

Marine Biodiversity & Environment
Management Division

KNOW YOUR MARINE BIODIVERSITY AND ENVIRONMENT (MARBIE-1)

Theory and Hands-on
Training Programme

February 05th-09th, 2024



ICAR-CMFRI, Kochi



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CMFRI Training Manual Series No. 42/2024

**Training Manual on Know Your Marine Biodiversity & Environment
(MarBiE-1)**

Publisher

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Citation: Sreeram, Miriam Paul and George, Grinson (Eds) 2024. Training Manual on Know Your Marine Biodiversity and Environment (MarBiE-I). CMFRI Training Manual Series No. 42/2024, ICAR-Central Marine Fisheries Research Institute, Kochi, 190p.

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This manual has been prepared as a supplementary reference material for the training programme on 'Know Your Biodiversity and Environment (MarBiE-I)'. This training programme was organized by the Marine Biodiversity & Environment Management Division of ICAR-Central Marine Fisheries Research Institute, Kochi during 05th to 09th February 2024

FOREWORD



Marine biodiversity, encompassing the vast array of life forms within our oceans, represents a cornerstone of a healthy planet. From microscopic microbes to the apex predators that roam the open ocean, these organisms intricately interact, forming the foundation of complex marine ecosystems. Understanding and protecting this remarkable diversity is paramount for the well-being of our planet.

This training manual, based on the lectures imparted during the “Know Your Marine Biodiversity and Environment (MarBiE 1)” programme organized by the subject experts of ICAR-CMFRI, delves into the fascinating world of marine biodiversity and its intricate relationship with the marine environment. Designed for both researchers and students, it provides a comprehensive overview of the key elements. In-depth exploration of marine life across all major taxonomic groups, from phytoplankton to marine mammals to marine macrophytes are included. Additionally, the manual examines aspects such as marine pollution that affect these ecosystems.

Crucially, this manual goes beyond theoretical knowledge. Detailed methodologies equip researchers with the tools to study marine biodiversity and its natural habitat. This practical approach ensures that users can grasp the fundamental concepts and also actively contribute to future research efforts, cultivating in the users a spirit of scientific curiosity to actively seek new knowledge, and contribute to the vital mission of safeguarding the incredible diversity of life within our oceans, thereby ensuring the health of our planet through research and conservation. I compliment the scientists and staff involved in bringing out this training manual for their commendable efforts and wishes the trainees the very best in employing the knowledge gained for successful enterprise.

With best wishes,

A handwritten signature in blue ink, consisting of stylized initials and a long horizontal stroke.

A. Gopalakrishnan
Director

PREFACE

This training manual equips the reader with the foundational knowledge and practical skills necessary to study marine biodiversity and environment. It is based on the notes provided by the scientists of ICAR-CMFRI on the series of lectures delivered during the training programme “Know Your Marine Biodiversity and Environment (MarBiE 1)” held from 5th to 9th February 2024 for researchers and postgraduate students at ICAR-CMFRI, Kochi, and it provides a comprehensive overview of key topics.

The training manual examines the vast taxonomic spectrum of marine life, encompassing **marine microbes**, **plankton**, **invertebrates** (sponges, jellyfish, soft corals, anemones, corals, crustaceans, molluscs, echinoderms), **vertebrates** (cartilaginous and bony fishes, sea turtles, marine mammals), **marine flora** (seaweeds, seagrasses and mangroves) and specialised groups (coral reef fishes). A detailed understanding of the ecological roles they play within marine ecosystems is gained from the chapters.

Beyond the organisms themselves, the training manual explores pressing issues like **plastic and microplastic pollution**, **abandoned fishing gear**, and the impact of **harmful algal blooms**. Additionally, it explores the vital role of **seagrasses** and the importance of **mangrove ecosystems**. Emphasis is also placed on practical application and developing analytical skills. Essential techniques for **underwater sampling, monitoring, and assessment** of marine biodiversity and sample collection, qualitative analysis, and methods for monitoring ecosystem health are described.

As the field of marine biodiversity and environment is constantly evolving, this training manual serves as a springboard for further exploration. Literature cited or further reading are provided at the end of each chapter which the reader can use to gain more insights into specific topics. The manual provides a sound knowledge base for future contributors to research, conservation, and the sustainable management of our vital oceans.

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Marine microbes form a diverse and complex group that plays a crucial role in the functioning of marine environments. They encompass a wide range of organisms, including bacteria, archaea, viruses, and microeukaryotes, each contributing uniquely to marine ecosystems' dynamics and functions. For the initial 2-3 billion years of planetary and biological evolution, microbes stood as the sole life forms. It is widely believed that life emerged in the oceans, making marine microorganisms the closest extant descendants of these primordial life forms. These early marine microbes played a crucial role in setting the stage for subsequent life forms. Around two billion years ago, photosynthetic marine microorganisms began generating oxygen, profoundly altering the chemical landscape in which plants, animals, and all other life evolved. This transition was monumental, as the generation of oxygen facilitated the development of aerobic life forms and shaped Earth's habitability. Beyond oxygen production, marine microbes continue to be indispensable. They act as microscopic factories, catalyzing essential chemical reactions within biogeochemical cycles. Their metabolisms, both aerobic and anaerobic, enable them to perform crucial steps within these cycles that other organisms cannot accomplish. The smooth operation of these biogeochemical cycles is vital for sustaining life on our planet. From nutrient cycling to carbon sequestration, marine microbes play a pivotal role in maintaining Earth's ecological balance. Without their contributions, the intricate web of life would cease to function effectively. Thus, acknowledging and understanding the significance of marine microbes is imperative for preserving the health and continuity of life on Earth.

The diversity of microbial life in the sea is vast, encompassing organisms from all three domains of life—archaea, bacteria, and eukarya—as well as viruses, although viruses are often not classified as living organisms by most authorities. These groups or taxa exhibit distinct differences in morphology, physiology, and phylogeny, spanning both prokaryotic and eukaryotic domains. The remarkable adaptability of microorganisms to

thrive under diverse physicochemical conditions underscores their critical role in maintaining ecosystem balance. Given their significance, it is essential to catalog their diversity comprehensively. However, their microscopic size renders them invisible to the naked eye, posing challenges for effective classification.

The diversity of microbial communities varies significantly within and between marine habitats. These habitats can be categorized based on several factors:

Presence of other organisms: This includes symbiotic relationships, free-living microbes, and biofilms

Proximity to ocean features: Marine habitats can be distinguished based on their depth and location, such as euphotic zones (0-150 m), mesopelagic zones (150 – 1000 m), bathopelagic zones (>1000 m), and benthic habitats within sediments

Nutrient concentrations: Habitats can also be classified as oligotrophic (low nutrient concentrations), mesotrophic (moderate nutrient levels), or eutrophic (high nutrient levels)

Interfaces between different habitats are often biodiversity hotspots, such as air-water, water-sediment, water-ice, and host macroorganism-water interfaces. However, studying these interface habitats in detail is challenging due to their sub-millimeter scale of physical and chemical variability.

The recent focus on biogeography in microbial diversity studies is due to the small size of microorganisms and the complexity of their environments (Fierer, 2008). Environmental complexity plays a crucial role in shaping microbial diversity, with spatial heterogeneity leading to the formation of numerous niches within a habitat. Tools like metagenomics provide valuable nucleic acid sequence data, allowing for direct identification of microorganisms and comparison of microbial diversity profiles across habitats. Alpha diversity refers to diversity within a specific location or community, while beta diversity measures differences in community composition between multiple locations. Gamma diversity applies to larger regions,

encompassing continents and biomes, and is larger in scale compared to alpha diversity. These concepts help researchers understand the distribution and composition of microbial communities across various marine habitats.

Understanding microbial diversity is a challenging yet crucial aspect of marine biodiversity research, as it sheds light on biogeography, community assembly, and ecological processes (Pedros-Alio, 2006). While species richness has traditionally been a key metric in ecological and conservation studies, the concept of biodiversity encompasses much more than just the number of species present. Estimating microbial diversity often involves statistical approaches that extrapolate species numbers from relatively small sample sizes. Hughes *et al.* (2001) highlighted the effectiveness of rarefaction and richness estimators in predicting bacterial species numbers, emphasizing the utility of nonparametric estimators in microbial diversity studies. However, these estimators rely on operational taxonomic units (OTUs), which may treat divergent and redundant taxa equally. To address this limitation, recent advancements have introduced statistical techniques from population genetics and systematics to estimate species richness and phylogenetic diversity without solely relying on sequence frequencies (Martin, 2002). Measures such as the reciprocal of Simpson's index ($1/D$), F-statistics (FST), and phylogenetic grouping of taxa (P tests) have been applied to microbial datasets as indicators of diversity. These metrics, widely used in ecological studies, offer a more nuanced understanding of microbial diversity by considering both species richness and phylogenetic relationships among taxa (Stach *et al.*, 2003). By combining species richness estimates with measures of diversity like phylogenetic relationships, researchers can gain deeper insights into marine microbial diversity, enabling more informed ecological analyses and conservation strategies.

Within ocean-surface bacterioplankton communities, the dominant clade is the heterotrophic SAR11, while non-photosynthetic protists of diverse origins regulate picoplankton populations and nutrient supply into marine food webs. Collectively, bacterial, archaeal, and protist communities constitute over 90% of oceanic biomass and are responsible for 98% of primary production. Archaea stand out for their ability to thrive in extreme environments, differing from bacteria notably due to the

absence of peptidoglycan in their cell walls. Both domains, archaea, and bacteria, play crucial roles in shaping marine environments, contributing significantly to ecological processes and nutrient cycling essential for marine life. Over the past two decades, molecular studies utilizing gene sequences encoding the small subunit rRNA (SSU rDNA) have unveiled a plethora of new marine microorganisms. Marine microbiologists are experiencing a sense of living in an era of continual discovery, with no foreseeable end in sight. However, much of this newfound diversity remains undescribed due to the necessity of pure cultures to define a species.

Recent investigations into microbial diversity have yielded remarkable revelations about previously unknown microorganisms, many of which exert significant impacts on oceanic processes (Zinger *et al.*, 2012). Among these discoveries are vast populations of picoplankton encompassing diatoms, dinoflagellates, picoflagellates, and cyanobacteria. These picoplankton serve as primary drivers of carbon fixation, orchestrating nitrogen cycling and forming the foundation of the traditional marine food web. Modern technologies, including molecular techniques and automated fluorescence cell sorting, have revolutionized our understanding of microbial life in the oceans. These advancements have unveiled the immense abundance and diversity of microbial forms, particularly through DNA sequencing of environmental genomes, also known as metagenomics. Metagenomics has become crucial in studying microbial communities, especially since an estimated 99% of the microbial population is considered uncultivable using traditional methods. One of the significant findings of molecular techniques is the identification of SAR11 as a dominant clade within ocean-surface bacterioplankton communities. Bacteria belonging to the SAR11 clade, specifically within the Pelagibacteraceae family, constitute approximately one-third of cells at the ocean's surface. In fact, SAR11 bacteria are estimated to represent between a quarter and a half of all prokaryotic cells in the ocean, showcasing their remarkable prevalence. These SAR11 bacteria are classified as alphaproteobacteria and include the highly abundant marine species known as *Candidatus Pelagibacter ubique*, which has gathered attention for its ubiquity and ecological significance in marine environments. This species has not yet been validly published, though the strain

HTCC1062 has been successfully isolated in pure culture (Rappe *et al.*, 2002), and therefore the species name does not have official taxonomic standing.

Taxonomic classification on marine microbes

In modern microbial taxonomy, a polyphasic approach is utilized to define a microbial species, combining both phenotypic and genotypic characteristics. When proposing a new taxon, it is crucial to isolate the organism in pure culture and assess its characteristic features under standardized conditions. Consistency in phenotypes among all strains within a species is essential. A designated type strain of a species serves as the reference specimen for that species. The 16S rDNA sequences play a vital role in species delineation. Organisms with 16S rDNA sequences $\leq 98.5\%$ identical are considered members of different species. However, uncultured microbes cannot be assigned to a specific species since their phenotype remains unknown. Instead, they may be designated as 'Candidatus' provided their 16S rRNA sequence aligns with known species' identity principles. A concept pertinent to taxa lower than the strain level is the ecotype. Ecotypes refer to microorganisms that occupy specific ecological niches and are adapted to the conditions prevalent in those niches (Koeppel *et al.*, 2008). This adaptation often leads to genetic and phenotypic divergence, reflecting the diverse ecological roles microorganisms play in their environments.

Numerical taxonomy

Numerical taxonomy is a method that utilizes a range of biochemical, morphological, cultural, and susceptibility characteristics, including responses to antibiotics and inorganic compounds, to assess the similarity between organisms. Typically, between 50 to 200 traits are considered for each organism. The degree of similarity, expressed as a coefficient or percentage, is then calculated between strains, where each strain represents a single isolate from a specimen. Using these similarities, a dendrogram or similarity matrix is constructed, organizing individual strains into groups based on their degree of similarity. This dendrogram places groups that share higher similarity closer together, providing a visual representation of the relationships between different strains and groups.

While 16S rDNA sequences have caught attention as a powerful tool for delineating species uniqueness, numerical taxonomy,

which relies on phenotypic traits from a broad range of species, holds its ground as a robust approach. In fact, it compares favourably with genotypic data and aligns well with modern taxonomy practices. This methodology, by considering a diverse array of characteristics, offers valuable insights into the relationships and classifications of organisms based on their observable traits and behaviours.

Polyphasic taxonomy

In the polyphasic approach to microbial taxonomy, researchers aim to provide a comprehensive description of organisms by integrating phenotypic, genotypic, and phylogenetic information. Phenotypic characteristics encompass colony traits, cell morphology, cell wall composition, pigmentation patterns, protein profiles, and other chemotaxonomic markers. Genotypic features are derived from nucleic acids (DNA/RNA), providing insights into the genetic makeup of the organism. Phylogenetic information plays a crucial role and is often obtained by studying sequence similarities in specific genes such as 16S rRNA or 23S rRNA for bacteria and 18S rRNA for fungi. Various molecules are employed to delineate and describe taxa, with certain components like 16S rRNA genes, phenotypic traits, and chemotaxonomy being mandatory. Optional components may include amino-acid sequencing of specific proteins or DNA-DNA hybridization, which are included as needed for accurate taxonomic descriptions.

The DNA barcoding approach is gaining popularity in assessing microbial diversity, although the availability of comprehensive datasets, especially for eukaryotic microbes, remains somewhat limited. However, advancements in sequencing technologies have led to faster and more cost-effective methods, improving the availability and accuracy of genetic information for microbial taxonomy.

Marine microbes under the three domains of life

Bacteria

Bacteria, forming the Domain Bacteria, represent one of the earliest branches on the tree of life and are genetically distinct from both archaea (Domain Archaea) and eukaryotes (Domain Eukarya). They are ubiquitous in all marine environments, playing a crucial role in sustaining life on Earth by facilitating the recycling of essential nutrients within oceanic food webs. Despite their fundamental importance, our understanding

of bacterial biology in marine environments remains limited. This is primarily due to the fact that only a small fraction, averaging around 1%, of marine bacteria can be successfully cultured under laboratory conditions. This limitation hinders our ability to study the vast majority of bacterial diversity and their ecological roles in marine ecosystems. Majority of bacterial isolates obtained from marine environments, belong to the five major bacterial phyla: Proteobacteria, Cyanobacteria, Firmicutes, Actinobacteria, and Bacteroidetes:

Phylum Proteobacteria

Includes diverse groups of Gram-negative bacteria, such as Alpha-, Beta-, Gamma-, Delta-, and Epsilon-Proteobacteria, each with distinct metabolic capabilities and ecological roles. They contribute significantly to nutrient cycling, bioremediation, and symbiotic relationships with plants and animals. Some Proteobacteria are of medical importance due to their pathogenicity, highlighting the diverse ecological roles and impacts of this phylum in ecosystems and human health.

Phylum Cyanobacteria

Autotrophic Gram-negative bacteria that can obtain biological energy by photosynthesis, which contribute significantly to primary production in marine ecosystems. Certain Cyanobacterial species are capable of nitrogen fixation, converting atmospheric nitrogen into a usable form for plants and other organisms. This process is essential for maintaining nitrogen levels in marine ecosystems. Under certain conditions, Cyanobacteria can undergo rapid population growth, leading to harmful algal blooms (HABs). Some Cyanobacteria produce toxins harmful to marine life and humans, causing water quality issues and impacting aquatic ecosystems.

Phylum Firmicutes

A significant marine phylum comprising Gram-positive bacteria, possessing the unique ability to form spores. These spores serve as resting stages characterized by inactivity, strong dehydration, and high resistance to environmental stresses. Despite being dormant, spores contain sufficient energy for germination and are specifically adapted to swiftly respond to substrate availability. Upon encountering favourable conditions, spores undergo germination, giving rise to vegetative cells capable of replication and growth. This adaptability allows Firmicutes to effectively navigate varying environmental challenges

and exploit opportunities for growth and proliferation in marine habitats

Phylum Bacteroidetes

Known for their ability to degrade complex organic compounds and plays a key role in nutrient cycling. Their metabolic versatility and ability to degrade complex organic compounds make them significant contributors to ecosystem stability and functioning.

Phylum Actinobacteria

Actinobacteria are prevalent inhabitants of marine sediments, thriving in the nutrient-rich and diverse environments found in oceanic sediments. Their presence is crucial for the decomposition of organic materials and nutrient cycling within these ecosystems. Actinobacteria are renowned for their ability to produce a vast array of bioactive secondary metabolites, including antibiotics, antifungals, and anticancer compounds.

Bacteria play a significant role in marine ecosystems, constituting a major portion of the organic matter that sustains countless bottom-dwelling animals. As organic particles sink through the water column, they are predominantly composed of bacteria. These bacteria primarily feed on dead organic material, contributing to nutrient recycling and energy transfer within marine food webs. Notably, some bacteria, such as cyanobacteria, are photosynthetic, making them the most abundant photosynthetic organisms in the ocean due to their small size and prolific distribution. Beyond their roles as free-living organisms, some bacteria have evolved to form symbiotic relationships with other marine organisms. These symbiotic associations have led to the evolution of organelles found in eukaryotic organisms, originating from symbiotic bacteria. Ultimately, bacteria are crucial in the decomposition of organic matter in oceans, contributing significantly to nutrient cycling and ecosystem functioning in marine environments.

