Zahuranec, 2000 | ● | ● | ● | ● |
| 128 | *Lampichthys procerus* (Brauer, 1904) | ● | ● | ● | ● |
| 129 | *Lobianchia dofleini* (Zugmayer, 1911) | ● | ● | ● | ● |

| SL NO | Species Name | WIO | AS | BOB | AN |
|---|---|---|---|---|---|
| 130 | *Lobianchia gemellarii* (Cocco, 1838) | ● | ● | ● | ● |
| 131 | *Loweina interrupta* (Tåning, 1928) | ● | ● | ● | ● |
| 132 | *Loweina rara* (Lütken, 1892) | ● | ● | ● | ● |
| 133 | *Metelectrona herwigi* Hulley, 1981 | ● | ● | ● | ● |
| 134 | *Metelectrona ventralis* (Becker, 1963) | ● | ● | ● | ● |
| 135 | *Myctophum affine* (Lütken, 1892) | ● | ● | ● | ● |
| 136 | *Myctophum aurolaternatum* Garman, 1899 | ● | ● | ● | ● |
| 137 | *Myctophum fissunovi* Becker & Borodulina, 1971 | ● | ● | ● | ● |
| 138 | *Myctophum nitidulum* Garman, 1899 | ● | ● | ● | ● |
| 139 | *Myctophum punctatum* Rafinesque, 1810 | ● | ● | ● | ● |
| 140 | *Notolychnus valdiviae* (Brauer, 1904) | ● | ● | ● | ● |
| 141 | *Notoscopelus caudispinosus* (Johnson, 1863) | ● | ● | ● | ● |
| 142 | *Notoscopelus resplendens* (Richardson, 1845) | ● | ● | ● | ● |
| 143 | *Protomyctophum andriashevi* Becker, 1963 | ● | ● | ● | ● |
| 144 | *Protomyctophum bolini* (Fraser-Brunner, 1949) | ● | ● | ● | ● |
| 145 | *Protomyctophum choriodon* Hulley, 1981 | ● | ● | ● | ● |
| 146 | *Protomyctophum luciferum* Hulley, 1981 | ● | ● | ● | ● |
| 147 | *Protomyctophum normani* (Tåning, 1932) | ● | ● | ● | ● |
| 148 | *Protomyctophum parallelum* (Lönnberg, 1905) | ● | ● | ● | ● |
| 149 | *Protomyctophum subparallelum* (Tåning, 1932) | ● | ● | ● | ● |
| 150 | *Protomyctophum tenisoni* (Norman, 1930) | ● | ● | ● | ● |
| 151 | *Scopelopsis multipunctatus* Brauer, 1906 | ● | ● | ● | ● |
| 152 | *Symbolophorus barnardi* (Tåning, 1932) | ● | ● | ● | ● |
| 153 | *Symbolophorus boops* (Richardson, 1845) | ● | ● | ● | ● |
| 154 | *Symbolophorus evermanni* (Gilbert, 1905) | ● | ● | ● | ● |
| 155 | *Symbolophorus rufinus* (Tåning, 1928) | ● | ● | ● | ● |
| 156 | *Taaningichthys bathyphilus* (Tåning, 1928) | ● | ● | ● | ● |
| 157 | *Taaningichthys minimus* (Tåning, 1928) | ● | ● | ● | ● |
| 158 | *Taaningichthys paurolychnus* Davy, 1972 | ● | ● | ● | ● |
| 159 | *Triphoturus nigrescens* (Brauer, 1904) | ● | ● | ● | ● |

● Present ● Absent

# Annexure- 5b

Table 5b: Annotated checklist of deep-sea demersal fishery resources recorded during exploratory surveys from the continental margin of the east and west coast of India and the Andaman & Nicobar Islands in the Indian EEZ. Green dots represent the presence of the species in the region and red dots represents absence. New records are represented as ** and new species are marked as **.

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| Order | Anguilliformes | | | |
| Family | Colocongridae (Short tail eels) | | | |
| | *Coloconger raniceps* (Alcock, 1889) | 🟢 | 🟢 | 🟢 |
| Family | Congridae (conger eels) | | | |
| | *Ariosoma* sp. | 🟢 | 🔴 | 🔴 |
| | *Bathycongrus guttulatus* (Günther, 1887) | 🟢 | 🔴 | 🔴 |
| | *Bathycongrus* sp. | 🟢 | 🔴 | 🔴 |
| | *Bathycongrus macrocercus* (Alcock, 1894) | 🔴 | 🔴 | 🟢 |
| | *Bathycongrus nasicus* (Alcock, 1894)* | 🔴 | 🔴 | 🟢 |
| | *Bathycongrus trimaculatus* (Karmovskaya & Smith, 2008)* | 🔴 | 🔴 | 🟢 |
| | *Bathymyrus echinorhynchus* (Alcock, 1889) | 🔴 | 🔴 | 🟢 |
| | *Bathymyrus simus* (Smith, 1965) | 🔴 | 🔴 | 🟢 |
| | *Bathymyrus smithi* (Castle, 1968) | 🔴 | 🟢 | 🔴 |
| | *Bathyuroconger vicinus* (Vaillant, 1888)* | 🟢 | 🟢 | 🟢 |
| | *Conger* sp. | 🔴 | 🟢 | 🔴 |
| | *Congrhynchus talabonoides* (Fowler, 1934)* | 🔴 | 🔴 | 🟢 |
| | *Gnathophis* sp. | 🔴 | 🔴 | 🟢 |
| | *Macrocephenchelys* sp. | 🟢 | 🔴 | 🟢 |
| | *Promyllantor purpureus* (Alcock, 1890) | 🟢 | 🔴 | 🔴 |
| | *Rhynchoconger squaliceps* (Alcock, 1894) | 🔴 | 🔴 | 🟢 |