Archaea

Archaea, part of the Domain Archaea, represent some of the earliest and most basic life forms known. The discovery of 3.8-billion-year-old fossils resembling archaeal structures underscores their ancient lineage and potential significance in the early evolution of life on Earth. These prokaryotic organisms are unicellular and lack a nucleus and membrane-bound organelles, distinguishing them from eukaryotic cells. The existence of Archaea in

extreme environments initially earned them the title of "Extremophiles". They were first identified in extreme terrestrial settings like hot sulphur springs, saline lakes, and environments with highly acidic or alkaline conditions. The exploration of extreme marine habitats revealed that archaea are also prevalent in deep-sea environments, where they endure pressures ranging from 300 to 800 atmospheres. Notably, certain archaea thrive in the extreme temperatures of hydrothermal vents, with some unable to grow below 70-80°C. Impressively, a particular hydrothermal vent archaeon has been found to survive at an astonishing 121°C, marking it as the most heat-tolerant organism known to date. The diverse habitats where archaea are found highlight their resilience and adaptation to extreme conditions, providing valuable insights into the boundaries of life and the potential for life to exist in extreme environments. The majority of archaea from marine environments, comprising over 80% of their population, belong to several major phyla that are distinctive in their characteristics and ecological roles:

Phylum Euryarchaeota

One of the largest and most diverse archaeal phyla found in marine environments. Members of this phylum are known for their ability to thrive in extreme conditions such as high salinity, high temperatures, and anaerobic environments. They encompass diverse metabolic capabilities, including methanogenesis (methane production), sulphate reduction, and acetogenesis. Euryarchaeota includes methanogens, halophiles, and thermophiles, exhibiting diverse adaptations to extreme marine environments.

Phylum Thaumarchaeota

A significant phylum in marine ecosystems, particularly in oceanic waters. They are known for their involvement in the nitrogen cycle, specifically in the oxidation of ammonia to nitrite (ammonia oxidation). Thaumarchaeota are important contributors to nitrification processes in marine environments, influencing nutrient cycling and ecosystem dynamics.

Phylum Crenarchaeota

A diverse phylum of archaea found in various marine habitats, including deep-sea environments, hydrothermal vents, and sediments. They are often adapted to extreme conditions, such as high temperatures and acidic pH levels. Some members of

Crenarchaeota are involved in sulphur metabolism, ammonia oxidation, and other metabolic pathways crucial for marine ecosystems.

Phylum Nanoarchaeota

A less studied but intriguing phylum of archaea that includes extremely small and symbiotic organisms. They are often associated with other microorganisms, such as thermophilic archaea, forming symbiotic relationships. The ecological roles and metabolic functions of Nanoarchaeota in marine environments are areas of ongoing research and discovery.

Phylum Korarchaeota

A lesser-known group of archaea that has been primarily identified in high-temperature environments, such as hydrothermal systems and geothermal areas. However, their presence and significance in marine environments are still areas of active research and exploration.

These major archaeal phyla demonstrate the diversity, adaptability, and ecological significance of archaea in marine ecosystems. Archaea possess a diverse range of metabolic capabilities, including photosynthesis, chemosynthesis, and heterotrophy. Among archaea, a significant proportion are methanogens, which are anaerobic organisms capable of metabolizing organic matter to produce energy, with methane as a byproduct. Within the Archaea domain, the Halobacteria are notable photosynthetic organisms that thrive in environments with high salinity levels. These organisms utilize bacteriorhodopsins, purple proteins that enable them to trap light energy, facilitating photosynthesis even in extreme saline conditions. The adaptation of Halobacteria to high salinities and their unique light-capturing abilities highlight the diversity and resilience of archaeal organisms in varied environmental niches. Their metabolic capabilities, ranging from methane production to nitrogen cycling, contribute to nutrient dynamics, energy flow, and ecosystem stability in marine habitats. Understanding the roles and interactions of these archaeal groups is essential for comprehending marine microbial communities and their impact on global biogeochemical cycles.

Microeukaryotes

Marine microbial eukaryotes are an integral part of marine ecosystems, belonging to various kingdoms such as Protista, Fungi,

Plantae, and Animalia. Unlike prokaryotes, which are predominantly unicellular, eukaryotes encompass both unicellular and multicellular organisms. The majority of marine microbial eukaryotes are classified under the Kingdom Protista, which contribute significantly to primary production and trophic interactions in marine food webs. This diverse group includes organisms that can be autotrophic (capable of producing their own food) or heterotrophic (relying on external sources for nutrition). Among these microbial eukaryotes are algae, diatoms, dinoflagellates, zooxanthellae, coccolithophores, foraminiferans, radiolarians, ciliates, and marine fungi. Algae are a significant component of marine microbial eukaryotes, playing a crucial role in primary production and nutrient cycling. Diatoms, with their intricate silica shells, are abundant in marine environments and are essential primary producers. Zooxanthellae are symbiotic algae found in coral reefs, providing essential nutrients to corals through photosynthesis. Coccolithophores, characterized by their calcium carbonate plates, are vital contributors to marine carbon cycling and play an important role in climate regulation. Foraminiferans and radiolarians are amoeboid protists with intricate shell structures, contributing to marine biodiversity. Ciliates are diverse protozoans with cilia for movement and feeding, occupying various niches in marine ecosystems. Marine fungi, although less studied compared to their terrestrial counterparts, play roles in nutrient recycling and decomposition processes. Overall, the diversity of marine microbial eukaryotes underscores their importance in marine food webs, nutrient cycling, and ecosystem dynamics.

Viruses

Viruses, although not classified as living organisms, play a crucial role in marine ecosystems, particularly in the marine food web. Viruses are essentially particles composed of nucleic acid, either RNA or DNA, enclosed in a protein coat. They are obligate parasites, relying on living cells for their replication and development. Unlike organisms which possess the ability for independent cell division and the machinery for DNA duplication and cell division, viruses lack these capabilities. Instead, they depend on infecting living cells to replicate their genetic material and produce new virus particles. Due to this dependency, viruses do not fall under any of the three domains of life. Despite their non-living status, viruses are immensely significant for generating and maintaining

genetic diversity across all three domains of life through horizontal gene transfer. They play a crucial role in the microbial food web and biogeochemical cycles by promoting nutrient production and maintaining high diversity, thereby preventing the dominance of specific microorganisms. Viruses primarily parasitize bacteria and plankton, releasing organic matter into the ocean. Studies suggest that viruses may be responsible for up to half of bacterial mortality in aquatic ecosystems and substantial mortality in phytoplankton populations. The abundance of viruses in an environment correlates directly with the abundance of microbial life they infect, highlighting their regulatory role in microbial populations. Viruses, although not alive in the true sense, are integral to marine ecosystems, contributing to nutrient cycling, genetic diversity, and the balance of microbial communities in marine environments.

Marine microbial diversity and ecological roles

Marine microbial diversity and ecological roles are fundamental to the functioning of marine ecosystems.

Functional diversity

Photosynthetic microbes like cyanobacteria and phytoplankton play a crucial role in marine primary production, contributing substantially to the ecosystem's energy input. On the other hand, heterotrophic bacteria and archaea act as decomposers, nutrient cyclers, and symbionts, engaging in organic matter degradation and nutrient recycling processes vital for ecosystem functioning. The diversity of viruses also plays a significant role, impacting microbial community structure, genetic exchange, and nutrient dynamics through both lytic and lysogenic cycles, thus influencing the overall balance and stability of marine ecosystems.

Spatial and temporal dynamics

Vertical stratification in microbial communities within water columns is influenced by factors like light availability, nutrient gradients, and predation pressure. This stratification creates distinct niches for different microbial species, contributing to overall ecosystem diversity and functioning. Seasonal variability further adds to microbial dynamics, with fluctuations in diversity and abundance driven by changes in temperature, nutrient availability, and daylight hours,

showcasing the dynamic nature of marine microbial communities over time.

Ecological interactions

Ecological interactions within marine ecosystems are incredibly diverse and dynamic, encompassing a multitude of relationships and processes that collectively shape the functioning and stability of these environments. Symbiotic interactions are of paramount importance in marine ecosystems, where they often involve mutually beneficial or parasitic relationships between microbes and host organisms such as corals, sponges, and other marine fauna. These symbiotic associations play a pivotal role in various ecosystem functions, including nutrient cycling, habitat provision, and even defence mechanisms against environmental stressors. For example, symbiotic algae living within coral polyps contribute significantly to coral reef productivity through photosynthesis, while certain bacteria can provide essential nutrients to their host organisms. Predation and grazing activities by protists (such as zooplankton) and metazoans (like fish and invertebrates) have a profound impact on microbial communities within marine ecosystems. Predators and grazers regulate the abundance and diversity of microbial populations by consuming them directly or indirectly through grazing on primary producers. This predation pressure can influence the structure and composition of microbial communities, affecting their resilience to environmental changes and their role in nutrient cycling.

The interactions between predators, grazers, and microbes help regulate population sizes within marine ecosystems. Predation acts as a natural control mechanism, preventing the unchecked proliferation of certain microbial species that could otherwise disrupt ecosystem balance. Grazing by marine organisms also influences the distribution and abundance of microbes, shaping community dynamics and contributing to overall biodiversity. Predation and grazing not only regulate population sizes but also have a significant impact on the composition and diversity of microbial communities. Selective feeding by predators and grazers can favour certain microbial taxa over others, leading to shifts in community structure and function. These changes can ripple through the entire ecosystem, influencing nutrient cycling, productivity, and resilience to environmental perturbations.

Collectively, these ecological interactions contribute to the overall balance and stability

of marine ecosystems. By regulating population sizes, influencing community composition, and participating in nutrient cycling processes, symbiotic relationships, predation, and grazing help maintain the health and resilience of marine ecosystems in the face of environmental challenges and disturbances

Factors shaping marine microbial diversity

Numerous factors influence marine microbial diversity, reflecting the intricate web of interactions within marine ecosystems. These factors encompass physical, chemical, and biological variables, each exerting varying degrees of influence on microbial communities. Key variables shaping marine microbial diversity include turbulence, light availability, temperature gradients, nutrient levels (such as nitrogen and phosphorus), salinity variations, pH levels, UV radiation, solar influx, surfaces/interfaces, redox potential, metal concentrations, and the presence of macroorganisms like invertebrates and macroalgae. These factors collectively contribute to the richness and composition of microbial communities, yet the precise extent of their influence and their significance across different environmental contexts remain subjects of ongoing research. Climate change is poised to emerge as a pivotal top-down force shaping marine microbial communities, primarily through alterations in ocean temperatures. These changes are anticipated to bring about unforeseen shifts in community diversity and structure. Additionally, pollution, notably anthropogenic nitrogen inputs arising from human activities, profoundly impacts marine microbial diversity. Anthropogenic nitrogen influxes now constitute nearly half of the total nitrogen inputs to oceans, contributing to the emergence of extensive dead zones in coastal regions and an escalation in harmful algal blooms. These anthropogenic impacts underscore the urgency of understanding and mitigating human-induced pressures on marine microbial ecosystems. Understanding the complex interplay of these factors is crucial for predicting and managing changes in marine microbial diversity, especially in the context of ongoing environmental challenges such as climate change and pollution

Conclusion

The taxonomy and diversity of marine microbes are fundamental to understanding the structure, function, and resilience of marine ecosystems. Advances in molecular techniques have revolutionized our ability to

study and characterize these diverse microbial communities, shedding light on their ecological roles, interactions, and responses to environmental changes. The wealth of sequence information, such as 16S rRNA sequences, genome sequences, and metagenomes, along with rRNA-targeted probes like Fluorescent *In Situ* Hybridization (FISH), has facilitated the discovery of numerous new bacterial groups. In the realm of marine microbial genomics, ranging from model organisms' genome studies to various meta-omics approaches (e.g., metagenomics, metatranscriptomics, and metaproteomics), researchers have made significant strides in understanding roles played by microbes in the marine environment. Recent advancements in technology have the potential to revolutionize how we characterize, identify, and study microbial communities. Innovative tools like microbial ecological DNA microarrays, such as PhyloChip and GeoChip, have been developed to comprehensively investigate microbial community composition and function. These microarrays offer a high-throughput platform for analyzing microbial diversity and metabolic potential. Another groundbreaking approach is Single Cell Genomics, which allows for the amplification and sequencing of DNA from individual cells directly obtained from environmental samples. This approach is particularly valuable for obtaining genomes from uncultured phyla, providing insights into the genetic make-up and potential functions of previously elusive microbial groups. The advent of Single Cell Genomics promises to reshape the field of microbiology by enabling the study of individual cells within complex microbial communities. Future research efforts aimed at unravelling the complexities of marine microbial diversity will contribute significantly to marine conservation, biotechnology, and ecosystem management.

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Planktonic diversity in Indian waters

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Phytoplankton is microscopic, plant-like organisms that drift in the water. These single-celled photo synthesizers can either swim using their flagella or be carried by the currents. They are an essential part of aquatic food chains and are found in almost all bodies of water. German biologist Victor Hensen first used the term "plankton" in 1887 to describe these microorganisms.

Phytoplankton thrives in the open surface waters of lakes, rivers, and oceans, constituting a diverse group of organisms that include both prokaryotic and eukaryotic species. These unicellular algae play a pivotal role in the primary productivity of aquatic ecosystems through their photosynthetic processes, which form the foundation of the food web, supporting zooplankton, fish, and various other aquatic life forms.

According to Field et al. (1998), marine phytoplankton contribute approximately half of the planet's net primary production. Furthermore, phytoplankton are instrumental in carbon dioxide sequestration and oxygen production. Geider et al. (1997) reported that in marine environments, phytoplankton biomass accounts for nearly 48% of the total carbon fixed on Earth's surface.

The marine environment regulates the phytoplankton population through various elements such as the presence of nutrients, the level of thermal separation, and the impact of zooplankton feeding.

Methods of Phytoplankton Collection:

In order to ensure accurate and comprehensive data collection, it is important to gather samples from multiple locations or stations, rather than restricting the sampling to just one site or station. This will help to avoid an uneven distribution of phytoplankton community structure. By collecting samples from a variety of locations, a sufficient amount of data can be obtained for the analysis of the phytoplankton community structure.

Samples of phytoplankton were gathered using a variety of tools, including bottle samplers, plankton nets, and plankton pumps. Bottle sampling is a straightforward approach for obtaining water samples from a specific depth.

It is suggested for the quantitative analysis of phytoplankton structures. To collect surface water samples, a measured volume of water can be collected using a bottle or bucket. However, for subsurface sampling, specialized water samplers such as Meyer's, Niskin, and Friedinger's water samplers can be used.

Phytoplankton sampling is commonly carried out using nets of varying designs, which are known as plankton nets. These nets enable size-selective quantitative sampling by adjusting the towing speed. They can be operated in different ways depending on the sampling requirements. Horizontal towing is effective for collecting surface phytoplankton samples, while vertical towing provides composite samples of the water column. By measuring the diameter of the net mouth opening and the distance traveled through a flow meter, the volume of water sampled can be estimated (Eaton et al. 2003).

Plankton pumps continuously draw water and plankton into the vessel, where it can be filtered through a net for sample collection. Additionally, submersible pumps can be used to collect subsurface phytoplankton samples from a specified depth. Furthermore, plankton pumps enable the collection of integrated phytoplankton samples from the surface to a desired depth.

Phytoplankton fixation and preservation

The samples were preserved using various fixatives such as formalin, Lugol's Iodine, osmic acid, and gluconaldehyde. Among these, formalin is the most commonly used fixative and preservative for phytoplankton.

Formalin is primarily utilized for the preservation and fixation of phytoplankton samples. Commercial formaldehyde is typically diluted to a concentration of 2-5% for this purpose. Marine phytoplankton samples are typically preserved using a 5% formalin solution. An acidified formaldehyde solution made with 20% formaldehyde and 50% acetic acid (in a 1:1 ratio) is also an effective phytoplankton preservative, with the exception of dinoflagellates. Lugol's iodine solution, which consists of 100g of potassium iodide, 50g of crystal iodine, and 100ml of glacial acetic acid in 1 liter of distilled water, is a popular choice for preserving small-sized

phytoplankton. This solution, however, is not suitable for preserving coccolithophorids. Iodine fixes and preserves the color of phytoplankton, while acetic acid helps to preserve flagella and cilia.

For preserving a phytoplankton sample, three to six drops of osmic acid can be utilized. This solution comprises 200 mg of osmium tetroxide dissolved in 10 ml of distilled water and can effectively preserve a 100 ml phytoplankton sample.

Alternatively, a preservation solution consisting of 8 g of glutaraldehyde mixed with 100 ml of distilled water in a 1:1 ratio can also be employed for the same purpose.

Analysis of phytoplankton:

Aquatic ecosystems' primary productivity is typically determined using quantitative analysis of phytoplankton biomass, which also provides an estimate of the organic material available for zooplankton consumption. There are two methods for estimating phytoplankton biomass: total biomass estimation and species or group biomass estimation. Chlorophyll a estimation and direct cell counting are the preferred methods for total biomass estimation, while indirect estimates are based on cellular counts and biovolumes. These methods allow for the assessment of diversity and productivity in the area.

The direct count method involves counting individual phytoplankton cells and recording the number per cubic meter of water using the Sedgwick Rafter. This process involves diluting phytoplankton samples (1 ml) and spreading them uniformly to be counted under a microscope. To determine the total number of phytoplankton cells, multiple replicates of the samples are counted. The formula $N = nv/V$ is then applied, where:

- N represents the total number of phytoplankton cells per liter of water,
- n is the average number of phytoplankton cells in 1 ml of the sample,
- v denotes the volume of phytoplankton concentrate (in ml), and
- V represents the total volume of filtered water.

The chlorophyll a estimates were obtained using a spectrophotometric method.

Phytoplankton classification

Fritsch (1935) categorized the algal kingdom into 11 classes, distinguishing them based on morphological characteristics.

1. Chlorophyceae
2. Xanthophyceae
3. Chrysophyceae
4. Bacillariophyceae
5. Cryptophyceae
6. Dinophyceae
7. Chloromonadineae
8. Euglenineae
9. Phaeophyceae
10. Rhodophyceae
11. Myxophyceae

In 1950, Smith grouped algae into seven classifications. Prescott (1984) divided the algal kingdom into seven phyla, including classes and orders. Bold and Wynne (1985) categorized the algal kingdom into nine divisions by introducing the new division Charophyta, which is the most widely recognized classification system among the classical algal taxonomy. Lee (1980) introduced groundbreaking changes in algal classification based on cell structures, such as prokaryotes and eukaryotes, and chloroplast ultrastructure, and this is widely accepted. Lee (1980, 1989, 1999) also proposed a new division, Prochlorophyta, with prokaryotic members containing Chl b.

Lee's modified algal classification from 1989, 1999, and 2008 identified four separate categories based on the development of algal chloroplasts and flagellar structure.

Prokaryotic algae comprise cyanobacteria, while eukaryotic algae can be divided into four groups based on their chloroplast structure. The first group includes Glaucophyta, Rhodophyta, and Chlorophyta, which have chloroplasts with two membranes. The second group consists of Euglenophyta, Dinophyta, and Apicomplexa, which possess one chloroplast ER with a total of three membranes. The third group comprises Cyptophyta, Heterokontophyta, and Prymnesiophyta, which have two chloroplast ERs with a total of four membranes.

Phytoplankton exhibit a wide range of sizes, and Schütt (1892) first classified phytoplankton based on size variations.

Megaplankton	> 20 mm
Macroplankton	2 – 20 mm
Mesoplankton	0.2 – 2 mm
Microplankton	20 – 200 µm
Nannoplankton	2 – 20 µm
Picoplankton	0.2 – 2 µm
Femtoplankton	<0.2 µm

Plankton are broadly classified into two main categories based on their protein content: phytoplankton, which comprise plant-like

organisms, and zooplankton, which consist of animal-like organisms. Phytoplankton encompasses a variety of organisms, including diatoms, dinoflagellates, blue-green algae (cyanophytes), coccolithophores, and green algae.

Bacillariophyceae

Diatoms stand out as the most diverse and abundant single-celled photosynthetic eukaryotes present in virtually all aquatic environments. They represent a significant component of both marine and freshwater floating algae. Diatoms play a crucial role in aquatic biomass within nutrient-rich coastal ecosystems and serve as sensitive indicators of environmental conditions. Consequently, they hold immense ecological significance. Studies by Falkowski et al. (1998), Field et al. (1998), Mann (1999), and Malviya et al. (2016) estimate that diatoms contribute 40-45% of oceanic primary productivity, accounting for roughly 20% of global carbon fixation and oxygen production.

Diatoms are categorized into two main structural types based on their symmetry and organization: centric diatoms and pennate diatoms. Centric diatoms have radial symmetry and are characterized by their valves having a concentric or radiating pattern around a central or lateral point or points. The raphe or pseudoraphe is absent in these diatoms. These cells are usually circular, oval, or elliptical in shape, but may occasionally be polygonal or crescent-shaped. Centrales are more commonly found in open seas and are represented by three suborders: Discoideae, Solenoideae, and Biddulphioidae, which include nine families, 14 subfamilies, and 35 genera. On the other hand, pennate diatoms have bilateral symmetry and are distinguished by their valves having a symmetrical arrangement on both sides of a longitudinal axis. These diatoms have a raphe and are typically elongated and slender in shape. Pennate diatoms are more commonly found in freshwater environments and are classified into several orders based on their shape and other characteristics.

Pennales, also referred to as Pennate Diatoms, are characterized by elongated and symmetrical valves. Their outlines may vary, appearing boat-shaped, oval, cuneate, crescent-shaped, or sigmoid, with markings typically arranged in either pinnate or transverse patterns. These diatoms always feature a true raphe or hyaline median line (pseudoraphe), while processes are absent. In

cases where a true raphe is present, the cells are capable of spontaneous movement. Pennales are predominantly found in coastal waters and are classified into three suborders: Araphidineae, Monoraphideae, and Biraphideae, encompassing five families, 10 subfamilies, and 28 genera.

Dinoflagellates (Dinophyceae)

Dinophytes, a type of unicellular, motile algae, are distinguished by their characteristic two-part structure (two halves) and are composed of a multitude of intricately sculptured plates. Some members of this class possess a cellulose envelope and branched filaments. Motile cells of dinophytes have two flagella that they use for locomotion, one longitudinal and one transverse. Dinophytes are also capable of luminescence due to the presence of numerous discoid chromatophores. These organisms often form large, toxic blooms and are more commonly found in seawater than in freshwater.

Chlorophyceae (Green Algae)

Green algae are typically characterized by their unicellular, microscopic, filamentous, or colonial structures. These algae belong to the class Chlorophyta, which is distinguished by the presence of green chromatophores and the same pigment composition (chlorophyll a and b) found in higher plants. Green algae primarily inhabit freshwater environments, although they can also be found in coastal marine waters. They are widely distributed in tropical and subtropical seas and are represented by 15 orders and 22 families.

Cyanophyceae (Blue-green algae)

Members of the Cyanophyceae family, commonly known as blue-green algae, are typically referred to as cyanobacteria. These organisms can be either unicellular or multicellular, and they lack true nuclei or chromatophores. Their cells are smaller in size, blue-green in color, and lack membrane-bound cell organelles. In contrast to bacteria, cyanobacteria possess the ability to perform photosynthesis through chlorophyll a (some also have chlorophyll b or d). There are five orders of cyanobacteria: Chroococcales, Chaemosiphonales, Pleurocapsales, Nostocales, and Stigonematales. Picophytoplanktonic cyanobacteria are more abundant in nutrient-poor offshore waters and are found in almost all seas. Larger cyanobacteria often make up a significant proportion of oceanic phytoplankton.

Prymnesiophyceae (Cocolithophores): The Prymnesiophyceae are a group of single-nucleus flagellates that have a haptonema situated between two smooth flagella. These primarily marine organisms also have freshwater representatives, and their size ranges between 5 and 20 μm . The cells are often covered with scales, with many of these scales being calcified, resulting in the production of coccoliths.

The most prevalent genera of phytoplankton in Indian waters are *Hemidiscus*, *Coscinodiscus*, *Triceratium*, *Biddulphia*, *Bacteriastrium*, *Skeletonema*, *Climacosphenia*, *Rhizosolenia*, *Fragilaria*, *Pleurosigma*, *Pinnularia*, *Navicula*, *Nitzschia*, *Bacillaria* (bacillariophyceae); *Ceratium*, *Noctiluca*, *Peridinium*, *Dinophysis* (Dinophyceae); *Trichodesmium* (Cyanophyceae); *Globigerina* (Polythalamaea) and *Tintinnopsis* (Spirotrichea).

Zooplankton

Zooplankton are aquatic organisms that lack the ability to maintain a stable position against the flow of water. They are composed of a variety of animal taxa, primarily invertebrates, and serve as an essential trophic level in the ecosystem. Zooplankton help to transfer energy from primary producers to secondary consumers, and they play a crucial role in the food chain, making them a critical factor in determining the productivity of marine ecosystems as secondary producers. (Nair, 2001). The use of zooplankton communities is commonly employed to evaluate the productivity and overall health of ecosystems. (Thirunavukkarasu et al., 2013), Some species can serve as potential indicators for various water masses and environmental changes, such as water quality parameters and climate change, although the use of these indicators may vary depending on the specific context. (Russell, 1939). Coastal and marine regions are characterized by significant variability, which arises from fluctuations in water circulation patterns and land-based factors, such as river and sewage flow, resulting in substantial temporal changes. (Walsh, 1988). The production of zooplankton in coastal and inshore waters is primarily determined by seasonal changes caused by monsoons and upwelling. (Nair, 2001). The abundance and composition of zooplankton populations are directly influenced by changes in water quality parameters. (Gaonkar et al., 2010).

Coastal regions are continuously endangered by the discharge of sewage and industrial waste from urban and industrialized areas, which damages their ecosystems. Moreover,

shifts in environmental conditions can also impact the abundance and variety of zooplankton. (Calbet et al., 2001).

Methods of zooplankton collection

During the past years, zooplankton have been gathered using various equipment, including water bottles, pumps, and nets. Water bottles are commonly used for collecting smaller plankton forms, such as microzooplankton. To collect water samples, a 5-20 litre capacity sampler is typically employed at the sampling site. To gather surface water, a suitable-sized bottle may be filled by scooping water from the surface. The disturbance of the water should be minimized to prevent plankton from reacting negatively. Von Dorn bottles, named after Dr. William Van Dorn from the Scripps Institute of Oceanography, are commonly utilized for precise depth sampling. They allow for composite sampling from various depths or pooling samples from a single depth, facilitating both horizontal and vertical sampling. Horizontal bottles are frequently employed for sampling at specific levels like the thermocline or above the seabed. They collect whole water samples, ensuring representation across all plankton size classes. Zooplankton obtained in these bottles can be concentrated through settling, centrifugation, or fine filtration. While this method offers accurate sampling depths and ease of use, it filters less water and might miss larger plankton forms and rare species, making it less suitable for qualitative and quantitative assessments.

Pumps, typically used on boats or ships, involve submerging an inlet pipe in the water and connecting an outlet pipe to a net with suitable mesh size to filter zooplankton. This method allows for quantitative estimation and small-scale plankton distribution studies, but it has limitations on sampling depth and may damage larger plankton forms.

Plankton nets, available in various sizes and types, are the most widely used method for collecting zooplankton. They can be open nets for horizontal and oblique hauls or closed nets with messengers for vertical sampling at specific depths. Made of materials like bolting silk or nylon, these nets are conical and consist of a ring, a filtering cone, and a collecting bucket. Plankton nets enable both qualitative and quantitative studies, with mesh size influencing the types of zooplankton collected. Factors such as net type, length, towing speed, and time of collection affect sample quality and quantity. Zooplankton collections can be conducted through horizontal, oblique, or vertical hauls. Horizontal sampling entails

towing the net at a slow speed (1.0 to 2.0 knots) for 10 minutes. Oblique hauls involve towing the net above the seabed, risking inaccurate sampling depth measurement and potential net damage from substrate contact. Vertical hauls are used to sample the water column by lowering the plankton net to the desired depth and slowly retrieving it, capturing zooplankton as it passes through the net. This method is valuable for studying zooplankton abundance at various depths, especially as species often migrate vertically in response to light, though their presence in upper layers is typically low during the day. Effective zooplankton collection often occurs before dawn, after dusk, or at night, with the net submerged in water to start the process. Continuous net samplers and multiple net zooplankton samplers are utilized for continuous or simultaneous sampling. Continuous net samplers, like the Continuous Plankton Recorder by Hardy (1939) and Longhurst Hardy Continuous Plankton Recorder (1966), collect animals on a continuous strip of netting. In contrast, multiple net samplers open and close individual plankton nets in sequence, often employing 5–10 nets to collect zooplankton at various depths simultaneously. Furthermore, there are automated sampling systems and Recording Instrumental Environmental Sampling Systems, exemplified by the one devised by Dunn et al. in 1933a and 1933b, along with the high-speed Gulf-III OCEAN sampler crafted by Nellen and Hempel in 1969. Modern net systems incorporate sensors to measure water qualities and net properties, with flow meters installed to accurately estimate water volume filtered and plankton collected. Calibration involves towing the net with the flow meter attached for a known distance, recording the revolutions made, and calculating the volume of filtered water using the formula $\pi r^2 h$, where r is the mouth ring radius and h is the depth or distance.

Zooplankton-Preservation and Fixation

To uphold the quality of taxonomic studies, it's imperative to promptly fix and preserve specimens following collection. This precaution is essential to prevent degradation, which can arise from factors like bacterial activity, cannibalism, or chemical breakdown. Fixation entails terminating the organism's life while retaining its morphological features, while preservation involves maintaining this fixed state over an extended period. Formaldehyde serves as the most prevalent fixing and preserving agent, typically utilized at a concentration of 4-5%. Buffered formalin storage can effectively preserve zooplankton

samples for numerous years. Commonly employed buffers include borax (sodium tetraborate) and hexamethylenetetramine, the latter being added at a concentration of 200 g per liter of concentrated formalin.

Estimation of zooplankton:

i) Quantitative estimation

Zooplankton biomass can be determined using any of the three following methods outlined by Goswami (2004): the volumetric method, which involves measuring displacement and settling volumes; the gravimetric method, which involves calculating wet and dry weights; and the chemical method. To ensure precision in results, it's essential to segregate larger zooplankton specimens like medusae, ctenophores, fish larvae, salps, and siphonophores from the sample and document their biomass individually. The combined biomass of these larger forms, along with the remaining zooplankton, constitutes the total biomass, which should be clearly noted on the analysis sheet.

The volumetric method for determining zooplankton volume employs the displacement volume method, expressed in milliliters per cubic meter. This method involves estimating the displacement volume using a volume determiner. The volume determiner is a transparent cylindrical plastic device with a capacity of 100 milliliters and open ends. One end is equipped with a piece of netting matching the mesh size of the plankton net, and it can be securely sealed over the base, which is made of plastic. The other end features a detachable plastic lid with a side hole and a metallic pointer that aligns with the 50-milliliter mark on the cylinder when fixed over it.

To utilize this method, preserved plankton is poured into the volume determiner, and water is filtered out by repeatedly placing the cylinder over blotting paper until all the water is removed. The cylinder, now containing the plankton, is sealed watertight over its base. Then, an appropriate quantity of 5% formaldehyde solution is slowly dispensed from a 50-milliliter burette without introducing air bubbles until the water level reaches the tip of the needle on the lid. The volume of solution remaining in the burette corresponds to the volume of plankton in the cylinder.

Another method involves using a net with a mesh size equal to or smaller than the one used for collecting plankton. The plankton is filtered through the netting material, and any interstitial water is removed using blotting paper. The plankton is then transferred to a

measuring cylinder containing a known volume of 4% buffered formalin. The difference in solution levels equates to the volume of the plankton.

Alternatively, the volume of plankton can be determined by allowing the sample to settle for at least 24 hours and noting the settled volume. The volume of plankton per cubic meter of water filtered can be estimated by calculating the quantity of water filtered by the net during sampling.

The wet weight and dry weight of the plankton can also be obtained using the Gravimetric method. The wet weight is obtained after filtering and removing interstitial water on a pre-weighed filter paper or aluminum foil, expressed in grams. The dry weight is determined by drying an aliquot of the zooplankton sample in a pre-dried and pre-weighed filter paper in an electric oven at a constant temperature of 60°C for 24 hours, expressed in milligrams. The weight of plankton is then expressed as grams per cubic meter or milligrams per cubic meter. The Chemical method is a technique that involves measuring the levels of elements like carbon, nitrogen, and phosphorus, as well as biochemical components like proteins, lipids, and carbohydrates.

ii) Qualitative estimation

In qualitative assessments, individuals within the sample are identified and counted. Due to the often large number of individuals in a sample, enumerating the entire sample is usually impractical. Instead, a subsample or aliquot of 10%–25% is typically used for enumeration. The percentage of aliquots chosen can vary depending on the zooplankton abundance in the sample.

To obtain the subsample, a Folsom plankton splitter is commonly employed, dividing the

sample into two equal halves. This process is repeated until a suitable subsample size is achieved for counting. A Sedgwick Rafter Counting Cell is then utilized for counting, positioned under a stereoscopic microscope. The counts within the subsample are extrapolated to represent the total volume. These numbers are expressed per cubic meter of water, accounting for the volume of water filtered by the net during sampling.

Classification of zooplankton

Zooplankton are typically classified in a number of ways. Initially, they are categorized into two groups: holoplankton and meroplankton. Holoplankton consist of the species that reside exclusively in the pelagic zone throughout their lifetimes, such as copepods and chaetognaths. On the other hand, the meroplankton encompass organisms that only float in the ocean for a portion of their life cycle, such as the larvae of benthic mollusks and barnacles. Additionally, zooplankton are divided into two main types: protozoa and metazoans. Protozoa are a significant group because they multiply rapidly and are often the first organisms to consume algal blooms, such as diatoms. Metazooplankton, on the other hand, have a longer lifespan, ranging from a few days to several years, depending on the species. Thirdly, the zooplankton are classified based on their size. Finally, they are categorized as either neritic or oceanic. Neritic plankton live in inshore waters up to a depth of approximately 200 meters, while oceanic plankton inhabit the open ocean. Within the oceanic regime, they are further divided into epipelagic, mesopelagic, and bathypelagic zones, with the epipelagic and mesopelagic regions being the primary habitats for zooplankton.

Table 1. List of commonly available zooplankton groups/ species

Groups	Species Name	Groups	Species Name
Copepods	<i>Paracalanus aculeatus</i>	Sergestids/ Lucifers	<i>Lucifer hansenii</i>
	<i>Canthocalanus pauper</i>		<i>Lucifer penicillifer</i>
	<i>Paracalanus parvus</i>	Polychaetes	<i>Pelagobia spp</i>
	<i>Acartia centrura</i>	Ostracoda	<i>Cypridina dentata</i>
	<i>Acartia spinicauda</i>	Appendicularia	<i>Oikopleura dioica</i>
	<i>Acartia spp</i>	Salpida	<i>Thalia democratica</i>
	<i>Acrocalanus similis</i>	Doliolum	<i>Dolioletta gegenbauri</i>
	<i>Acrocalanus spp.</i>	Foraminifera	<i>Ammonia falsobeccarii</i>

	<i>Tortanus barbatus</i>		<i>Ammonia tepida</i>
	<i>Tortanus sp.</i>	Amphipods	<i>Hyperia sp.</i>
	<i>Centropages furcatus</i>		<i>Gammarus sp.</i>
	<i>C. orsinii</i>	Cladocerans	<i>Penilia avirostris</i>
	<i>Centropages tenuiremis</i>		<i>Evadne tergestina</i>
	<i>Temora turbinata</i>	Tintinnids	<i>Favella sp.</i>
	<i>Temora sp.</i>		<i>Tintinnopsis sp.</i>
	<i>Eucalanus crassus</i>	Isopods	<i>Sphaeroma sp.</i>
	<i>E. subcrassus</i>	Brachyurans	Crab zoea
	<i>Euchaeta marina</i>	Cirripedia	Cypris larvae
	<i>Euterpina spp</i>	Lobster	Phyllosoma larvae
	<i>Microsetella sp.</i>	Molluscs	Bivalve
	<i>Oithona sp.</i>		Gastropod
	<i>Oncaea sp.</i>	Chordata	Fish egg
	<i>Corycaeus sp.</i>		Fish larvae
Hydrozoans	<i>Lensia subtilis</i>	Decapods	Penaeid larvae
	<i>Lensia subteloides</i>	Crustacea	Zoea
	<i>Aequorea conica</i>	Stomatopods	Alima larvae
Chaetognaths	<i>Sagitta enflata</i>		
	<i>Sagitta bedoti</i>		

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Diversity of marine sponges

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Sponges which belong to the Phylum Porifera are also commonly called 'pore bearers' are asymmetrical or radially symmetrical metazoans characterized by a porous body and an internal system of canals. These primitive animals have cellular grade of organization i.e. the sponge body is formed of loose aggregation of cells, without tissues and organs. The body is perforated by numerous openings, called ostia or incurrent pores through which water enters into the body of the animal, besides few larger pores through which water goes out of the body; the phylum Porifera gets its name from this feature (L. porous = opening, fere = to bear). The sponges are also characterized by an elaborate system of canals for the circulation of water and the transport of food and oxygen. The body encloses a central cavity called spongocoel. Water enters the spongocoel through the ostia (small pores) and passes out through the osculum (large pores). The animal is devoid of mouth and digestive system. Lining the spongocoel and the canal system are a unique type of flagellated cells or collar cells called the choanocytes. The body wall of sponges consists of a gelatinous matrix, supported by spongin fibres and spicules. The spicules are small bristle-like structures, formed of either silica or calcium carbonate. The sponges are known to have high regeneration potential. Reproduction is both by sexual and asexual means. Asexual reproduction is by fragmentation and budding, while sexual reproduction involves a flagellated and free-swimming larva (Parenchymula, Amphiblastula).