| | *Uroconger lepturus* (Richardson, 1845) | 🟢 | 🔴 | 🔴 |
| | *Xenomystax trucidans* (Alcock, 1894)* | 🟢 | 🔴 | 🟢 |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| Family | Derichthyidae | | | |
| | *Nessorhamphus danae* (Schmidt, 1931)* | 🟢 | 🔴 | 🔴 |
| Family | Muraenesocidae (pike congers) | | | |
| | *Congresox* sp. | 🔴 | 🟢 | 🔴 |
| | *Gavialiceps* sp. | 🔴 | 🔴 | 🟢 |
| | *Gavialiceps taeniola* (Alcock, 1889) | 🟢 | 🟢 | 🟢 |
| | *Muraenesox bagio* (Hamilton, 1822) | 🟢 | 🟢 | 🔴 |
| | *Sauromuraenesox vorax* (Alcock, 1889)* | 🟢 | 🔴 | 🟢 |
| Family | Muraenidae (moray eels) | | | |
| | *Gymnothorax reticularis* (Bloch, 1795)* | 🟢 | 🔴 | 🟢 |
| Family | Nemichthyidae (snipe eels) | | | |
| | *Avocettina infans* (Günther, 1878) | 🟢 | 🟢 | 🟢 |
| | *Nemichthys scolopaceus* (Richardson, 1848)* | 🟢 | 🟢 | 🟢 |
| Family | Nettastomatidae (duckbill eels) | | | |
| | *Facciolella* sp. | 🔴 | 🔴 | 🟢 |
| | *Nettastoma solitarium* (Castle & Smith, 1981)* | 🔴 | 🟢 | 🟢 |
| | *Nettenchelys taylori* (Alcock, 1898) | 🔴 | 🔴 | 🟢 |
| Family | Ophichthidae (snake eels or worm eels) | | | |
| | *Ophichthus maccoskeri* (Sumod, 2019) | 🔴 | 🔴 | 🟢 |
| | *Ophichthus urolophus* (Temminck & Schlegel, 1846) | 🔴 | 🔴 | 🟢 |
| | *Pisodonophis cancrivorus* (Richardson, 1848) | 🟢 | 🔴 | 🔴 |
| Family | Serrivomeridae (sawtooth eels) | | | |
| | *Serrivomer* sp. | 🔴 | 🔴 | 🟢 |
| | *Serrivomer beanii* (Gill & Ryder, 1883) | 🔴 | 🔴 | 🟢 |
| | *Serrivomer sector* (Garman, 1899) | 🟢 | 🔴 | 🔴 |
| Family | Synaphobranchidae (cutthroat eels) | | | |
| | *Dysomma bucephalus* Alcock, 1889 | 🟢 | 🔴 | 🔴 |
| | *Dysomma muciparus* (Alcock, 1891) | 🟢 | 🔴 | 🔴 |
| | *Synaphobranchus* sp. | 🟢 | 🟢 | 🟢 |
| | *Synaphobranchus oregoni* (Castle, 1960)* | 🟢 | 🔴 | 🟢 |
| | *Synaphobranchus affinis* (Günther, 1877) | 🟢 | 🔴 | 🔴 |
| | *Synaphobranchus brevidorsalis* (Günther, 1887) | 🟢 | 🔴 | 🔴 |
| Order | Ateleopodiformes | | | |
| Family | Ateleopodidae (Jellynose fishes or tadpole fishes) | | | |
| | *Ateleopus indicus* (Alcock, 1891) | 🟢 | 🔴 | 🟢 |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Ijimaia loppei* (Roule, 1922) | 🔴 | 🔴 | 🟢 |
| Order | Aulopiformes | | | |
| Family | Chlorophthalmidae (greeneyes) | | | |
| | *Chlorophthalmus acutifrons* (Hiyama, 1940) | 🟢 | 🔴 | 🟢 |
| | *Chlorophthalmus corniger* (Alcock, 1894) | 🟢 | 🔴 | 🟢 |
| | *Chlorophthalmus nigromarginatus* (Kamohara, 1953) | 🔴 | 🔴 | 🟢 |
| | *Chlorophthalmus bicornis* | 🔴 | 🟢 | 🔴 |
| | *Parasudis truculenta* (Goode & Bean, 1896) | 🔴 | 🟢 | 🔴 |
| Family | Evermannellidae | | | |
| | *Evermannella indica* (Brauer, 1906) | 🔴 | 🟢 | 🔴 |
| Family | Ipnopidae (tripodfishes) | | | |
| | *Bathypterois atricolor* (Alcock, 1896) | 🟢 | 🟢 | 🟢 |
| | *Bathypterois guentheri* (Alcock, 1889) | 🟢 | 🟢 | 🟢 |
| Family | Synodontidae (lizardfishes) | | | |
| | *Harpadon* sp.* | 🔴 | 🟢 | 🟢 |
| | *Harpadon squamosus* (Alcock, 1891) | 🔴 | 🟢 | 🔴 |
| | *Saurida tumbil* (Bloch, 1795) | 🔴 | 🟢 | 🔴 |
| Order | Beryciformes | | | |
| Family | Berycidae (squirrelfishes) | | | |
| | *Beryx decadactylus* (Cuvier, 1829)* | 🔴 | 🔴 | 🟢 |
| | *Beryx splendens* (Lowe, 1834)* | 🟢 | 🔴 | 🟢 |
| | *Centroberyx rubricaudus* (Liu & Shen, 1985) | 🔴 | 🔴 | 🟢 |
| Order | Trachichthyiformes | | | |
| Family | Anoplogastridae | | | |
| | *Anoplogaster cornuta* (Valenciennes, 1833)* | 🟢 | 🟢 | 🟢 |
| Family | Diretmidae (spinyfins) | | | |
| | *Diretmoides veriginae* (Kotlyar, 1987)* | 🔴 | 🔴 | 🟢 |
| Family | Trachichthyidae (slime heads) | | | |
| | *Gephyroberyx darwinii* (Johnson, 1866)* | 🟢 | 🔴 | 🟢 |
| | *Hoplostethus melanopus* (Weber, 1913)* | 🟢 | 🟢 | 🟢 |
| | *Hoplostethus rubellopterus* (Kotlyar, 1980) | 🟢 | 🔴 | 🟢 |
| Order | Carcharhiniformes | | | |
| Family | Carcharhinidae (grey sharks) | | | |