The sponges are sessile aquatic organisms. They occur in marine and freshwater ecosystems; though higher diversity of these poriferans is found in marine habitats. The marine forms are found both in inshore as well as in deeper waters. They are presumed to be the earliest-branching metazoan taxon and therefore have immense significance in the reconstruction of early metazoan evolution. The sponges are the oldest Parazoans still extant and their continued existence in vast numbers is closely linked to the apparent adaptability to changes in the environmental characteristics and competing biota (Bergquist, 1978; Muller 2003).

The sponges are important components of coral

reefs having ecological, commercial and biopharmaceutical importance. Their biomass and ecological tolerance often exceed that of the reef-building corals (Reutzler, 1978). They are also known to be effective filter feeders with an ability to filter four to five times their own volume every minute (Allen, 2000). Some species of sponges are also capable of bio-eroding as well as consolidating reef structures (Hooper, 2000). Some specialized sponges are bio-eroders in coral reefs, coralline bottoms and oyster beds and may compete with other sessile organisms such as corals. Some species are also capable of binding unconsolidated substrate such as coral rubbles, gravels and pebbles to form stable surfaces. Many fossil sponges and a small group of Recent sponges are also capable of extensive reef formations that shape the contours of the benthos, in some places. Some of the megabenthic species may form high-density aggregations in many shelf edge and sea mount regions playing significant roles in deep-sea ecosystems.

The sponges have great commercial demand as some species are good sources of bath sponges used in cosmetic industries. They have also become the focus of biochemical studies due to the presence of novel compounds and bioactive secondary metabolites which can be used for curing many diseases, including cancer. Some sponges like *Aplysina fulva* and *Mycale microsigmatosa* have been found to have potential to prevent marine biofouling (Pereira et al., 2002). This renewed interest in sponges has accelerated the discovery and documentation of species in all the oceans. It is believed that the extant fauna may be twice as diverse as that currently described species (Hooper & Levi, 1994).

Classification of sponges

The Phylum Porifera is divided into three classes, based largely upon the chemical composition and structure of the supporting skeleton. These classes are Calcispongiae or Calcarea, Demospongiae and Hyalospongiae or Hexactinellida.

Class I: Calcispongiae or Calcarea

Calcispongiae are calcareous sponges whose spicules are formed entirely of calcium carbonate. They are the most primitive of all sponges and are generally inhabitants of

shallow coastal waters of seas all over the world. The members of Calcarea are small and simple; they are either solitary or colonial. The body is cylindrical or vase-like and the osculum are often fringed with bristles. The spicules are monaxonic (single-rayed) or tetraxonic (four-rayed) and are formed entirely of calcium carbonate. The choanocytes of species of this class are relatively large.

Class II: Demospongiae

Demospongiae is the largest group of sponges and encompasses more than 80% of the known species. The members of this class are most widely distributed and are the most highly organized of all sponges. They are large-sized and are either solitary or colonial. With the exception of the Family Spongillidae, all members are marine. The species of class Demospongiae are compact, mostly massive and brightly coloured. The spicules are made up of silica, but never of calcium carbonate. The spicules are monaxonic or tetraxonic and are differentiated into large spicules, also called megascleres and smaller ones called microscleres. In some of the forms, skeleton is absent.

Class III: Hyalospongiae or Hexactinellida

The members of Hyalospongiae are predominantly deep-sea forms, found at depths ranging from 300 to 8,000 metres. They are generally solitary forms, with cylindrical or funnel-shaped bodies, having structural complexity. The outer layer and inner flagellated layer of the body wall are syncytial rather than cellular. The spicules are glass-like and siliceous, and are four rayed or six rayed (hence the name Hexactinellida).

The members of this group have a simple canal system. The canal system is a unique feature encompassing a system of pores, canals and cavities through which water enters the body from outside, circulates within the body and passes out. The canals are lined by flagellated cells, also called collar cells and the beating of collar cells helps to maintain a constant circulation of water which is required for nutrition, respiration and excretion in sponges. Based on the canal system, sponges are classified into three types namely Asconoid, Syconoid and Leuconoid.

Type I: Asconoid

This is the simplest type of canal system consisting of a simple wall and a complete and continuous lining epithelium of choanocytes, interrupted only by the inner ends of the porocytes. The asconoid types of sponges are

generally radially symmetrical with a vase-like body. The body wall is thin and encloses a cavity called spongocoel which opens at the summit through a narrow opening called osculum. The movement of the flagella of choanocytes produces water current which passes through the incurrent pores (ostia) into the spongocoel and escapes out through the osculum.

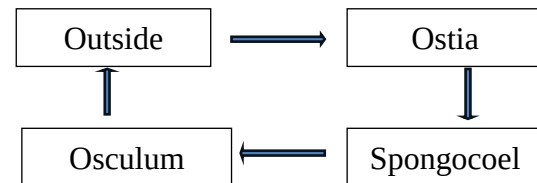


Fig. 1. Course of water current in the Asconoid canal system.

Type II: Syconoid

The Syconoid type of canal system is slightly advanced and a modified form of Asconoid type. The wall of these sponges is pushed into finger-like projections called radial canals, at regular intervals. In simpler forms, the radial canals are free projections and water surrounds the entire length. But in advanced forms, the walls of the radial canals are fused together, leaving tubular spaces between them called incurrent canals. The incurrent canals are lined with epidermis and they open to the exterior through ostia or dermal pores.

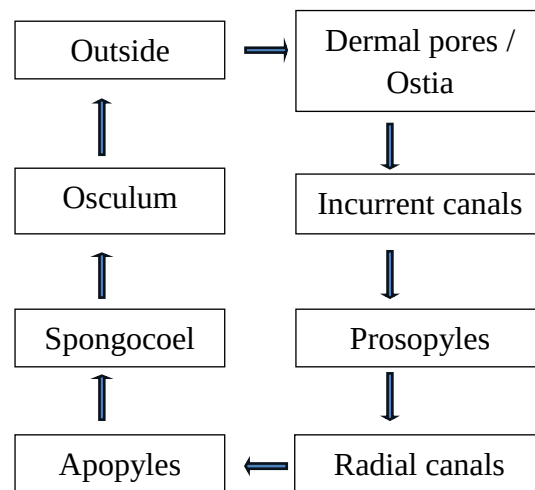


Fig. 2. Course of water current in the Syconoid canal system

The wall between the incurrent and the radial canals is pierced by numerous pores called prosopyles. The radial canals open into the spongocoel through the internal ostia or apopyles.

Type III: Leuconoid

The leuconoid type of canal system is more complex and advanced than the asconoid and syconoid type of canal systems. It is a modification of the syconoid structure in which the choanoderm of the radial canal evaginates forming clusters of small rounded or oval flagellated chambers, replacing the elongated radial canals seen in the syconoid type of canal system which involves an increased outward folding of choanoderm and thickening of the body wall. The dermal pores or ostia lead into incurrent canals that branch irregularly through the mesenchyme. The incurrent canals lead into small round flagellated chambers through prosopyles.

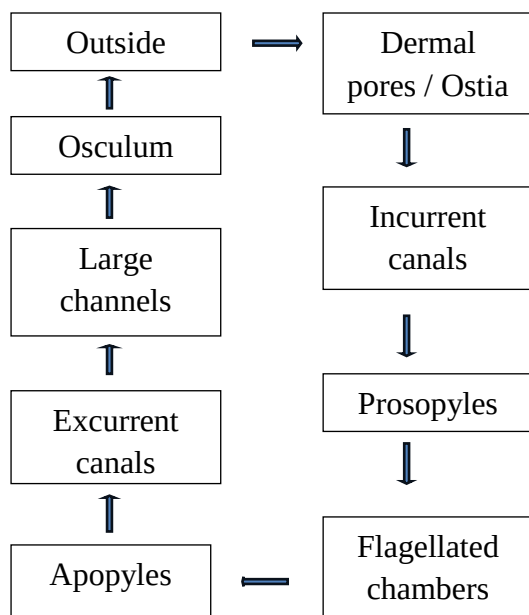


Fig.3. Course of water current in the Leuconoid canal system.

Water from the flagellated chambers enters the excurrent channels through openings called apopyles. The excurrent channels unite to form large tubes leading to the osculum through which water goes out.

Reproduction and propagation

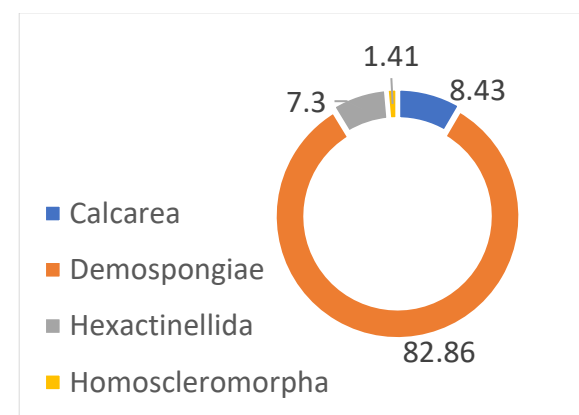
Sponges have the ability to reproduce asexually and sexually and most of them are hermaphrodites. Asexual reproduction is by fragmentation and budding wherein parts of the sponge body or buds get detached from the sponge body and carried away by water currents to different locations where they settle on a hard substratum and develop into an adult sponge. Some of the sponges also form gemmules which are commonly found in freshwater species.

Sexual reproduction takes place when the male releases the gametes into the water which moves in the water column and thereby captured by female choanocytes leading to internal fertilization. The larvae are then released into the water which uses their cilia to propel through water and settle down on a substratum to develop into an adult sponge. The sponges thus take role changes on male and female during every reproductive cycle.

Diversity of marine sponges

The sponges are found distributed in both tropical and temperate waters. Currently, a total of 9,637 valid species of sponges are enlisted in the World Porifera Database (de Voogd et al., 2024); however, it is believed that there could be more species. The World Porifera Database (WPD) is the database of all recent sponges ever described, and is a part of the World Register of Marine Species (WoRMS), a global initiative to arrive at a register of all marine organisms. Table 1. Accepted described species numbers extracted from the World Porifera Database (2024).

Class	Total No. of accepted species
Calcarea	812
Demospongiae	7,985
Hexactinellida	704
Homoscleromorpha	136
TOTAL	9,637



The coral reef areas in the Indian waters are rich in sponge fauna and a total of 486 species of marine sponges were described from the Indian

waters (Thomas, 1998). The highest diversity was recorded in the Gulf of Mannar and Palk Bay (319 species), followed by Andaman & Nicobar Islands (95 species), Lakshadweep Islands (82 species) and the Gulf of Kachchh (25 species). A total of 34 species of coral boring sponges have also been reported – 20 from the Gulf of Mannar and Palk Bay, five from the Andaman & Nicobar Islands and 18 species from the Lakshadweep reefs. Venkataraman and Wafar (2005) in their review on coastal and marine biodiversity of India, has mentioned a total of 451 species of sponges that belong to 169 genera and 65 families. Intensive field surveys in the hitherto unexplored areas may result in the discovery of many new species that were not reported earlier.

Studies on the taxonomy of sponges in India dates back to the nineteenth century with the pioneering studies of Bowerbank (1873), Carter (1880), Dendy (1887, 1905, 1916, 1922), Schulze (1902), Annandale (1915), Burton (1928, 1930, 1937), Dendy & Burton (1926), Burton & Rao (1932) and Rao (1941). Efforts by Thomas (1968, 1986) have led to the discovery of many new species of sponges. Pattanayak (1999) brought out the first checklist of sponges. Studies on the sponge fauna of east of India were more (Dendy, 1905; Burton, 1930, 1937; Thomas, 1968, 1986) when compared to the west coast of the country (Dendy, 1916, 1922; Thomas, 1979, 1980, 1989).

Taxonomic studies in sponges – Approaches

Specimen collection

The sponges from the intertidal region can be collected by wading while the sub-tidal specimens can be collected by diving or dredging. The specimens that come as bycatch in trawl or the specimens that get entangled in bottom-set gill nets can also be collected when fresh. The deep-sea sponges can be collected using epibenthic or hyperbenthic sledges in the bathyal and abyssal zones.

Coding and preservation

The specimens are to be given codes, and photographs of the whole specimen need to be taken before their preservation. The specimens should be examined for their morphological features like growth forms, shape, surface ornamentation, colour, consistency and faunal associates. The surface of the specimen needs to be examined for oscules, conules etc. with the help of a hand lens. For taxonomic purposes, the specimens can be preserved in 70% ethanol, while a small portion of the specimen can be

preserved in absolute alcohol for molecular taxonomy studies.

Histology

Most of the species belonging to the Class Demospongiae and Hexactinellida contain both soft tissues and mineral skeleton and hence require clearing of tissues to view the spicules. The subclass Keratosa and Verongimorpha of Class Demospongiae lack mineral skeleton and hence require clearing of tissues to view the spongin fibres and soft tissues. The members of the Class Calcarea have soft tissues and calcitic spicules and hence require tissue clearing to view the spicules. Thin sections of specimen are placed in containers having saturated solution of phenol crystals in xylene or any other histological clearing agent overnight. The sections can then be mounted on microscope slides using any viscous mounting medium. The slides are kept in oven at low heat overnight to set the mounting medium.

Spicule preparation

For sponges belonging to the class Demospongiae, a small portion of specimen is removed using a razor blade. This is placed in a test tube and a few drops of concentrated nitric acid is added to the test tube. This will digest all the organic material and only the siliceous spicules remain. Subsequently, three to four washings are given to remove the acid completely from the test tube and the spicules are removed and stored in vials with water. In the case of calcareous sponges, bleach is used instead of nitric acid.

Species identification

After gathering the morphological details, the architecture of the skeleton is observed under microscope. The geometry and size of the spicules are very crucial in the identification of sponges to the species level. Some species of sponges have only one type of spicule, while some have several types of spicules and there are few which do not have any spicules. The extracted spicules, both megascleres and microscleres, are observed under a compound microscope at different magnifications ranging from 4x to 100x, to ensure that all spicules that are present are recorded. The different types of spicules are measured using Image Analysis software. The keys and illustrations given in 'Systema Porifera' by Hooper and Van Soest (2002) is suggested for identification of specimens to the species level.

Table 2. Important Orders and Families of the most dominant Class Demospongiae

Order	Family
Keratosida	Spongiidae
	Dysideidae
	Aplysillidae
	Halisarcidae
Haplosclerida	Haliclonida
	Desmacidonidae
	Adociidae
	Callyspongiidae
Poecilosclerida	Phorbasidae
	Coelosphaeridae
	Taprobaneidae
	Plocamiidae
	Myxillidae
	Tedaniidae
	Psammascidae
	Raspailidae
	Microcionidae
	Ophlitaspongiidae
	Amphilectidae
	Axinnellidae
Halichondrida	Halichondriidae
	Hymeniacidonidae
	Monathidae
	Spirastrellidae
Hadromerida	Suberitidae
	Placospongiidae
	Clionidae
	Gastrophanellidae
Epipolasida	Jaspidae
	Sollasellidae
Choristida	Tethyidae
	Ancorinidae
	Geodiidae
Carnosida	Craniellidae
	Halinidae
	Plakinastrellidae
	Chondrillidae
	Chondrosiidae

Examples of some Demospongiae sponges and their spicule characteristics

1) *Sigmadocia carnosa*

Class: Demospongiae
Order: Haplosclerida
Family: Adociidae

Characteristic features:

- Colour: pale yellow when alive.
- Texture: compressible with good resiliency.
- Sessile, lamellate or encrusting; marginate in lamellate specimens.
- Oscules terminal and compound, diameter 1 to 2mm.

- Dermal skeleton a well developed unispicular reticulation.

Spicules:

- Oxeas: 0.10-0.13x0.003-0.009 mm.
- Sigmas: chord 0.034-0.038mm.

2) *Petrosia similis*

Class: Demospongiae
Order: Haplosclerida
Family: Adociidae

Characteristic features:

- Colour: purplish blue when alive.
- Texture: hard and incompressible.
- Spongethick, surface irregularly ridged.
- Oscules scattered; oscule diameter 0.5 to 2.0mm.
- Pores minute.
- Surface hispid due to the presence of terminal parts of the main fibres.

Spicules:

- Oxeas: size 0.2-0.34x0.011-0.027mm.
- Strongyles: size 0.2-0.3x0.02-0.03mm.

3) *Callyspongia fibrosa*

Class: Demospongiae
Order: Haplosclerida
Family: Callyspongiidae

Characteristic features:

- Colour: pale yellow when alive.
- Sponge composed of finger-shaped/flattened branches; surface with strong conules, conules prominent at growing tips.
- Oscules irregularly distributed, terminal or marginal, rounded or elliptical, shallow and compound; oscule diameter 1 to 4mm.

Spicules:

- Oxeas: straight or slightly curved, tips abruptly pointed, size 0.08-0.11x0.002-0.007mm.

4) *Myxilla arenaria*

Class: Demospongiae
Order: Poecilosclerida
Family: Myxillidae

Characteristic features:

- Colour: brownish with yellow tinge when alive.
- Texture: hard.
- Sponge massive with sand grains heavily incorporated.

- Oscules scattered; oscule diameter 0.5 to 1.0mm.
- Pores not traceable.
- Surface rough and uneven.
- Dermal skeleton tangential, stongyles and micro scleres are irregularly scattered.
- The main skeleton consists of an agglutination of sandgrains united by films of spongin.
- Spicules:
 - Strongyles: size 0.10-0.14 x 0.002-0.004 mm.
 - Acanthostyles: size 0.06-0.069x0.003-0.006mm.
 - Isochelas: size 0.015-0.03mm chord.
 - Sigmas (mediumsize): chord, 0.013-0.034mm.
 - Sigmas (large): chord,0.051-0.057mm

5) *Clathria frondifera*

Class: Demospongiae
Order: Poecilosclerida
Family: Ophlitaspongiidae

Characteristic features:

- Maximumheightofspecimen:67mm.
- Colour:brick-redwhenalive.
- Texture:firmandcompressible.
- Spongeconsistsofaclathrousmassofflattened orroundedtrabeculae.
- Osculesandporesarenotttraceable.
- Skeletonisareticulationoffibrescoredandechi natedbystylesandacanthostyles.
- Two typesof subtylostylesare present,the largeroneinterstitiallyandsmaller,inthederma lpart.
- Spicules:
 - Styles: size 0.164-0.338x 0.003-0.010mm.
 - Acanthostyles:size0.104-0.115x0.011mm;moremagnified(bottom).
 - Subtylostyles:size0.09-0.23x0.005-0.013mm.
 - Isochelas,palmate:chord,0.012-0.016mm.
 - Toxas(hair-like):notseen

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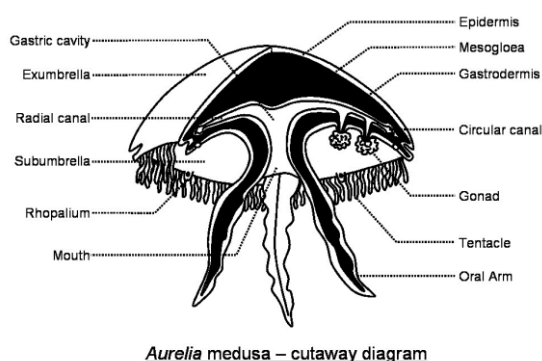
Diversity of jellyfishes

Dr. R. Saravanan

Mandapam Regional Centre, ICAR-CMFRI

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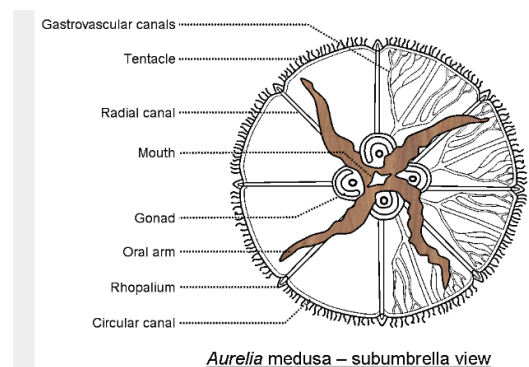
Jellyfish is a common term used for any gelatinous animal in marine waters. These include a wide variety of stinging and non-stinging jellyfishes. Jellyfish are the oldest animal on planet Earth, dating from the pre-Cambrian period, and have passed through 500 million years of natural selection. The word "jellyfish" is usually used for a group of jelly-like zooplankton that includes planktonic members of the phylum Ctenophora, Salps and Pyrosomes, and medusae from the phylum Cnidaria (scyphomedusae, hydromedusae, cubomedusae, and siphonophores). The true jellyfish come under the three Cnidarian classes, viz., Hydrozoa, Scyphozoa, and Cubozoa, and seasonally swarm in the coastal waters. Among the three classes, representatives of Scyphozoan and Cubozoan jellyfish range in size from 2 mm to 2 m in bell diameter, however, most of the hydrozoan jellyfish are smaller than 2 mm in bell diameter and belong to the mesoplankton. The biodiversity of pelagic scyphozoan jellyfishes and cubozoan jellyfishes is largely ignored in India, other than a few works in this line. The first work on scyphozoan medusae was published way back in 1930, in which the scyphomedusae of Madras were described with illustrations (Menon, 1930). Subsequent to this publication, the above author has brought out the scyphomedusae of Kurusadai Island (Menon, 1936). These are the two classic works that describe the taxonomic features and distribution of scyphomedusae along the south-east coast of India. Since then, there has been a long gap in the study of scyphomedusae in India. The scyphomedusae available in India were listed as 34 by Chakrapany (1984). The Medusae of the Travancore waters was studied by Nair (1951)



and assessed for its impact on fisheries.

Morphometric features of Jellyfishes

Jellyfishes are simple organisms with three layers of tissue, viz., endoderm, ectoderm, and mesoderm. The body is composed of over 90 percent water. The umbrella shaped body, which is called the bell, and the underside are covered with oral arms, or tentacles. In jellyfish, differences in the bell margin are used as a differentiating characteristic between different



(Image based on: <https://cronodon.com/BioTech/Jellyfish.html>)

groups. The members of the order Semaestomeae have tentacles on the bell margin, whereas the members of the order Rhizostomeae have tentacles on the tip of their oral arms. Jellyfish are 97% water and are semi-transparent.

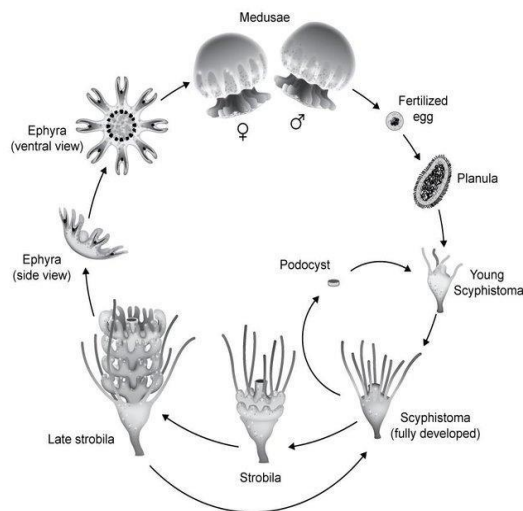
Jellyfish have two body layers: the outer layer, the epidermis and the interlayer, the gastrodermis. Between both layers is a thick layer of mesoglea, which consists of fibres embedded in a hydrated matrix that contains cells. These layers of tissues make up the umbrella of the jellyfish, which is usually bell-shaped; thus, the umbrella is also known as the bell. The scyphozoan jellyfish are tetra-radially symmetrical, meaning they have many structures in multiples of four. It contains a simple gastrovascular cavity that acts as the stomach. They are also characterised by having gastric filaments in the stomach. Some scyphozoan jellyfish, such as Semaestomeae, contain an opening, or mouth, at the subumbrella. There are four to eight oral arms near the mouth, which function as arms to capture and transport food to the gastrovascular cavity. Jellyfish lack

eyes but possess many sensory receptors capable of detecting light, pressure, temperature, and gravity. These sensory receptors are concentrated in the marginal sense organ that contains the rhopalium (Nakanishi, 2015). Not all jellyfish possess tentacles. For Semaestomeae jellyfish, tentacles can be found at the margin of the bell or at the subumbrella, whereas tentacles are absent from the Rhizostomeae jellyfish. Jellyfish contain a network of canals that usually anastomose with each other and form various patterns.

Life cycle and biology

Cnidarian jellyfish, also called medusae, have complex life cycles that often involve a benthic stage: the polyp and the pelagic stage: the medusae or jellyfish. This bipartite life cycle alternates between an asexual, benthic polyp and a sexual, pelagic medusa. Medusae typically are produced asexually in abundance and grow rapidly in seasons (Russel, 1970).

Life cycle of the cannonball jellyfish



Stomolophus meleagris based on Calder (1982)

Diversity and distribution of jellyfishes in India

Class Scyphozoa is ascribed to four orders, namely Stauromedusae, Coronatae, Semaestomeae, and Rhizostomeae, with 65 genera and over 187 species globally. The diversity of scyphozoan jellyfish along the Indian coastal waters has been reported at 29; however, given the poor research attention given to this group, there may be more species to be recorded in the coming years.

Order Semaestomeae

The order Semaestomeae composed of three families, four subfamilies, 18 genera and 56 species (Kramp, 1961). Semaestomeae jellyfish are characterized by four oral arms around the mouth. Tentacles are found at the umbrella margin. (Arai, 1997). The two important families of Semaestomeae are Cyaneidae and Pelagiidae.

Order Rhizostomeae

The order Rhizostomeae is composed of two suborders, 10 families, 25 genera, and approximately 89 species (Kramp, 1961). Rhizostomeae jellyfish are characterised by having a bell margin cleft into a lappet, with no tentacle on the bell margin, without a central mouth, and with eight oral arms extended from the subumbrella, where each oral arm bears numerous secondary mouths. A network of canals is found beyond the stomach. (Kramp, 1961; Arai, 1997). The important orders of this family are Mastigiidae, Versurigidae, Lychnorhizidea, Catostylidae, Lobonematidae, and Rhizostomatida.

List of Scyphozoan jellyfishes Occuring in Indian waters

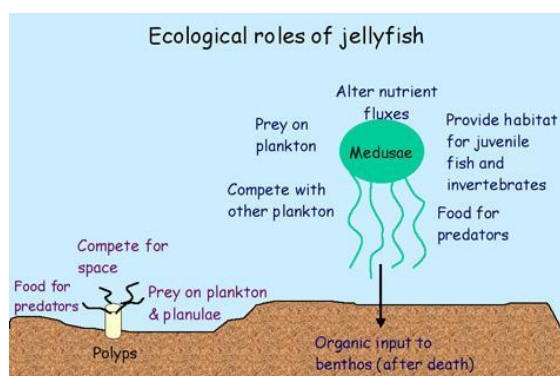
- *Atollawylliei* Haeckel, 1880
- *Nausithoe punctata* Kölliker, 1853
- *Periphylla periphylla* (Péron & Lesueur, 1810)
- *Cyanea nozakii* Kishinouye, 1891
- *Pelagia noctiluca* (Forsskål, 1775)
- *Aurelia aurita* (Linnaeus, 1758)
- *Acromitus flagellatus* (Haeckel)
- *Acromitus maculosus* Light, 1914
- *Catostylus mosaicus* (Quoy & Gaimard, 1824)
- *Crambionella orsini* (Vanhöffen)
- *Crambionella annandalei* Rao, 1931
- *Lobonemasmithii* Mayer, 1910
- *Lobonemoides robustus* Stiasny, 1920
- *Lobonemoides sewelli* Rao, 1931
- *Lychnorhiza malayensis* Stiasny, 1920
- *Rhopilema hispidum* (Vanhöffen, 1888)
- *Cassiopea andromeda* (Forsskål, 1775)
- *Cassiopea xamachana* Bigelow 1892
- *Cephea cephea* (Forsskål, 1775)
- *Marivaghiastellata* Galil & Gershwin, 2010
- *Netrostomacoerulea* Maas, 1903
- *Netrostomasetouchianum* (Kishinouye, 1902)
- *Mastigias papua* (Lesson)
- *Versuriga anadyomene* (Maas)
- *Phyllorhiza punctata* Lendenfeld, 1884
- *Thysanostoma loriferum*
- *Thysanostoma thysanura* Haeckel, 1880

List of Cubozoan Jellyfishes occurring in Indian waters

- *Alatinaalata* (Reynaud, 1830)
- *Alatinamadraspatana* (Menon, 1930)
- *Tamoyagargantua* Haeckel, 1880
- *Chiropsalmusquadrumanus* (F. Muller, 1859)
- *Chiropsoides quadrigatus* (Haeckel, 1880)
- *Chiropsoidesbuitendijki* (van der Horst, 1907)
- *Chironexindrasaksajiae* Sucharitakul, 2017

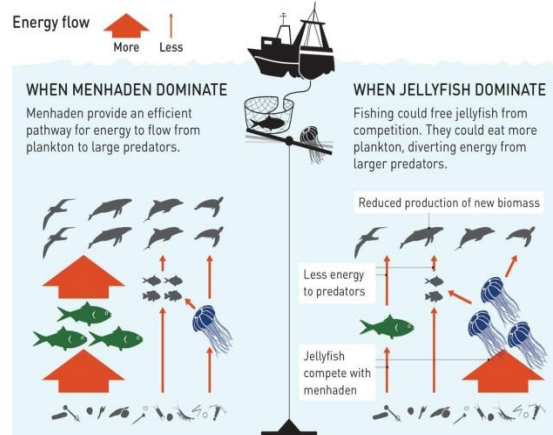
Ecosystem importance of Jellyfishes

Jellyfishes are distributed globally and often form swarms under favourable conditions that last for weeks to months before they collapse. Though jellyfish population swarms occur in many places at an increasing trend, the lack of time series data on their distribution and abundance along the Indian coast prevents us from concluding their population dynamics. Establishing time series data around the Indian subcontinent and



island territories on jellyfish abundance is difficult due to the fact that, in most cases, these jellyfish get damaged in bottom trawls and zooplankton tows and are not properly recorded. Jellyfish directly interfere with many human activities (reviewed by Purcell et al., 2007; Richardson et al., 2009), specifically through stings (beach closures, tourism impacts, injuries, deaths), clogging intakes (coastal power and desalination plants, mining and military operations, shipping, aquaria), interference with fishing (clogged and split nets, spoiled catch, stung fishers, damaged gear, capsized boats), aquaculture (fish deaths, pens fouled by polyps), and marine biological surveys (interference with trawls and acoustic surveys). Jellyfish also have ecosystem impacts with indirect effects on fisheries resources that are difficult to quantify, such as their roles as predators of zooplankton, fish eggs, and ichthyoplankton, as vectors for parasites, as food for fish, and as refugia and food for some species of juvenile fish.

Invasive species of jellyfish are reported in 21 of 45 LMEs. For the most part, invasive species were not responsible for the observed increases reflected in the results; however, the widespread detections demonstrate that jellyfish are truly global invaders of significant concern. Thriving populations of invasive jellyfish in systems like the Mediterranean and Black Seas should serve as warnings for other ecosystems around the



Potential ecosystem shifts due to fishing- From fish dominated to jellyfish dominated (Robinson et al. 2015)

Gut content studies of Jellyfishes

In order to study the gut content of jellyfish, their gastric pouches are excised, opened, and the contents rinsed through a 100- μ m mesh sieve. This is a common procedure for concentrating gut contents and handling samples of large medusae. The collection of jellyfish for gut content studies should be preferably done in the night. All medusae should be studied within 35 minutes of collection, which is less than published prey digestion times (Arai 1997).

Global jellyfish Fisheries

Dried jellyfish is considered a delicacy in many Asian countries. Jellyfish are also purported to have beneficial medicinal properties and are traditionally used to treat ailments such as arthritis, hypertension, and back pain (Hsieh et al., 2001). Jellyfish have been harvested off the coast of China for more than 1700 years (Omori & Nakano, 2001).

Only jellyfish belonging to the order Rhizostomeae are harvested for food. The rhizostomes are preferred because they are typically larger and have more rigid bodies than other scyphozoan orders. When processed, the rhizostomes produce a product that has a desirable, almost crunchy texture. Some species considered to be edible are:

Cepheidae	<i>Cephea cephea</i>
Catostylidae	<i>Catostylus mosaicus</i> , <i>Crambione mastigophora</i> , <i>Crambionella</i> <i>orsini</i> , <i>Crambionella</i> <i>annandalei</i>
Lobonematidae	<i>Lobonema smithi</i> , <i>Lobonemoides gracilis</i>
Rhizostomatidae	<i>Rhopilema esculentum</i> , <i>Rhopilema hispidum</i> , <i>Rhizostoma pulmo</i>
Stomolophidae	<i>Stomolophus meleagris</i> , <i>Stomolophus nomurai</i>

Indian Jellyfish fisheries

There are active jellyfish fisheries along Kerala, Gujarat, and Andhra Pradesh, and four species support jellyfish fisheries in India, viz., *Crambionella annandalei*, *C. orsini*, *Catostylus perezii*, and *Rhopilema hispidum*, which are processed and exported to overseas markets.

Guidelines for Jellyfish studies

Preservation Method

Scyphozoans are typically preserved for morphological analyses in a solution of 4% formalin in seawater with the appropriate label (i.e., 4 parts formalin [37% w/v] and 96 parts seawater). Place the jellyfish in a plastic container with a label (waterproof paper) and pour formalin until the organism is completely covered.

If you are using a plastic bag, place the organisms in a bag, fill it with formalin, twist the bag, and use a rubber band to wrap the plastic bag. When it is tight enough, fold the tip of the plastic bag, and with the last part of the rubber band, secure the folded part of the bag. An excess of 4% formalin solution is used, and it can be renewed after two weeks to ensure successful fixation.

Tissue storage for DNA studies

1. Flush the oral arms or bell margin with tap water. Repeat several times to displace all the debris.
2. Using clean forceps or scissors, cut a half-fingernail-sized piece of tissue from the oral arm or bell margin.
3. Preserve the tissue in one vial of preservative. (Make sure there is excess preservative; guard against diluting the preservative with too much water.)

4. With forceps, hold a piece of oral arm and cut it with clean scissors or razor blades.

5. Place the piece of tissue in a vial with 95% ethanol.

Specimen Information to be collected

- Geographic location
- Depth
- Date (of collection)
- Collector (e.g. your name)
- Photograph
- Whole jellyfish preserved? (yes/no; where)
- Conditions

Photograph of the following features

Bell

Differences in the bell margin can be useful to distinguish orders of medusae. For example, the semaeostomeae, in contrast to the rhizostomeae, have tentacles on the bell margin.

Canal

Canal structure inside the bell

Cnidae

In jellyfish, most cnidae are located in and around the tentacles and/or oral arms. Their shape is used for identification.

Mouth-arms

Differences in the form of the mouths distinguish orders of scyphomedusae. The Rhizostomeae have many small mouths distributed over their oral arms in contrast to semaeostomes, for example, which have a single, much larger, central mouth. The form and distribution of mouths over the oral arms can also be useful for distinguishing taxa within the Rhizostomeae.

Rhopalia

Rhopalia (singular rhopalium) are the most obvious sensory structures of scyphozoan jellyfish. They include specialised structures for sensing light (eyespot) and movement or direction with respect to gravity (statoliths).