| | *Carcharhinus albimarginatus* (Rüppell, 1837) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus altimus* (Springer, 1950) | 🔴 | 🔴 | 🟢 |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Carcharhinus amboinensis* (Müller & Henle, 1839) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus dussumieri* (Valenciennes, 1839) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus falciformis* (Müller & Henle, 1839) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus hemiodon* (Müller & Henle, 1839) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus leucas* (Müller & Henle, 1839) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus limbatus* (Valenciennes, *1839)* | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus longimanus* (Poey, 1861) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus plumbeus* (Nardo, 1827) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus macloti* (Müller & Henle, 1839) | 🔴 | 🔴 | 🟢 |
| | *Carcharhinus sorrah* (Müller & Henle, 1839) | 🔴 | 🔴 | 🟢 |
| | *Prionace glauca* (Linnaeus, 1758) | 🔴 | 🔴 | 🟢 |
| | *Rhizoprionodon acutus* (Rüppell, 1837) | 🔴 | 🔴 | 🟢 |
| | *Galeocerdo cuvier* (Péron & Lesueur, 1822) | 🔴 | 🔴 | 🟢 |
| Family | Pentanchidae (deep water catshark) | | | |
| | *Apristurus* sp. | 🔴 | 🟢 | 🟢 |
| | *Apristurus breviventralis* (Kawauchi, Weigmann & Nakaya, 2014) | 🔴 | 🟢 | 🔴 |
| | *Apristurus investigatoris* (Misra, 1962) | 🟢 | 🟢 | 🟢 |
| | *Apristurus indicus* (Brauer, 1906) | 🟢 | 🟢 | 🔴 |
| | *Apristurus microps* (Gilchrist, 1922) | 🟢 | 🔴 | 🟢 |
| | *Apristurus saldanha* (Barnard, 1925) | 🟢 | 🔴 | 🔴 |
| | *Bythaelurus hispidus* (Alcock, 1891) | 🟢 | 🔴 | 🟢 |
| | *Bythaelurus lutarius* (Springer & D'Aubrey, 1972) | 🟢 | 🟢 | 🔴 |
| | *Halaelurus quagga* (Alcock, 1899) | 🔴 | 🟢 | 🔴 |
| Family | Proscylliidae (finback catsharks) | | | |
| | *Eridacnis radcliffei* Smith, 1913 | 🟢 | 🟢 | 🟢 |
| | *Eridacnis sinuans* (Smith, 1957) | 🟢 | 🔴 | 🔴 |
| | *Proscyllium magnificum* (Last & Vongpanich, 2004) | 🔴 | 🔴 | 🟢 |
| Family | Scyliorhinidae (catsharks) | | | |
| | *Cephaloscyllium silasi* (Talwar, 1974) | 🟢 | 🔴 | 🟢 |
| Family | Triakidae (hound sharks) | | | |
| | *Iago* sp. | 🔴 | 🔴 | 🟢 |
| | *Iago omanensis* (Norman, 1939)* | 🔴 | 🔴 | 🟢 |
| | *Mustelus mosis* (Hemprich & Ehrenberg, 1899) | 🔴 | 🔴 | 🟢 |
| Order | Chimaeriformes | | | |
| Family | Chimaeridae (shortnose chimeras or ratfishes) | | | |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Hydrolagus* cf. *africanus* (Gilchrist, 1922)* | ● | ● | ● |
| Family | Rhinochimaeridae (longnose chimeras) | | | |
| | *Neoharriotta pinnata* (Schnakenbeck, 1931) | ● | ● | ● |
| | *Rhinochimaera* sp. | ● | ● | ● |
| | *Rhinochimaera africana* (Compagno, Stehmann & Ebert, 1990) | ● | ● | ● |
| Order | Gadiformes | | | |
| Family | Bregmacerotidae (unicorn cod) | | | |
| | *Bregmaceros* sp. | ● | ● | ● |
| | *Bregmaceros mcclellandi* (Thompson, 1840) | ● | ● | ● |
| Family | Macrouridae (grenadiers) | | | |
| | *Bathygadus furvescens* (Alcock, 1894) | ● | ● | ● |
| | *Bathygadus melanobranchus* (Vaillant, 1888) | ● | ● | ● |
| | *Coelorinchus braueri* (Barnard, 1925) | ● | ● | ● |
| | *Coelorinchus flabellispinnis* (Alcock, 1894) | ● | ● | ● |
| | *Coryphaenoides* sp. | ● | ● | ● |
| | *Coryphaenoides hextii* (Alcock, 1890)* | ● | ● | ● |
| | *Coryphaenoides macrolophus* (Alcock, 1889) | ● | ● | ● |
| | *Coryphaenoides woodmasoni* (Alcock, 1890)* | ● | ● | ● |
| | *Gadomus capensis* (Gilchrist & von Bonde, 1924) | ● | ● | ● |
| | *Malacocephalus laevis* (Lowe, 1843) | ● | ● | ● |
| | *Nezumia* sp. | ● | ● | ● |
| | *Nezumia brevirostris* (Alcock, 1889) | ● | ● | ● |
| | *Nezumia investigatoris* (Alcock, 1889) | ● | ● | ● |
| | *Nezumia propinqua* (Gilbert & Cramer, 1897) | ● | ● | ● |
| | *Nezumia semiquincunciata* (Alcock, 1889) | ● | ● | ● |
| | *Ventrifossa* sp. | ● | ● | ● |
| | *Ventrifossa petersonii* (Alcock, 1891) | ● | ● | ● |
| Family | Moridae (deepsea codfishes) | | | |
| | *Lepidion inosimae* (Günther, 1887)* | ● | ● | ● |
| | *Physiculus roseus* (Alcock, 1891) | ● | ● | ● |
| | *Physiculus capensis* (Gilchrist, 1922) | ● | ● | ● |
| | *Physiculus argyropastus* (Alcock, 1894) | ● | ● | ● |
| | *Physiculus natalensis* (Gilchrist, 1922) | ● | ● | ● |
| Order | Hexanchiformes | | | |
| Family | Hexanchidae (cow sharks) | | | |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Heptranchias perlo* (Bonnaterre, 1788) | ● | ● | ● |
| | *Hexanchus griseus* (Bonnaterre, 1788) | ● | ● | ● |
| Order | Lamniformes | | | |
| Family | Alopiidae (thresher sharks) | | | |
| | *Alopias superciliosus* (Lowe, 1841) | ● | ● | ● |
| | *Alopias vulpinus* (Bonnaterre, 1788) | ● | ● | ● |
| | *Alopias pelagicus* (Nakamura, 1935) | ● | ● | ● |
| | *Alopias vulpinus* (Bonnaterre, 1788) | ● | ● | ● |
| Family | Odontaspididae (sand tiger sharks) | | | |
| | *Carcharias taurus* (Rafinesque, 1810) | ● | ● | ● |
| Family | Pseudocarchariidae (crocodile Sharks) | | | |
| | *Pseudocarcharias kamoharai* (Matsubara, 1936) | ● | ● | ● |
| Order | Lampriformes | | | |
| Family | Trachipteridae (ribbonfishes) | | | |
| | *Desmodema polystictum* (Ogilby, 1898) | ● | ● | ● |
| Order | Lophiiformes | | | |
| Family | Chaunacidae (sea toads or coffin fishes) | | | |
| | *Chaunax apus* (Lloyd, 1909)* | ● | ● | ● |
| | *Chaunax multilepis* (Ho, Meleppura & Bineesh, 2016)** | ● | ● | ● |
| | *Chaunax penicillatus* (McCulloch, 1915)* | ● | ● | ● |
| Family | Ceratiidae | | | |
| | *Cryptopsaras couesii* (Gill, 1883)* | ● | ● | ● |
| | *Ceratias uranoscopus* (Murray, 1877)* | ● | ● | ● |
| Family | Diceratiidae | | | |
| | *Bufoceratias shaoi* (Pietsch, Ho & Chen, 2004)* | ● | ● | ● |
| | *Diceratias bispinosus* (Günther, 1887)* | ● | ● | ● |
| | *Bufoceratias thele* (Uwate, 1979)* | ● | ● | ● |
| Family | Ogcocephalidae (batfishes) | | | |
| | *Coelophrys micropa* (Alcock, 1891) | ● | ● | ● |
| | *Halicmetus ruber* (Alcock, 1891) | ● | ● | ● |
| | *Halieutaea coccinea* (Alcock, 1889) | ● | ● | ● |
| | *Halieutaea indica* (Annandale & Jenkins, 1910)* | ● | ● | ● |
| | *Halieutaea stellata* (Vahl, 1797)* | ● | ● | ● |
| | *Halieutopsis* sp. | ● | ● | ● |
| | *Halieutopsis stellifera* (Smith & Radcliffe, 1912)* | ● | ● | ● |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Malthopsis gigas* (Ho & Shao, 2010) | 🔴 | 🔴 | 🟢 |
| | *Malthopsis lutea* (Alcock, 1891) | 🟢 | 🔴 | 🟢 |
| Family | Himantolophidae (football fishes) | | | |
| | *Himantolophus kalami* (Rajeeshkumar, Pietsch & Saravanane, 2022)** | 🔴 | 🔴 | 🟢 |
| Family | Lophiidae (monkfishes or goose fishes) | | | |
| | *Lophiodes gracilimanus* (Alcock, 1899)* | 🟢 | 🔴 | 🟢 |
| | *Lophiodes mutilus* (Alcock, 1894)* | 🟢 | 🟢 | 🟢 |
| | *Lophiodes triradiatus* (Lloyd, 1909)* | 🟢 | 🔴 | 🟢 |
| | *Lophiomus setigerus* (Vahl, 1797) | 🟢 | 🟢 | 🟢 |
| | *Lophiodes lugubris* (Alcock, 1894)* | 🟢 | 🔴 | 🟢 |
| Order | Myliobatiformes | | | |
| Family | Dasyatidae (whiptail stingray) | | | |
| | *Bathytoshia lata* (Garman, 1880) | 🔴 | 🟢 | 🟢 |
| | Himantura sp. | 🔴 | 🟢 | 🔴 |
| | *Pateobatis fai* (Jordan & Seale, 1906) | 🔴 | 🔴 | 🟢 |
| | *Pteroplatytrygon violacea* (Bonaparte, 1832) | 🟢 | 🔴 | 🟢 |
| Family | Hexatrygonidae (sixgill stingrays) | | | |
| | *Hexatrygon bickelli* (Heemstra & Smith, 1980) | 🟢 | 🟢 | 🟢 |
| Family | Plesiobatidae (deepwater stingray) | | | |
| | *Plesiobatis daviesi* (Wallace, 1967) | 🟢 | 🟢 | 🟢 |
| Order | Notacanthiformes | | | |
| Family | Notacanthidae (deep-sea spiny eels) | | | |
| | *Notacanthus* sp. | 🔴 | 🔴 | 🟢 |
| | *Notacanthus indicus* (Lloyd, 1909) | 🔴 | 🟢 | 🔴 |
| Order | Ophidiiformes | | | |