Table .1 Checklist to study the Morphological features of Scyphozoan and Cubozoan Jellyfishes

1	Tentacles present on umbrella (on margin or underside) (or) Tentacles lacking on umbrella	
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2	Umbrella almost spherical (or) Umbrella not spherical	
3	Umbrella without prominent white spots(or) umbrella with numerous prominent white spots	
4	Mouth-arms with stout finger-like appendages (or)Mouth-arms with long and slender fi laments basally	
5	Tentacles on underside of umbrella (or) Tentacles on margin of umbrella	
6	Tentacles in a wide band around underside of umbrella; medusae large (or) Tentacles in 8 U-shaped clusters on underside of umbrella	
7	Colour of the Umbrella	
8	Umbrella cuboid or not cuboid	
9	Umbrella higher than a hemisphere (or) Umbrella decidedly flattened.	
10	Tentacles round noodles like or pasta like flattened	

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Soft coral and Gorgonids Diversity

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Coral reefs, which constitutes 0.2% of the ocean's area, are the most productive and diverse ecosystems (Appeltans et al. 2012). Octocorals are one of the most abundant benthic animals in coral reef community. Octocorallia is a subclass within class Anthozoa and phylum Cnidaria. Soft corals, gorgonids, blue corals and sea pens belong to the subclass octocorallia. Globally, Octocorals are found in all marine environments from intertidal to the deep waters (Perez et al. 2016). In addition to serving as special importance for life-history stages for a wide range of different species, they also serve as microhabitats for marine animals and provide protection from predators. They are extremely significant from an ecological standpoint. Research on octocorals (soft corals and gorgonids) is inadequate as compared to hard corals, in spite of their importance to reef ecology and biodiversity.

Soft corals are ahermatypic corals (Alcyonacea) that do not produce reefs or the calcium carbonate skeleton. They typically have vibrant colors and resemble underwater plants that sway in the ocean's waves. They are colonial, and small polyps frequently join together to become larger organisms. Gorgonids are soft corals commonly known as Sea fans and Sea whips. They form colonies which are modular in nature, typically having several branches. They exhibit a rigid internal axis, made of calcite and gorgonin, in both the main stem and all of the branches.

These sclerites can be fused together or be made of scleroproteinous gorgonin. The soft tissue coenenchyme covering the entire axial skeleton is packed with many calcareous sclerites that are either embedded in it or resting on its surface.

General morphology

The characters including colony shape and sclerite characterization have historically been used to classify and identify members of the Order Alcyonacea (Fabricius & Alderslade 2001).

Colony form

The colony morphology of many common octocorals is branching type. Certain species can be easily distinguished based on the kind and degree of branching. Whip-like, capitate, encrusting, leaf-like, club-shaped, and pen-like are typical non-branching colony forms.

Polyps

Each polyp has a cup-like form with a ring of tentacles encircling a central opening known as a pharynx, which serves as the organism's mouth and anus. Eight tentacles, or octo-coral, are borne by polyps invariably. These tentacles are typically (though not always) bordered along both edges by one or more rows of pinnules and eight complete mesenteries. Polyps can exist alone or in colonies. Monomorphic colonies are those that contain only one kind of polyp, whereas dimorphic colonies contain two different types of polyps. Monomorphic taxa are those that only have autozoid polyps (Bayer et al. 1983). A secondary reduced polyp (siphonozooid) that is responsible for siphoning water into the colony and potentially involved in reproduction, may also be present in certain taxa which are deemed dimorphic (Bayer et al. 1983).

Tissues

The outer layer of polyp tissue in contact with the external environment is the epidermis, which contains various specialized cells, such as cnidocytes. The inner tissue layer, the gastrodermis, lines the tentacles and the gastrodermal cavity, and thus covers eight mesenteries and the inner surface of the pharynx. The coenenchyme is the colonial tissue between the polyps and includes the calyces or polyp mounds (if present). This tissue is perforated by many solenia, the narrow canals that transport fluids between the polyps. In species that have a spiculated axis, the coenenchyme is often referred to as the cortex.

Sclerites

All calcified tiny components imbedded in the coenenchyme of octocorals are referred to as sclerite. The terms capstan, spicule, spindle, double head, rod, plate, club, etc. are more precise terms for each sclerite form. Bayer et al.

(1983) provided images that represent the different morphologies of over 150 types of sclerites. With the exception of few species, sclerite morphology plays an important role in the classification and identification of octocorals.

Axis

Octocorals, or more precisely, the Alcyonacea, are divided into sub-orders based on axis shape. The axis of the majority species might be horny, horny and calcified, or largely composed of sclerites.

Systematics and Taxonomy

Class Anthozoa Ehrenberg, 1831

Subclass Octocorallia Haeckel, 1866

Order Alcyonacea Lamouroux, 1812

There are 46 families of soft corals and sea fans in the order Alcyonacea (McFadden et al., 2022). Traditional taxonomic classification of the order into different sub-orders and families mostly based on gross morphological features (presence/absence and composition of a skeletal axis and the overall growth form of the colony). Alcyonacea are further subdivided into six sub-orders such as Alcyoniina, Calcaxonia, Holaxonia, Protoalcyonaria, Scleraxonia, and Stolonifera. Gorgonids (sea fans and sea whips) belongs to three sub-orders such as Scleraxonia, Holaxonia and Calcaxonia depending on the structure of the supporting axis. The soft corals are included in three sub-orders such as Protoalcyonaria, Stolonifera, and Alcyoniina due to lack of internal axes (Grasshoff 1999). Taxonomic assignments are conventionally based on similarities in colony morphology and sclerites according to the classification of Bayer (1981). In the order Alcyonacea, family-level classification is still considered unstable (McFadden et al., 2010). However, this classification is presently referred by the majority taxonomists.

Methods for identification

Some basic laboratory equipments (dissection kit, Teasing needles or fine-pointed dental picks, Fine tipped forceps, Scalpels, Compound and Stereomicroscopes) are needed to examine specimens for identification. Furthermore, different chemicals are required to anesthetize, fix, and isolate sclerites. As with any work involving specialized tools and chemicals, care should be given to proper safety procedures and expert guidance. Basic procedure followed for identification are as follows:

- a. **Anaesthetization:** Polyps can contract or completely retract into the coenenchyme in response to any disturbance of a live colony. Anaesthetizing the polyps in a colony to maintain them in their natural condition of expansion is crucial for accurate identification. There are different methods for narcotizing or anaesthetizing marine invertebrates. Magnesium sulfate solution (5 grams Magnesium sulfate and 45 milliliters de-ionized water) is the ideal choice in chemical narcotizing or relaxing octocoral polyps.
- b. **Specimen Fixation:** Once coral samples are removed from their aquatic environment, autolysis occurs, causing a breakdown of cells. A fixative solution is used to preserve soft tissue structure. Formalin is the easiest fixative, but may not retain nuclear details. Helly's Modified Seawater fixative is effective for histological work.
- c. **Sclerites preparations:** To collect tissue samples from a colony, remove fixed specimens from storage and cut them into pieces. Place the cut pieces on a glass slide and fit two to three samples on a microscope slide. Add sodium hypochlorite solution to the slide for digestion and separation of sclerites. After five minutes, the tissue breaks down, forming a foam or bubble, which is then removed by a teasing needle. Rinse the sclerites with distilled water and examine under a compound microscope.

Diversity and Distribution

Octocorals (soft corals and gorgonids) are found in all oceans across the world, ranging in depth from coastal waters to deep-sea abyssal depths, as well as from tropical to arctic regions (Van de Water et al., 2018). The Indo-Pacific's shallow coral reefs have been found to have the highest variety (Perez et al., 2016; Van de Water et al., 2018). Globally, benthic marine environments ranging from shallow waters to the deep sea are home to more than 3500 nominal species of gorgonian sea fans and soft corals (Williams and Cairns, 2018).

Pioneer works on alcyonarians from marine water of India was published in 1904 and 1905 by James Hornell and it was later discussed by Thomson and Crane (1909). Eight species have been documented from the Okhamandal, Gulf of Kutch. Moreover, an account of deep-sea alcyonaceans obtained from the Indian Ocean was published by Hickson (1903; 1905), Pratt (1903), Thomson and Henderson (1906), and Thomson and Henderson (1905). Gravely (1927) documented the distribution of alcyonarians around the Krusadai Island. A taxonomic study

was carried out by Ridley (1888) on a few novel species of alcyonaceans that were gathered from the Indian Ocean and Bay of Bengal. According to Hickson (1931), there are a few extremely interesting issues raised by the limited collection of Alcyonaria from the Gulf of Mannar. There are 253 species of octocorals (Soft corals and gorgonids) from 66 genera and 21 families have been reported from Indian marine water. The species diversity have been reported more in the Andaman and Nicobar Islands (190 species) followed by Gulf of Mannar (47 species), and Lakshadweep islands (40 species). Species richness is highest for the family Alcyoniidae (87 species). *Simularia* is reported to be more diverse among the octocoral genus from Indian coral reef ecosystem (Padmakumar and R. Chandran, 2012).

Pioneer research on the diversity of gorgonians from India was started in 1906 by Thomson and Henderson. They identified 50 species, 26 of which were new, from the oyster banks in the Gulf of Mannar. Later, 62 species from 27 genera and 22 species from 15 genera have been reported from Indian water by Thomson and Simpson (1909) and Thomas and Rani (1987) respectively. There are reportedly 135 species of gorgonians in the Indian marine water. Venkataraman et al. (2004) reported 27 species of gorgonians from 8 families and 19 genera from India. Along the northeast coast of India, 12 species of gorgonians from four families and nine genera have been documented (Thomas et al., 1995). However, only 10 species (four families and nine genera) have been recorded from the Andaman and Nicobar Islands (Venkataraman et al., 2004).

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Sea anemone Diversity

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Sea anemones are animals belonging to the phylum Cnidaria, which includes the jellyfish, corals, and sea pens. They live in coastal waters throughout the world, are abundant in tropical oceans from the shore to a depth of 10,000 metres, and range in size from one centimetre to almost two metres in diameter. They attach themselves to rocks, seafloors, and other hard surfaces; some forms burrow in the mud and sand. There are over 1,000 species of sea anemones reported worldwide. They are usually about 2.5–10 cm across, but a few grow up to 1.8 m across.

India's scenario

Though India has 7600 km of coastline, studies on sea anemones in Indian waters are very limited. The actiniarian sea anemone fauna of India is so far known from a few places: West Bengal (Port Canning), Orissa (Chilika Lake), Tamil Nadu (Adyar backwaters, Palk Bay, and the Gulf of Mannar), Kerala (Cochin backwaters and Ashtamudi), Gujarat (Gulf of Kachchh), Maharashtra (Mumbai, Malvan), Goa, northern Karnataka, and the Andaman and Nicobar Islands.

The sea anemones of India were documented from various coastal and marine habitats of India (Annandale, 1907, 1915; Carlgren, 1925; Panikkar, 1936, 1937a-c, 1939; Parulekar, 1967, 1968, 1969a, 1971, 1990;

Seshaiya and Cuttress, 1969; Hartog and Vennam, 1993; Madhu and Madhu, 2007; Raghunathan et al., 2014), and the recorded diversity is represented by 54 species belonging to 40 genera and 20 families, and the majority of the records are from the west coast (Raghunathan et al., 2014). They are radial-symmetric with a columnar body and have a single body opening, the mouth, which is surrounded by tentacles. However, the body shape of sea anemones is often related to the habitat in which they live. Sea anemones are solitary polyps and are considerably larger and heavier than the polyps of hydrozoans (Barnes,

1982). They have a flat upper surface with a central mouth surrounded by tentacles, a tubular body, and a flat base that attaches to the substrate.

Taxonomic positions:

Kingdom: Animalia

Phylum: Cnidaria

Class: Anthozoa

Sub-class: Hexa-corallia Order: Actinaria

The class Anthozoa - key characters: (includes corals, anemones, sea pens and sea fans) solitary or colonial polyps that don't have a medusoid stage; they only live in the ocean; they are attached to or fixed to the substrate; their bodies are cylinder-shaped and symmetrical in two directions; about 6,100 species are known.

- The oral end is expanded to form an oral disc, bearing six to several hundred hollow tentacles surrounding the mouth; the ectoderm and endoderm are separated by a strong mesoglea containing fibres and cells.
- Vertical partitions are present in the entrance.
- A skeleton may or may not be present. (Absent in Sea Anemone).
- The sex cells are endodermal in origin, and the sexual products are discharged into the coelenteron for asexual reproduction by budding.

The Order: Actinaria

- Sea anemones are in the order Actinaria and are often called true anemones.
- They have an adhesive pedal disc or foot used to hold them in place and a hollow cylindrical or column-shaped body.
- An oral disc or mouth at the top is surrounded by a circle of tentacles containing stinging cells or nematocysts.
- They lack the calcareous skeletons in their bodies.

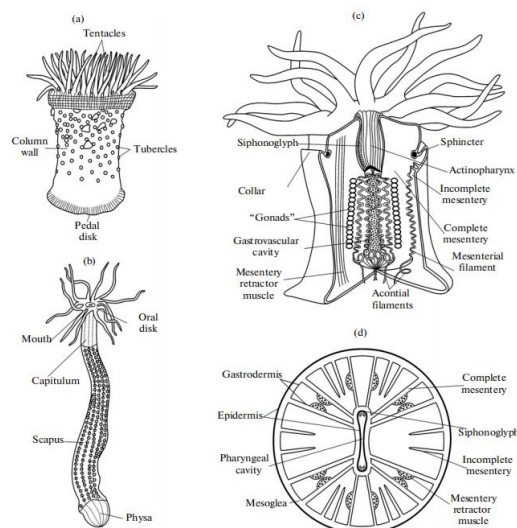
The Order: Ceriantharia

- They are also known as tube-dwelling anemones.
- Tube-dwelling anemones are known for being solitary and living and withdrawing into tubes that are buried in soft sediments.
- The tube anemones have elongated bodies adapted for burrowing, and they lack a pedal disc or foot.
- The cylindrical-shaped body is covered by a tube of secreted mucus and is usually hidden in the muddy substratum.
- The mouth is surrounded by short tentacles in the centre and longer tentacles on the margins.

Ceriantharia includes the orders Spirularia and Penicillaria.

External view and structure of sea anemones:

(a) *Anthopleura artemisia*; (b) wormlike sea anemone *Edwardsia andresi*; (c) general anatomical scheme; and (d) scheme of transverse section of sea anemone at the actinopharynx level (Bocharova & Kozevich, 2011).



In sea anemones, the tentacles number (from a few to hundreds), their colour, and their arrangements are the distinguishing characteristics for species identification. Normally, tentacles are short or long, thin or thick, pointed, blunt, globular, or tree-like.

Diversity and Distribution of sea anemones in India

Sl. No	Order/Family/Genus/Species	West Coast	East Coast	Andaman and Nicobar Islands
1	Order: Actiniaria Family: Acontiophoriidae, Carlgren 1938 Genus: <i>Acontiophorum</i> Carlgren, 1938 1. <i>Acontiophorum bombayensis</i> Parulekar, 1968	Mumbai, Malvan and Karwar		
2	Family: Actiniidae Rafinesque, 1815 Genus: <i>Actinogeton</i> Carlgren, 1938 2. <i>Gyractis sesere</i> (Haddon & Shackleton, 1893) Genus: <i>Entacmaea</i> Ehrenberg, 1834 3. <i>Entacmaea quadricolor</i> (Rueppel and Leuckart, 1828) Genus: <i>Anemonia</i> Risso, 1826 4. <i>Anemonia indica</i> Parulekar, 1968 Genus: <i>Anthopleura</i> Duchassaing de Fonbressin & Michelotti, 1860 5. <i>Anthopleura asiatica</i> Uchida and	Mumbai (Cuffe Parade) Gulf of Kachchh, Maharashtra, Goa and North Karnataka		North, Middle, South and Little Andaman, Ritchie's Archipelago and MGNP

3	Family: Actinodendronidae Haddon, 1898 Genus: <i>Actinodendron</i> de Blainville, 1830 20. <i>Actinodendron glomeratum</i> Haddon, 1898			Ritchie's Archipelago
4	Family: Actinostoiidae Carlgren, 1938 Genus: <i>Bathydactylus</i> Carlgren, 1928 21. <i>Bathydactylus valdiviae</i> Carlgren, 1928	Off west coast		
5	Family: Aiptasiidae Carlgren, 1924 Genus: <i>Aiptasia</i> Gosse, 1858 22. <i>Aiptasia</i> sp. Genus: <i>Neoaipiasia</i> Parulekar, 1969 23. <i>Neoaipiasia commensali</i> Parulekar, 1969	Mumbai Padmagad		
6	Family: Aiptasiomorphidae (Stephenson, 1920) Genus: <i>Haliplanella</i> Hand, 1956 24. <i>Haliplanella lineata</i> (Verrill, 1870)	Gulf of Kachchh, Mumbai, Central and southwest coast		
7	Family: Aliciidae (Duerden, 1897) Genus: <i>Alicia</i> Johnson, 1861 25. <i>Alicia sansibarensis</i> Carlgren, 1900	Central and southwest coast		
8	Family: Boloceroidae Carlgren, 1924 Genus: <i>Boloceractis</i> Panikkar, 1937 26. <i>Boloceractis gopalayi</i> Panikkar, 1937 Genus: <i>Boloceroides</i> Carlgren, 1899 27. <i>Boloceroides mcmurrici</i> Kwiteriewski, 1898 Genus: <i>Bunodeopsis</i> Andres, 1881 28. <i>Bunodeopsis</i> sp.	Cochin backwaters and Asthamudi Lake Central westcoast	Chennai Chennai	
9	Family: Diadumeneidae (Stephenson, 1920) Genus: <i>Diadumene</i> Stephenson, 1920 29. <i>Diadumene schilleriana</i> Stoliczka, 1863	West coast	Tuticorin, Mandapam, Chandipur and Digha	
10	Family: Edwardsiidae Andres, 1880 Genus: <i>Edwardsia</i> Quatrefages, 1842 30. <i>Edwardsia jonesii</i> Seshaiya & Curtress, 1969 31. <i>Edwardsia tinctoria</i> Annandale, 1915	Mumbai, Malvan and Goa	Port Novo (Tamil Nadu) Chennai,	