| Family | Ophidiidae (cusk-eels) | | | |
| | *Bassozetus robustus* (Smith & Radcliffe, 1913)* | 🟢 | 🟢 | 🟢 |
| | *Bassogigas* sp. (Goode & Bean, 1896) | 🔴 | 🟢 | 🔴 |
| | *Brotula* sp. | 🔴 | 🟢 | 🔴 |
| | *Dicrolene* sp. | 🔴 | 🟢 | 🔴 |
| | *Dicrolene introniger* (Goode & Bean, 1883) | 🟢 | 🔴 | 🔴 |
| | *Dicrolene multifilis* (Alcock, 1889) | 🟢 | 🟢 | 🟢 |
| | *Dicrolene nigricaudis* (Alcock, 1891) | 🟢 | 🔴 | 🟢 |
| | *Dicrolene tristis* (Smith & Radcliffe, 1913)* | 🟢 | 🔴 | 🟢 |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Dicrolene vaillanti* (Alcock, 1890) | ● | ● | ● |
| | *Glyptophidium argenteum* (Alcock, 1889) | ● | ● | ● |
| | *Glyptophidium lucidum* (Smith & Radcliffe, 1913)* | ● | ● | ● |
| | *Glyptophidium macropus* (Alcock, 1894) | ● | ● | ● |
| | *Glyptophidium oceanium* (Smith & Radcliffe, 1913) | ● | ● | ● |
| | *Holcomycteronus pterotus* (Alcock, 1890) | ● | ● | ● |
| | *Hypopleuron caninum* (Smith & Radcliffe, 1913) | ● | ● | ● |
| | *Lamprogrammus brunswigi* (Brauer, 1906)* | ● | ● | ● |
| | *Lamprogrammus exutus* (Nybelin & Poll, 1958) | ● | ● | ● |
| | *Lamprogrammus fragilis* (Alcock, 1892) | ● | ● | ● |
| | *Lamprogrammus niger* (Alcock, 1891) | ● | ● | ● |
| | *Luciobrotula bartschi* (Smith & Radcliffe, 1913) | ● | ● | ● |
| | *Mastigopterus imperator* (Smith & Radcliffe, 1913) | ● | ● | ● |
| | *Monomitopus* sp. | ● | ● | ● |
| | *Monomitopus conjugator* (Alcock, 1896)* | ● | ● | ● |
| | *Monomitopus microlepis* (Smith & Radcliffe, 1913) | ● | ● | ● |
| | *Monomitopus nigripinnis* (Alcock, 1889) | ● | ● | ● |
| | *Neobythites andamanensis* (Nielsen, 2002)* | ● | ● | ● |
| | *Neobythites macrops* (Günther, 1887) | ● | ● | ● |
| | *Neobythites steatiticus* (Alcock, 1894) | ● | ● | ● |
| | *Neobythites multistriatus* (Nielsen & Quéro, 1991)* | ● | ● | ● |
| | *Pycnocraspedum squamipinne* (Alcock, 1889)* | ● | ● | ● |
| Family | Bythitidae (aphyonids or blindfishes) | | | |
| | *Hephthocara simum* (Alcock, 1892) | ● | ● | ● |
| Order | Osmeriformes | | | |
| Family | Alepocephalidae (smooth-heads or slickheads) | | | |
| | *Alepocephalus bicolor* (Alcock, 1891) | ● | ● | ● |
| | *Alepocephalus blanfordii* (Alcock, 1892)* | ● | ● | ● |
| | *Alepocephalus longiceps* (Lloyd, 1909) | ● | ● | ● |
| | *Bathytroctes macrolepis* (Günther, 1887) | ● | ● | ● |
| | *Bathytroctes squamosus* (Alcock, 1890) | ● | ● | ● |
| | *Conocara microlepis* (Lloyd, 1909) | ● | ● | ● |
| | *Leptoderma affine* (Alcock, 1899)* | ● | ● | ● |
| | *Narcetes erimelas* (Alcock, 1890) | ● | ● | ● |
| | *Narcetes lloydi* (Fowler, 1934) | ● | ● | ● |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Narcetes stomias* (Gilbert, 1890) | ● | ● | ● |
| | *Rouleina attrita* (Vaillant, 1888) | ● | ● | ● |
| | *Rouleina guentheri* (Alcock, 1892)* | ● | ● | ● |
| | *Rouleina nuda* (Brauer, 1906) | ● | ● | ● |
| | *Rouleina squamilatera* (Alcock, 1898) | ● | ● | ● |
| | *Talismania* sp. | ● | ● | ● |
| | *Talismania longifilis* (Brauer, 1902) | ● | ● | ● |
| Family | Platytroctidae (tubeshoulders) | | | |
| | *Maulisia* sp. | ● | ● | ● |
| | *Maulisia mauli* (Parr, 1960) | ● | ● | ● |
| | *Searsia koefoedi* (Parr, 1937) | ● | ● | ● |
| | *Platytroctes mirus* (Lloyd, 1909) | ● | ● | ● |
| Order | Perciformes | | | |
| Family | Acropomatidae (lanternbellies) | | | |
| | *Acropoma* sp. | ● | ● | ● |
| | *Acropoma japonicum* (Günther, 1859)* | ● | ● | ● |
| | *Parascombrops pellucidus* (Alcock, 1889)* | ● | ● | ● |
| | *Parascombrops philippinensis* (Günther, 1880) | ● | ● | ● |
| Family | Apogonidae (cardinalfishes) | | | |
| | *Apogonichthyoides nigripinnis* (Cuvier, 1828) | ● | ● | ● |
| Family | Ariommatidae (eyebrowfishes) | | | |
| | *Ariomma indicum* (Day, 1871) | ● | ● | ● |
| Family | Bathyclupeidae (deepsea herrings) | | | |