			Chilka Lake	
11	Family: Halcampidae Andreas, 1883 Genus: <i>Halcampa</i> Gosse, 1858 32. <i>Halcampa capensis</i> Carlgren, 1938 Genus: <i>Mena</i> Stephenson, 1920 33. <i>Mena limnicola</i> Annandlae, 1915	Northwest coast	Chilka Lake and Balramghadi (Odisha)	
12	Family: Haliactiidae Carlgren, 1949 Genus: <i>Pelocoetes</i> Annandale, 1915 34. <i>Pelocoetes exul</i> (Annandlae, 1915) 35. <i>Pelocoetes minima</i> Panikkar, 1939 Genus: <i>Phytocoetes</i> Annandale, 1915 36. <i>Phytocoetes gangeticus</i> Annandale, 1915 Genus: <i>Phytocoetopsis</i> Panikkar 1936 37. <i>Phytocoetopsis ramunni</i> Panikkar, 1936 Genus: <i>Stephensonactis</i> Panikkar, 1936 38. <i>Stephensonactis ornata</i> Panikkar, 1936	Gulf of Cambay, Mumbai, Malvan, Goa estuaries, and Cochin backwaters West coast West coast	Chennai and Gangetic delta Chennai and Sagar Island East coast Chennai East coast	
13	Family: Haloclavidae Verrill, 1899 Genus: <i>Metapeachia</i> Carlgren, 1943 39. <i>Metapeachia tropica</i> Panikkar, 1938	Mumbai, Malvan and Goa	Kurusadai Island in Gulf of Mannar	
14	Family: Hormathiidae Carlgren, 1932 Genus: <i>Calliactis</i> Verrill, 1869 40. <i>Calliactis miriam</i> Haddon & Shackleton, 1893 Genus: <i>Paraphellia</i> Haddon, 1889 41. <i>Paraphellia sanzoi</i> Colabresi, 1926	Gulf of Kachchh		South Andaman
15	Family: Isophelliidae Stephenson, 1935 Genus: <i>Telmatactis</i> Gravier, 1916 42. <i>Telmatactis decora</i> (Hemprich &			South Andaman

	Ehrenberg in Ehrenberg, 1834)			
16	Family: Metridiidae (Carlgren 1893) Genus: <i>Metridium</i> de Blainville, 1824 43. <i>Metridium senile</i> (Linnaeus, 1761)	West coast	East coast	South Andaman (Port Blair)
17	Family: Nevadneidae, Carlgren 1925 Genus: <i>Nevadne</i> Stephenson, 1922 44. <i>Nevadne glauca</i> Annandale 1915	Goa estuaries	Chilka Lake	
18	Family: Phymanthidae Andres, 1883 Genus: <i>Phymanthus</i> Milne Edwards, 1857 45. <i>Phymanthus buitendijki</i> Pax, 1924 46. <i>Phymanthus loligo</i> Hand E Ehrenberg 1834	Gulf of Kachchh	Gulf of Mannar	South Andaman
19	Family: Stichodactylidae Andres, 1883 Genus: <i>Heteractis</i> Milne Edwards, 1857 47. <i>Heteractis aurora</i> (Quoy and Gaimard, 1833) 48. <i>Heteractis crispa</i> (Hemprich & Ehrenberg, 1834) 49. <i>Heteractis magnifica</i> (Quoy and Gaimard, 1833) 50. <i>Heteractis malu</i> (Haddon & Shackleton, 1893) Genus: <i>Stichodactyla</i> Brandt, 1835 51. <i>Stichodactyla gigantea</i> (Forskål, 1775) 52. <i>Stichodactyla haddoni</i> (Saville-Kent, 1893) 53. <i>Stichodactyla mertensii</i> (Brandt, 1835)	Gulf of Kachchh	Gulf of Mannar	South Andaman and MGMNP North, Middle and Little Andaman, MGMNP, Ritchie's Archipelago and Nicobar North, Middle, South and Little Andaman, MGMNP, Ritchie's Archipelago and Nicobar South, Middle, and North Andaman MGMNP North, Middle and South Andaman, and MGMNP

				North Andaman
20	Family: Thalassianthidae Milne Edwards, 1857 Genus: <i>Cryptodendrum</i> Klunzinger, 1877 54. <i>Cryptodendrum adhaesivum</i> Milne Edwards, 1857			South, Middle, and North Andaman
	Number of Families, Genera & Species recorded	17, 29 & 32	11, 16 & 19	8, 13 & 19



Tentacle Sea anemone, *Anthopleura* sp

Anthopleura sp collected from Notchiurani, Gulf of Mannar. (Photo Credit: S. Thirumalaiselvan)

The oral disc is small, tentacles are moderately long and tapered at the tip. Verrucae is not prominent to which pieces of shell and gravel adhere at the distal part. The oral disc is dark brown, mouth is raised on the cone. Tentacles are transparent with prominent irregular lines (spots) that can be seen on the upper side and they are broad at the base and tapered at the tip. The column is white, and firmly attached to the substratum.

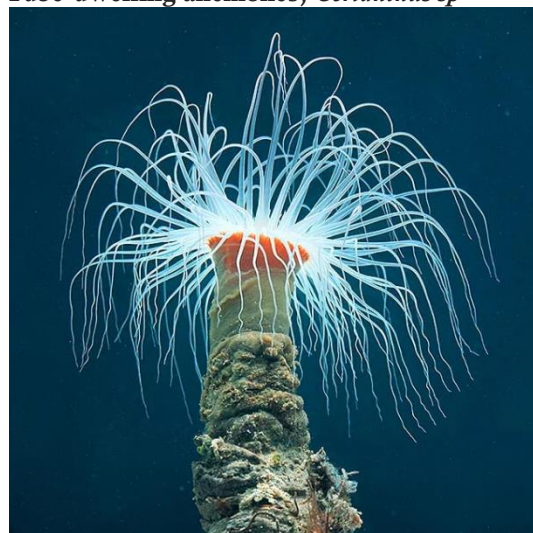
Carpet Sea anemone, *Stichodactyla* sp

The oral disc is flat, broad, and deeply folded with numerous short tentacles which are highly robust at the periphery of the disc. Tentacles are grey or green in colour and adhesive, no tentacles around the mouth, the upper side of the oral disc is pale orange and the column is brown in colour.



Stichodactyla haddoni from the Gulf of Mannar. (Photo Credit: Raju Saravanan)

Tube-dwelling anemones, *Cerianthus* sp



Cerianthus membranaceus reported from Mediterranean and East Atlantic water. (Photo Credit: G. Mazza)

They do not have a pedal disc with which to hold themselves in position. They live semi-buried in a soft substrate surrounded by a parchment-like tube which they secrete. This surrounds the whole anemone up to its crown of tentacles. Sand grains, debris and shell fragments usually stick to the outer side of the

tube. Some of the larger species can have a column of up to 25 inches (64 cm) in length.

Sea Anemone venom

Sea Anemone venom is delivered from specialised stinging cells called nematocysts that are fired semi-autonomously after mechanical or chemical stimulation and can penetrate skin to deliver venom. Nematocysts are utilised by anemones for a range of functions, including protection from predators, interspecific competition, and the acquisition of prey. In addition to nematocysts, anemones also secrete a mucus coat as a form of self-protection that contains cytolytic and neurotoxins.

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Coral Biology & Diversity

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The tropical latitudes of the oceans can be called the deserts of the ocean due to their similarity with terrestrial deserts, which are barren and relatively sterile places. The reason for this phenomenon is that the surface waters of the tropical oceans are so warm and thus they tend to float on top of the colder water underneath, inhibiting nutrient upwelling from the deep which brings nutrients to the ocean surface. However, coral reefs are a brilliant exception to the general scarcity of life in tropical oceans; they are known as the oases of ocean deserts. If we consider the area of coral reefs, it comprises less than 0.2% of the world's ocean, yet it is home to a wide array of marine organisms. Karlson and Cornell (1999) note that when considering the entire marine ecosystem, coral reefs exhibit the greatest diversity per unit area. It is estimated that almost 4-5% of all species or about 91,000 are found on coral reefs. We can find 32 out of 34 recognized animal phyla in coral reefs where there are only 9 phyla in the tropical rainforests (Porter and Tougas, 2001). Although corals are found in polar and temperate waters, coral reefs only develop in the tropics. This is primarily because there are two types of corals: hermatypic corals, which produce reefs, and ahermatypic corals, which do not form reefs. While ahermatypic corals have a worldwide distribution, hermatypic corals are found only in the tropics.

Coral reefs are vital ecosystems, both economically and ecologically. They provide a source of income, food, and coastal protection to millions of people who depend on them for their daily lives. Studies have shown that the goods and services provided by coral reefs amount to an annual net benefit of US\$30 billion (Cesar and Chong, 2003). Additionally, corals fulfill their ecological role by providing a habitat for a wide variety of marine organisms. Unfortunately, these bizarre and beautiful coral reefs are also among the most vulnerable ecosystems in the world. Various threats, including bleaching, overfishing, pollution, improper waste disposal, coastal development, SCUBA diving, anchor damage, outbreaks of predators, invasive species, epidemic diseases,

sedimentation, and river runoff, collectively undermine the health and resilience of coral reefs. About 70% of the world's corals are threatened, and 20% of that is damaged beyond repair (Wilkinson, 2004).

Coral Biology

Understanding coral reef biology is the key to understanding the ecology of reefs. Coral reef formations are the product of a symbiotic relationship between coral polyps and the photosynthetic microorganisms called zooxanthellae. The zooxanthellae which reside inside the gastrodermal tissue of coral polyps capture the sun's energy and pass a portion of it to their host. Using this extra energy gained from their guests the host corals secrete calcium carbonate to create shells around their bodies. This process continues over time and the mineral deposition grows upward and outward, with only the very surface of the structure inhabited by living polyps, the interior of the coral reef is made up of eons worth of abandoned polyp homes.

Coral anatomy

Hundreds of thousands of coral polyps like this one (Fig: 1) form most of the corals except some corals like mushroom coral which are only formed by a single polyp. The size range of coral polyps varies from one to three millimeters in diameter. These are anatomically very simple organisms, most of their body is taken up by their digestive system. Like all coelenterates, the body wall is mostly made up of two cell layers: the interior gastrodermis and the exterior ectodermis. These layers are separated by the mesoglea, initially acellular, and may evolve to incorporate various cells following initial development, serving as a divider between layers. In corals possessing tiny corallites, the mesoglea appears extremely thin under a microscope, whereas in certain species, such as the large corallite varieties of *Lobophyllia*, it can reach thicknesses of several millimeters and has a robust structure. Polyps, when extended,

resemble anemones in appearance. Typically, the mouth is slit-shaped and can be encircled by an oral cone. The area between the cone or mouth might form into an oral disc.

The tentacles are tubular, sharing the same dual tissue layers as the rest of the polyp, meaning their internal cavity is an extension of the coelenteron. In corals that consume detritus, the tentacles are smooth, whereas those that rely on defense or capturing food typically possess stinging cells. These stinging cells, known as nematocysts, are minuscule but are often clustered together in visible, wart-like formations called nematocyst batteries, which can be seen underwater.

There is only one opening through which they collect food and expel waste. Food capturing and waste expelling is done with the help of a ring of tentacles surrounding the opening (Mouth). Most of the food is captured with the help of specialized stinging cells known as nematocysts which are located inside the polyp's outer epidermis. Reef-building coral polyps secrete calcium carbonate which forms a protective cup-like structure known as the calyx upon which the coral polyp sits is called the basal plate. Calyx is surrounded by a wall known as theca. Each polyps are connected to the neighboring ones with the help of coenosarc which is a thin band of living tissue and this helps the polyps to become a successful colonial organism.

The structure of corallite

Corals are colonial animals, a single individual is known as a polyp, and a polyp's skeleton is known as a corallite. This is a tube with vertical plates extending from the center. Structural alignment of the coral polyps can be used to identify different corals. Some examples are Plocoid corallites which have their separate walls, Phaceloid colonies also have separate corallites but they are tubular shaped. Cerioid Corallites are divided into polygonal sections, with each corallite keeping its wall. Meandroid corallites have walls shared and valleys enclose many mouths. Thamnasteroid corallites are with confluent septa and lack defined boundaries (Fig. 2). Fig.1 Anatomy of coral polyp (Image: NOAA)

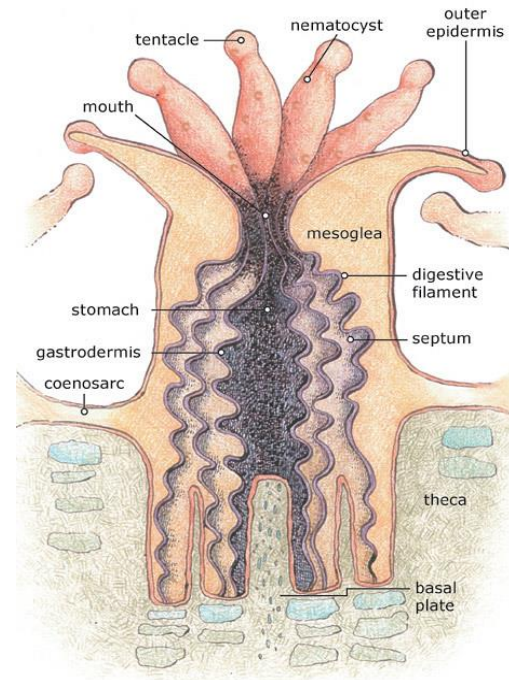
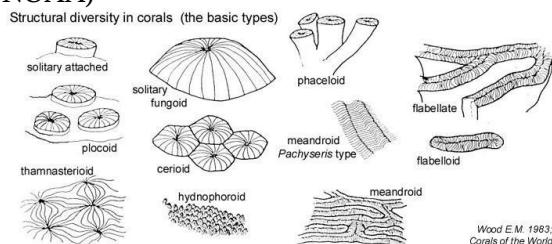


Fig.2 Structural diversity of corallites (Image: Wood E.M. 1983)

Coral Growth Forms

As colonies of hard coral grow and spread, they can evolve into various shapes or growth patterns. Typically, these patterns are identified as encrusting (forming a thin layer over surfaces), branching (developing branches), arborescent (resembling a tree), columnar (forming columns), laminar (resembling plates, sometimes in layers), free-living or solitary corals that do not form colonies and finally massive corals which are often large and solid often form hemispherical to spherical shapes (Fig. 3).

Growth rates are usually measured as linear extension of the coral branches, plates, or upward expansion of massive corals. The growth rate in coral can greatly differ among species. Under ideal tropical conditions, certain species like the branching *Acropora sp.* can exhibit rapid growth, advancing 10-20 cm annually, whereas other species, like *Porites*, expand at a much slower pace, approximately 1 cm each year.

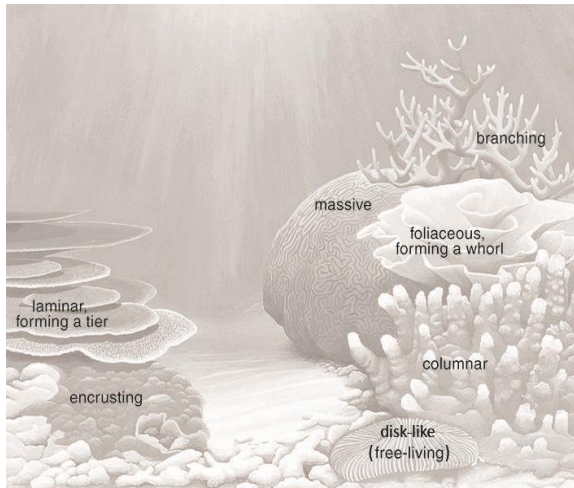


Fig:3. A range of tropical coral growth forms (Veron, corals of the world)

Coral Nutrition

It has been known for a long time that reef corals are carnivorous animals, similar to most other cnidarians. Most corals feed at night, capturing mainly small planktonic organisms with their tentacles, which are equipped with nematocysts, also known as stinging cells. These cells are capable of delivering powerful toxins that are often lethal to their prey (Barnes, R.D., 1987). Coral reefs are recognized as colonial organisms due to their vast number of colonies and the extensive area available for feeding. In addition to their nematocysts, the ciliated outer epidermis of corals produces mucus. This ciliary mucus mechanism helps corals rid themselves of sediments settling on their surface and, in some cases, aids in feeding as well.

Given the large numbers of corals and the nutrient-poor surrounding ocean, how corals obtain enough food has puzzled generations of coral biologists. Johannes et al. (1970) calculated that demersal plankton is only sufficient to satisfy 5-10% of corals' total nutrient requirements. The remainder of their food comes from zooxanthellae found in the coral tissue. Further experimental studies conducted on large tentacled corals, which were kept in the dark, showed that they would expel their symbionts but could survive for a few weeks without them. This survival is possible because corals can capture microorganisms and feed on them. Corals obtain zooxanthellae either directly from the parent or indirectly from the environment. Initially, it was thought that there was only one type of zooxanthellae, but later studies revealed there are 16 clades of zooxanthellae, each with different properties. Some are more heat tolerant, some are capable of fixing more energy, and corals harboring these types of zooxanthellae are

capable of growing at a faster rate. Therefore, different zooxanthellae may also characterize different reef microclimates.

Coral Growth and Calcification

Light is the primary factor for active coral growth; without it, or if corals are kept in shaded areas, their growth ceases. Long-term deprivation of light can lead to the death of the coral organism. This phenomenon is closely related to the role of zooxanthellae, which require light to fix energy, significantly enhancing the calcification and growth rate of coral reefs.

The growth rate of corals varies by species, reef location, and the age of the colony. Young colonies grow more rapidly than older ones. Moreover, corals vary in morphology, which influences their growth rates. Generally, branched corals grow more rapidly than massive corals. The growth rate is also influenced by the location within the reef, with the same species of coral growing in shallow water and deep water exhibiting differences. Deepwater corals are often thinner and more fragile than those in shallow water, likely due to reduced calcification. Furthermore, wave action causes branching corals to form shorter and stubbier branches, while ocean currents influence the arrangement of branches in branching corals.

Coral reef structures

Coral reefs are typically categorized into three principal types based on their structural features. The first one is fringing reefs, which is the most commonly found type, stretching outward from the shoreline, occasionally separated by a slim waterway or lagoon. They usually exist in shallow waters, with the reef flats becoming visible during low tide. The second one is barrier reefs, which lie parallel to the coast but are separated from it by a sizable lagoon that can be quite deep. These reefs often consist of a complex of individual reef formations, including fringing reefs that extend from islands situated offshore. Finally, the atolls are coral islands that form a ring or horseshoe shape around a central lagoon.