| | *Bathyclupea elongata* (Trunov, 1975) | ● | ● | ● |
| | *Bathyclupea hoskynii* (Alcock, 1891) | ● | ● | ● |
| | *Neobathyclupea elongata* (Trunov, 1975) | ● | ● | ● |
| Family | Caproidae (boarfishes) | | | |
| | *Antigonia indica* (Parin & Borodulina, 1986)* | ● | ● | ● |
| | *Antigonia rubescens* (Günther, 1860)* | ● | ● | ● |
| Family | Centrolophidae (trevallas or medusa fishes) | | | |
| | *Psenopsis cyanea* (Alcock, 1890) | ● | ● | ● |
| Family | Cepolidae (bandfishes) | | | |
| | *Cepola* sp. | ● | ● | ● |
| | *Owstonia kamoharai* (Endo, Liao & Matsuura, 2015)* | ● | ● | ● |
| | *Owstonia weberi* (Gilchrist, 1922) | ● | ● | ● |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Owstonia whiteheadi* (Talwar, 1973)* | 🔴 | 🔴 | 🟢 |
| Family | Champsodontidae | | | |
| | *Champsodon capensis* (Regan, 1908) | 🟢 | 🔴 | 🔴 |
| Family | Chiasmodontidae | | | |
| | *Kali kerberti* (Weber, 1913) | 🔴 | 🔴 | 🔴 |
| Family | Emmelichthyidae (bonnetmouths) | | | |
| | *Erythrocles schlegelii* (Richardson, 1846)* | 🔴 | 🟢 | 🟢 |
| Family | Epigonidae | | | |
| | *Epigonus pandionis* (Goode & Bean, 1881) | 🟢 | 🔴 | 🔴 |
| Family | Gempylidae (snake mackerels or escolars) | | | |
| | *Gempylus* sp. | 🔴 | 🔴 | 🟢 |
| | *Gempylus serpens* (Cuvier, 1829) | 🟢 | 🟢 | 🔴 |
| | *Lepidocybium flavobrunneum* (Smith, 1843) | 🔴 | 🔴 | 🟢 |
| | *Lepidocybium* sp. | 🔴 | 🔴 | 🟢 |
| | *Neoepinnula orientalis* (Gilchrist & von Bonde, 1924) | 🟢 | 🟢 | 🟢 |
| | *Promethichthys prometheus* (Cuvier, 1832)* | 🟢 | 🟢 | 🟢 |
| | *Rexea prometheoides* (Bleeker, 1856) | 🟢 | 🟢 | 🟢 |
| | *Ruvettus pretiosus* (Cocco, 1833) | 🟢 | 🔴 | 🟢 |
| Family | Gobiidae (gobies or dartfishes) | | | |
| | *Bathygobius* sp. (Bleeker, 1878) | 🔴 | 🟢 | 🔴 |
| | *Gobius* sp. | 🟢 | 🔴 | 🟢 |
| Family | Nomeidae (driftfishes) | | | |
| | *Cubiceps baxteri* (McCulloch, 1923) | 🟢 | 🟢 | 🟢 |
| | *Cubiceps whiteleggii* (Waite, 1894) | 🟢 | 🟢 | 🟢 |
| Family | Ostracoberycidae (spinycheek seabass) | | | |
| | *Ostracoberyx dorygenys* (Fowler, 1934) | 🔴 | 🔴 | 🟢 |
| Family | Percophidae (duckbills) | | | |
| | *Bembrops caudimacula* (Steindachner, 1876) | 🟢 | 🟢 | 🟢 |
| | *Bembrops platyrhynchus* (Alcock, 1894) | 🟢 | 🟢 | 🟢 |
| Family | Priacanthidae (bigeyes) | | | |
| | *Heteropriacanthus cruentatus* (Lacepède, 1801) | 🔴 | 🔴 | 🟢 |
| | *Priacanthus hamrur* (Forsskål, 1775) | 🟢 | 🟢 | 🟢 |
| Family | Scombrolabracidae | | | |
| | *Scombrolabrax heterolepis* (Roule, 1921) | 🟢 | 🔴 | 🔴 |
| Family | Serranidae (groupers) | | | |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Chelidoperca investigatoris* (Alcock, 1890)* | ● | ● | ● |
| | *Chelidoperca maculicauda* (Bineesh & Akhilesh, 2013) | ● | ● | ● |
| | *Chelidoperca occipitalis* (Kotthaus, 1973)* | ● | ● | ● |
| Family | Trichiuridae (ribbonfishes) | | | |
| | *Aphanopus microphthalmus* (Norman, 1939)* | ● | ● | ● |
| | *Trichiurus* sp. | ● | ● | ● |
| | *Trichiurus auriga* (Klunzinger, 1884) | ● | ● | ● |
| | *Trichiurus lepturus* (Linnaeus, 1758) | ● | ● | ● |
| Family | Uranoscopidae (stargazers) | | | |
| | *Uranoscopus archionema* (Regan, 1921)* | ● | ● | ● |
| | *Uranoscopus crassiceps* (Alcock, 1890)* | ● | ● | ● |
| Order | Pleuronectiformes | | | |
| Family | Bothidae (lefteyed flounders) | | | |
| | *Chascanopsetta lugubris* (Alcock, 1894)* | ● | ● | ● |
| | *Laeops macrophthalmus* (Alcock, 1889) | ● | ● | ● |
| | *Neolaeops microphthalmus* (von Bonde, 1922)* | ● | ● | ● |
| | *Psettina brevirictis* (Alcock, 1890) | ● | ● | ● |
| | *Bothus pantherinus* (Rüppell, 1830) | ● | ● | ● |
| | *Engyprosopon grandisquama* (Temminck & Schlegel, 1846) | ● | ● | ● |
| Family | Citharidae (largescale flounders) | | | |
| | *Citharoides* sp. | ● | ● | ● |
| | *Brachypleura novaezeelandiae* (Günther, 1862) | ● | ● | ● |
| Family | Cynoglossidae (tounguefishes) | | | |
| | *Cynoglossus acutirostris* (Norman, 1939)* | ● | ● | ● |
| | *Cynoglossus carpenteri* (Alcock, 1889)* | ● | ● | ● |
| Family | Paralichthyidae (large-tooth flounders) | | | |
| | *Pseudorhombus* sp. | ● | ● | ● |
| | *Pseudorhombus diplospilus* (Norman, 1926) | ● | ● | ● |
| | *Pseudorhombus arsius* (Hamilton, 1822) | ● | ● | ● |
| | *Pseudorhombus dupliocellatus* (Regan, 1905) | ● | ● | ● |
| | *Cephalopsetta ventrocellata* (Dutt & Rao, 1965) | ● | ● | ● |
| Family | Psettodidae | | | |
| | *Psettodes erumei* (Bloch & Schneider, 1801) | ● | ● | ● |
| Family | Soleidae (soles) | | | |
| | *Aesopia cornuta* (Kaup, 1858) | ● | ● | ● |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| Order | Polymixiiformes | | | |
| Family | Polymixiidae (beardfishes) | | | |
| | *Polymixia fusca* (Kotthaus, 1970) | 🔴 | 🔴 | 🟢 |
| | *Polymixia nobilis* (Lowe, 1836)* | 🟢 | 🟢 | 🟢 |
| | *Polymixia japonica* Günther, 1877 | 🟢 | 🔴 | 🔴 |
| Order | Echinorhiniformes | | | |
| Family | Echinorhinidae | | | |
| | *Echinorhinus brucus* (Bonnaterre, 1788) | 🟢 | 🔴 | 🔴 |
| Order | Myctophiformes | | | |
| Family | Neoscopelidae | | | |
| | *Neoscopelus microchir* (Matsubara, 1943) | 🟢 | 🔴 | 🔴 |
| | *Scopelengys tristis* (Alcock, 1890) | 🟢 | 🔴 | 🔴 |
| Family | Myctophidae | | | |
| | *Benthosema pterotum* (Alcock, 1890) | 🟢 | 🔴 | 🔴 |
| | *Diaphus watasei* (Jordan & Starks, 1904) | 🟢 | 🔴 | 🔴 |
| Order | Rajiformes | | | |
| Family | Crurirajidae (leg-skates or rough limbedskates) | | | |
| | *Cruriraja andamanica* (Lloyd, 1909) | 🔴 | 🟢 | 🟢 |
| Family | Rajidae (skates) | | | |
| | *Dipturus* sp. | 🔴 | 🟢 | 🟢 |
| | *Dipturus johannisdavisi* (Alcock, 1899)* | 🟢 | 🟢 | 🟢 |
| | *Fenestraja mamillidens* (Alcock, 1889)* | 🟢 | 🔴 | 🟢 |
| | *Leucoraja circularis* (Couch, 1838) | 🟢 | 🔴 | 🔴 |
| | *Orbiraja cf. powelli* (Alcock, 1898) | 🔴 | 🔴 | 🟢 |
| | *Raja* sp. | 🔴 | 🟢 | 🔴 |
| | *Raja miraletus* (Linnaeus, 1758) | 🟢 | 🔴 | 🔴 |
| Order | Scorpaeniformes | | | |
| Family | Bembridae (deep-water flatheads) | | | |
| | *Bembradium roseum* (Gilbert, 1905)* | 🔴 | 🔴 | 🟢 |
| | *Bembradium magnoculum* (Kishimoto, Kawai, Tashiro, 2019)* | 🔴 | 🔴 | 🟢 |
| Family | Peristediidae (armored searobins or armored gurnards) | | | |
| | *Heminodus philippinus* (Smith, 1917)* | 🔴 | 🔴 | 🟢 |
| | *Peristedion amblygenys* (Fowler, 1938)* | 🔴 | 🔴 | 🟢 |
| | *Peristedion liorhynchus* (Günther, 1872)* | 🟢 | 🔴 | 🟢 |
| | *Peristedion riversandersoni* (Alcock, 1894)* | 🔴 | 🔴 | 🟢 |

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|---|---|---|---|---|
| | *Satyrichthys laticeps* (Schlegel, 1852) | 🔴 | 🔴 | 🟢 |
| | *Satyrichthys milleri* (Kawai, 2013) | 🔴 | 🔴 | 🟢 |
| | *Scalicus investigatoris* (Alcock, 1898) | 🔴 | 🔴 | 🟢 |
| | *Scalicus orientalis* (Fowler, 1938)* | 🟢 | 🔴 | 🟢 |
| | *Scalicus serrulatus* (Alcock, 1898) | 🔴 | 🔴 | 🟢 |
| Family | Platycephalidae | | | |
| | *Platycephalus indicus* (Linnaeus, 1758) | 🟢 | 🔴 | 🔴 |
| Family | Plectrogeniidae (stinger flatheads) | | | |
| | *Plectrogenium nanum* (Gilbert, 1905)* | 🔴 | 🔴 | 🟢 |
| Family | Psychrolutidae (blobfishes) | | | |
| | *Psychrolutes* sp. | 🟢 | 🟢 | 🟢 |
| Family | Setarchidae (deep-sea bristly scorpionfishes) | | | |
| | *Ectreposebastes imus* (Garman, 1899) | 🟢 | 🔴 | 🟢 |
| | *Lythrichthys longimanus* (Alcock, 1894) | 🟢 | 🔴 | 🟢 |
| | *Setarches guentheri* (Johnson, 1862) | 🟢 | 🔴 | 🟢 |
| Family | Triglidae (sea robins) | | | |
| | *Lepidotrigla* sp. | 🔴 | 🔴 | 🟢 |
| | *Pterygotrigla* sp. | 🔴 | 🔴 | 🟢 |
| | *Pterygotrigla arabica* (Boulenger, 1888) | 🟢 | 🔴 | 🔴 |
| | *Pterygotrigla hemisticta* (Temminck & Schlegel, 1843) | 🟢 | 🔴 | 🟢 |
| Order | Squaliformes | | | |
| Family | Centrophoridae (gulper sharks) | | | |
| | *Centrophorus* sp. | 🔴 | 🟢 | 🟢 |
| | *Centrophorus atromarginatus* (Garman, 1913) | 🟢 | 🔴 | 🟢 |
| | *Centrophorus granulosus* (Bloch & Schneider, 1801) | 🟢 | 🔴 | 🟢 |
| | *Centrophorus moluccensis* (Bleeker, 1860) | 🟢 | 🔴 | 🟢 |
| | *Centrophorus squamosus* (Bonnaterre, 1788)* | 🔴 | 🟢 | 🟢 |
| | *Centrophorus zeehaani* (White, Ebert & Compagno, 2008) | 🔴 | 🔴 | 🟢 |
| Family | Etmopteridae | | | |
| | *Centroscyllium fabricii* (Reinhardt, 1825) | 🟢 | 🔴 | 🔴 |
| | *Etmopterus* sp. | 🔴 | 🟢 | 🔴 |
| | *Etmopterus pusillus* (Lowe, 1839) | 🟢 | 🔴 | 🔴 |
| | *Etmopterus granulosus* (Günther, 1880) | 🟢 | 🔴 | 🔴 |
| | *Centroscyllium kamoharai* Abe, 1966 | 🟢 | 🔴 | 🔴 |
| Family | Echinorhinidae (bramble sharks) | | | |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Echinorhinus brucus* (Bonnaterre, 1788) | 🔴 | 🔴 | 🟢 |
| Family | Somniosidae (sleeper shark) | | | |
| | *Scymnodon ichiharai* (Yano & Tanaka, 1984) | 🔴 | 🔴 | 🟢 |
| | *Zameus squamulosus* (Günther, 1877) | 🟢 | 🔴 | 🟢 |
| | *Centroscymnus crepidater* (Bocage & Capello, 1864) | 🟢 | 🔴 | 🔴 |
| Family | Squalidae (dogfishes) | | | |
| | *Squalus hemipinnis* (White, Last & Yearsley, 2007) | 🔴 | 🟢 | 🟢 |
| | *Squalus megalops* (MacLeay, 1881) | 🔴 | 🔴 | 🟢 |
| Order | Stomiiformes | | | |
| Family | Gonostomatidae | | | |
| | *Sigmops elongatus* (Günther, 1878) | 🟢 | 🔴 | 🔴 |
| Family | Phosichthyidae (lightfishes) | | | |
| | *Vinciguerria nimbaria* (Jordan & Williams, 1895) | 🔴 | 🔴 | 🟢 |
| Family | Sternoptychidae (hatchetfishes) | | | |
| | *Polyipnus spinosus* (Günther, 1887) | 🔴 | 🟢 | 🟢 |
| | *Argyropelecus* sp. | 🟢 | 🔴 | 🔴 |
| | *Argyropelecus affinis* (Garman, 1899) | 🔴 | 🟢 | 🟢 |
| | *Argyropelecus hemigymnus* (Cocco 1829) | 🔴 | 🔴 | 🟢 |
| Family | Stomiidae (dragon fishes) | | | |
| | *Astronesthes* sp. | 🟢 | 🔴 | 🔴 |
| | *Astronesthes indicus* (Brauer, 1902) | 🔴 | 🟢 | 🔴 |
| | *Astronesthes niger* (Richardson, 1845) | 🟢 | 🔴 | 🔴 |
| | *Chauliodus pammelas* (Alcock, 1892)* | 🟢 | 🔴 | 🟢 |
| | *Chauliodus sloani* (Bloch & Schneider, 1801) | 🔴 | 🟢 | 🟢 |
| | *Malacosteus niger* (Ayres, 1848)* | 🔴 | 🔴 | 🟢 |
| | *Photonectes* sp. | 🔴 | 🔴 | 🟢 |
| | *Stomias affinis* (Günther, 1887) | 🟢 | 🔴 | 🔴 |
| Order | Tetraodontiformes | | | |
| Family | Tetraodontidae (puffer fishes) | | | |
| | *Lagocephalus* sp. | 🔴 | 🔴 | 🟢 |
| | *Lagocephalus guentheri* (Miranda Ribeiro, 1915) | 🔴 | 🔴 | 🟢 |
| | *Lagocephalus inermis* (Temminck & Schlegel, 1850) | 🔴 | 🟢 | 🟢 |
| | *Lagocephalus lunaris* (Bloch & Schneider, 1801) | 🔴 | 🔴 | 🟢 |
| Family | Triacanthodidae (spikefishes) | | | |
| | *Halimochirurgus alcocki* (Weber, 1913)* | 🔴 | 🔴 | 🟢 |

| Order/ Family | Species Names | Arabian Sea | Bay of Bengal | Andaman & Nicobar |
|---|---|---|---|---|
| | *Halimochirurgus centriscoides* (Alcock, 1899)* | ● | ● | ● |
| | *Macrorhamphosodes* sp. | ● | ● | ● |
| | *Macrorhamphosodes uradoi* (Kamohara, 1933)* | ● | ● | ● |
| | *Paratriacanthodes retrospinis* (Fowler, 1934) | ● | ● | ● |
| | *Triacanthodes ethiops* (Alcock, 1894) | ● | ● | ● |
| | *Tydemania navigatoris* (Weber, 1913) | ● | ● | ● |
| Order | Myxiniformes | | | |
| Family | Myxinidae | | | |
| | *Eptatretus* sp. (Cloquet, 1819) | ● | ● | ● |
| | *Eptatretus hexatrema* (Müller, 1836) | ● | ● | ● |
| Order | Hexatdiniformes | | | |
| Family | Narcinidae (numbfishes) | | | |
| | *Benthobatis moresbyi* (Alcock, 1898) | ● | ● | ● |
| Order | Zeiformes | | | |
| Family | Parazenidae (little Dories) | | | |
| | *Cyttopsis rosea* (Lowe, 1843)* | ● | ● | ● |
| Family | Zeidae (dories) | | | |
| | *Zenopsis conchifer* (Lowe, 1852)* | ● | ● | ● |
| Family | Zeniontidae | | | |
| | *Zenion hololepis* (Goode & Bean, 1896)* | ● | ● | ● |

● Present ● Absent

## Notes




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