Coral Reproduction

Corals exhibit both sexual and asexual modes of reproduction, mirroring the life history of a typical sedentary animal. Dispersal primarily occurs through small planktonic larvae, often called planulae, which are produced in large numbers. After existing briefly in this motile form, a planula larva settles and metamorphoses

into a polyp. Once it has grown to a certain size, the polyp divides, forming an ever-expanding clone. Asexual reproduction is achieved when new individuals bud off from the parent. Observations by Highsmith (1982) indicated that fragmentation plays a significant role in starting new colonies in some species. While most corals are broadcast spawners, releasing eggs and sperm into the open water, a few species act as brooders, retaining fertilized eggs in the gastrovascular cavity until they develop into planula larvae.

Taxonomy and Diversity of corals

Coral Taxonomy & Classification

Corals refer to marine invertebrates within the phylum Cnidaria and the class Anthozoa, possessing either external or internal calcareous skeletons. These skeletal structures, known as coral, can be found both externally and internally within these organisms. Corals typically manifest as small polyps, akin to other members of the Cnidaria group, often forming colonies attached to solid surfaces. While they share a close kinship with sea anemones, which fall under the Anthozoa class, sea anemones are classified in the Actiniaria order. Corals and sea anemones belong to Anthozoa, a class within the invertebrate phylum Cnidaria. The name of this phylum is derived from cnidocytes, specialized cells that contain stinging organelles. Other members of the Cnidaria phylum include jellyfish, sea pens, sea pansies, sea wasps, and small freshwater hydra. Within Anthozoa, there are two main groups: Alcyonaria and Zoantharia. Both subclasses encompass species commonly referred to as corals. Zoantharia also encompasses sea anemones (Order Actiniaria) and tube-dwelling anemones (Order Ceriantharia), among others. Polyps in the Zoantharia subclass lacking skeletons are typically termed anemones.

The classification of corals into orders as follows (Chen et al. 1995, France et al. 1996, Myers et al. 2006):

- Subclass Alcyonaria (= Octocorallia) (eight tentacles)
- Alcyonacea (soft corals)
- Gorgonacea (sea fans, sea feathers)
- Helioporacea (Indo Pacific blue coral)
- Pennatulacea (sea pens and sea pansies)

- Stolonifera (organ pipe coral)
- Subclass Zoantharia (= Hexacorallia) (more than 8 tentacles - typically 12)
- Antipatharia (black corals, thorny corals)
- Scleractinia (=Madreporaria) (stony corals)
- Corallimorpharia
- Ptychodactilaria

Extinct orders, from the Paleozoic (570-245 mya) (Oliver 1996):

- Rugosa
- Kilbuchophyllida
- Cothoniida
- Tabulata
- Tabulacondia
- Heliolitida
- Heterocorallida
- Numidiaphyllida

Coral Diversity

Scleractinian Diversity in India

Coral reefs are among the most valuable ecosystems in India. Despite India's extensive coastline of around 8,000 km, the major reef formations are confined to the Gulf of Mannar, Palk Bay, the Gulf of Kutch, Andaman and Nicobar Islands, and the Lakshadweep Islands. India is home to three major reef types: atoll, fringing, and barrier. The reefs in Lakshadweep are atolls, whereas those in the other locations are primarily fringing reefs, with some barrier reefs found in the Andaman and Nicobar Islands. Among these four reef formations, the Andaman and Nicobar Islands are the most diverse and richest in species, while the Gulf of Kutch has the lowest species diversity. Pillai documented a total of 199 species across 37 genera from India, encompassing both hermatypic (reef-building) and ahermatypic corals from the four major coral reefs of India. A more recent study by Venkataraman et al. (2003) identified 15 families, 60 genera, and 208 species of Scleractinia (solely reef-building, hermatypic corals) from these locations, including the Gulf of Kachchh having 36 species, 20 genera, Lakshadweep hosts 91 species spanning 34 genera, while the Gulf of Mannar and Palk Bay is home to 82 species across 27 genera. The Andaman and Nicobar Islands boast an even richer diversity with 177 species distributed among 57 genera

Diversity of Commercially Important Crustaceans

R. Ratheesh Kumar

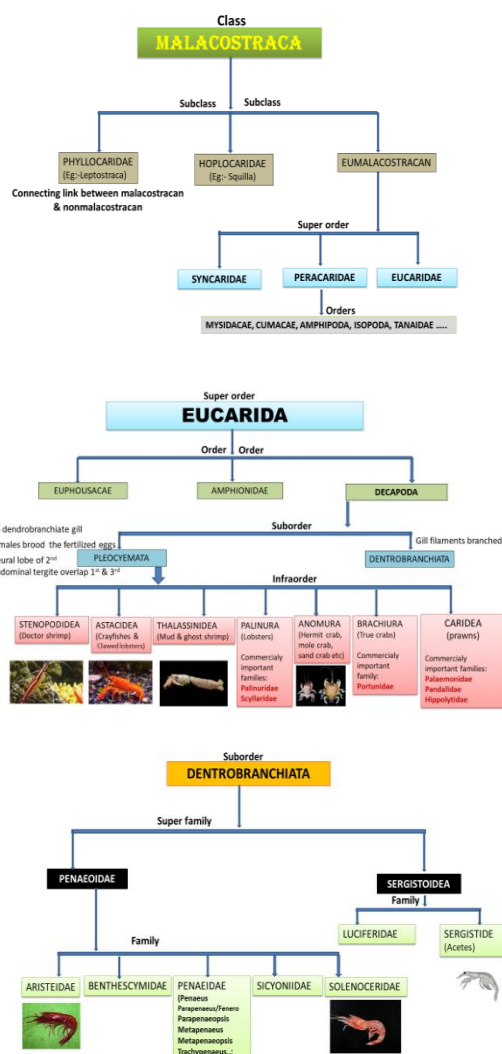
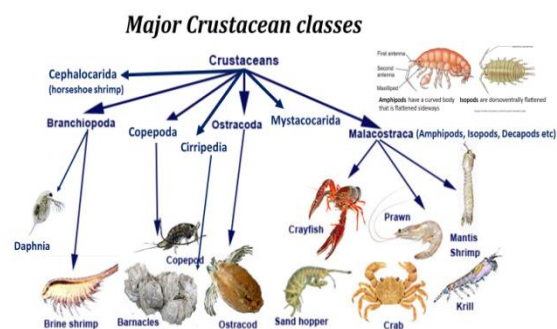
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Crustaceans are a diverse group of arthropods found in nearly all aquatic environments, with some even venturing onto land. They consist of more than 65,000 species distributed worldwide. Crustaceans show a great range of sizes from microscopic species measuring as little as a tenth of a millimeter to giant crabs, lobsters, and isopods with a body size of up to 4 meters in length, and weighing up to 20 kilograms. Thus they are a very diverse group of invertebrate animals that includes active animals such as crabs, lobsters, shrimp, krill, copepods, amphipods, and more sessile creatures like barnacles. Like other arthropods, crustaceans have an exoskeleton composed of chitin, which they molt when they grow.

General characteristics of crustaceans:

- They have a hard, but flexible exoskeleton or shell
- Two pairs of antennae
- A pair of mandibles (which are appendages used for eating)
- Two pairs of maxillae on their heads (additional mouth parts)
- Two compound eyes, often on stalks
- Segmented bodies (3 regions – cephalic, thoracic & abdominal) with appendages on each body segment

Crustacean Classification:



The decapod crustaceans belonging to the class Malacostraca are the most popular invertebrates due to their commercial value, of which the most important are shrimp species belonging to the five penaeidean families Solenoceridae, Aristeidae, Penaeidae, Sicyoniidae and Sergestidae and three caridean families - Pandalidae, Crangonidae and Palaemonidae. Among these, the families Penaeidae and Palaemonidae contain species of capture and culture importance. The features which are generally used for taxonomic analysis include the rostrum, carapace with its spines and carina,

carina of the abdomen, pleurae, telson appendages, petasma, appendix masculine, and thelycum. Shrimps/Prawns come under the order Decapoda Latrielle, 1980, an order which derives the name from the presence of five pairs (10 numbers) of walking legs (deca = ten).

The order Decapoda is characterized by –

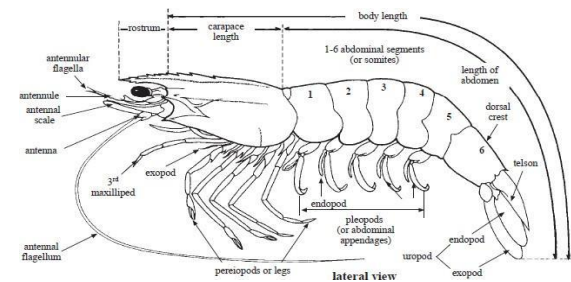
- The body can be divided into three broad regions – cephalic, thoracic, and abdominal regions with five, eight, and six segments respectively.
- The last five pairs (10 nos.) of appendages are pereopod and are walking legs.
- Gills are of three different types, namely, dendrobranchs, trichobranch and phyllobranch.

Morphology of prawn/shrimp

The body of a shrimp/prawn is elongated, and segmented with three broad divisions – cephalothorax, abdomen, and telson. The cephalothorax represents the 'head' and is generally sub-cylindrical in cross-section. The abdomen is laterally compressed with six segments. Telson is dorso-ventrally flattened. The body consists of 19 segments and in addition there is a pre-oral region and post-anal region (telson). Each of the 19 segments bears a pair of appendages. These appendages are – the antennule, antenna, mandible, maxillula, maxilla, first maxilliped, second maxilliped, third maxilliped, first pereopod, second pereopod, third pereopod, fourth pereopod, first pleopod, second pleopod, third pleopod, fourth pleopod, fifth pleopod, and uropod.

The body is covered by a chitinous exoskeleton. The exoskeleton of the cephalothoracic region is coalesced to form the carapace. The anterior extension of the carapace is the rostrum. The rostrum is laterally compressed and bears teeth on both margins. Several spines, grooves, and ridges mark the surface of the carapace. The cephalothoracic region consists of 13 segments (five cephalic and eight thoracic). The exoskeleton of abdominal segments is distinct. The dorsal plate is known as the tergum, and the ventral plate is known as the sternum. Both the tergum and sternum together form a box-like structure that covers the body. Into the sternum, the appendages are attached. The tergum extends below the level of

the sternum and is called the pleuron. Telson is a conical structure with a broad basal part and a pointed distal end. It is not a segment and it does not contain any internal organs and hemocoel.

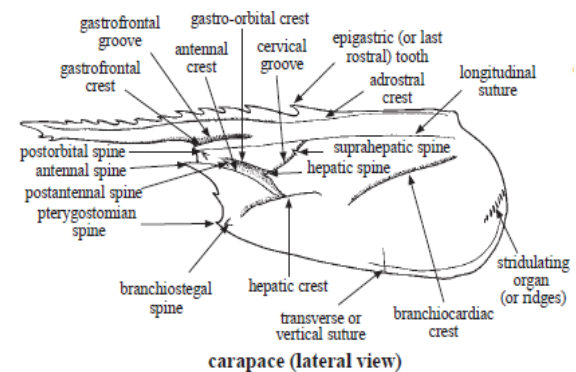


Appendages of a shrimp/prawn

There are 19 pairs of appendages and these are classified as follows –

1. Cephalic (5 pairs): antennule, antenna, mandible, maxillula, maxilla
2. Thoracic (8 pairs): first maxilliped, second maxilliped, third maxilliped, first pereopod, second pereopod, third pereopod, fourth pereopod, fifth pereopod
3. Abdominal (6 pairs): first pleopod, second pleopod, third pleopod, fourth pleopod, fifth pleopod and uropod.

Technical terms:



Key for the identification of the commercially important families of prawns

1.	Pleura of 2 nd abdominal segment overlapping those of the proceeding (1 st) and succeeding (3 rd) segments; no chela on 3 rd pereopods; gills phyllobranchiate.....	2
	Pleura of 2 nd abdominal segment overlapping that of the succeeding (3 rd) but not of the preceeding (1 st) segment; 3 rd pereopod chelate.....	3
2.	Carpus of second pair of pereopods entire; epipodites absent; upper antennular flagellum bifid; 3 rd maxilliped normal..... Palaemonidae	
	Carpus of second pair of pereopods divided into two or more articles; 1 st pair of pereopods non chelate or with a microscopic chela..... Pandalidae	
3	Last two pairs of walking legs well developed, gills many dendrobranchiate..... Penaeidae	
	Last one or two pairs of walking legs reduced or absent; gills few or wanting Sergastidae	

Classification of the Family Penaeidae

Subphylum	Crustace Brunnich, 1772
Class	Malacostraca Latreille, 1802
Subclass	Eumalacostraca Grobben, 1892
Order	Decapoda Latreille, 1802
Suborder	Dendrobranchiata Bate, 1888
Superfamily	Penaeoidea Rafinesque, 1815
Family	Penaeidae Rafinesque, 1815

Key to Genera under Family Penaeidae From Indian waters

1.	Rostrum serrated only on the dorsal margin.....	5
	Rostrum serrated on the dorsal and ventral margins.....	2
2.	Adrostral carina and sulcus extends as far as the level of epigastric tooth, gastro frontal carina absent.....	3
	Adrostral carina and sulcus extends behind epigastric tooth; gastro frontal carina present.....	4
3.	Hepatic carina generally absent, if present, only feeble..... Fenneropenaeus	
	Hepatic carina present and prominent..... Penaeus	

4.	Gastro-frontal sulcus not markedly bifid posteriorly; thelycum with pair of lateral plate on sternite XIV shielding sac like seminal receptacle opening along midline.....<i>Melicertus</i> Gastro-frontal sulcus markedly bifid posteriorly; thelycum with a ventral undivided plate on sternite XIV infolded laterally, forming pouch opening anteriorly.....<i>Marsupenaeus</i>	
5.	Telson with a pair of fixed subapical spines preceded by one to three pairs of movable spines; antennal peduncle usually bearing parapenaeid spine..... Telson generally without fixed subapical spine, but usually with movable lateral spines; antennular peduncle lacking parapenaeid spine.....	6 8
6.	Carapace with longitudinal sutures (extending from post orbital region to almost posterior margin of carapace) and transverse sutures; telson with only one pair of minute lateral spines anterior to subapical spines<i>Parapenaeus</i> Carapace without longitudinal sutures; telson with two or more pair of conspicuous spines anterior to subapical spines.....	7
7.	Third maxilliped and second peraeopod with basal spine; petasma asymmetrical.....<i>Metapenaeopsis</i> Third maxilliped and second peraeopod without basal spine; petasma symmetrical.....<i>Penaeopsis</i>	
8	Pleurobranch present on somite XIII; exopods on maxillipeds and anterior four pairs of pereopods; fifth pereopod without exopod.....<i>Metapenaeus</i> - Pleurobranch absent on somite XIII; exopod present on all pereopods.....	9
9	Carapace without longitudinal and transverse sutures; telson with subapical pair of lateral movable spines mounted on elongated shoulder; epipods not furcated; petasma with ventro-lateral lobule produced into three flaps; anterior plate of thelycum as long as wide.....<i>Trachypenaeopsis</i> - Carapace with either longitudinal and / or transverse sutures ;telson without lateral spines or with movable ones not mounted on elongate shoulders; petasma with ventro-lateral lobule not produced into distal flaps.....	10

10	Carapace without longitudinal sutures; second pereopod with ischial spine; hepatic spine present; petasma not constricted distally; anterior plate of thelycum rounded posteriorly..... <i>Atypopenaeus</i>	
-	Carapace with longitudinal sutures; second pereopod without ischial spine	11
11	Third pereopod without epipod body slender, integument thin ... <i>Parapenaeopsis</i>	
-	Third pereopod with epipod; body thick set; third maxilliped lacking basalspine.	12
12	Thelycum with plate on sternite XIV very short medially, deeply excavate, embracing extremely long caudal extension of median protuberance. Petasma with disto-lateral projections either moderately broad to rather narrow basally and extending laterally tomesially or forward directed hook like tip or extremely broad basally but narrowing rapidly, ending in forward directed tip <i>Megokris</i>	
-	Thelycum with plate on sternite XIV shallowly emarginated or occasionally produced in small median prominence, not continuous with medial protuberance; petasma with disto lateral projections tapering gently from relatively narrow base, extending almost straight laterally or curving slightly backwards <i>Trachysalambria</i>	

Key to species under the genus *Fenneropenaeus*

1.	Gastro-orbital carina absent or not reaching hepatic spine and occupying the middle 1/3 rd distance between hepatic spine and orbital angle..... Gastro- orbital carina occupying the posterior 2/3 distance between hepatic spine and orbital angle; dactyle of third maxilliped about as long as propodus; rostral crest may be elevated but not triangular in profile <i>indicus</i>	2
2.	Dactyl of third maxilliped of adult male 0.5-0.6 times propodus; adrostral carina not reaching as far as epigastric tooth; rostrum broad basally, directed anteriorwards, basal part much elevated into a triangular in profile <i>merguiensis</i> Dactyl of third maxilliped of adult male much longer than propodus; adrostral carina reaching just beyond epigastric tooth; rostrum slender, sharply directed downwards, basal part not much elevated <i>penicillatus</i>	

Key to species under the genus *Melicertus*

Adrostral carina and groove long, extending almost posterior region of carapace, groove wide, anterior plate of thelycum forming two subaccuminate, posterior process triangular; telson without movable spines; body with cross bands.....	<i>canaliculatus</i>
Adrostral carina and groove extending almost to posterior region of carapace; anterior plate of thelycum forming two subtriangular processes at the distal end at the apex ; telson with 3 pairs of movable spines; body without cross bands.....	<i>latisulcatus</i>

Key to species under the genus *Metapenaeus*

1.	Disto-medianpetasmas projection with fully developed or vestigial apical filament; impregnated thelycum usually with white conjoined pads.....	2
-	Disto-medianpetasmas projection without apical filament; thelycum of impregnated females without white conjoined pads	3
2	Posterior part of rostrum with distinctly elevated crest; basal spine on male third pereopod simple, disto median projection of petasma with a long and slender apical filament; thelycum with a large square and grooved anterior plate and lateral plates boomerang shaped, enclosing two pear shaped plates	<i>brevicornis</i>
-	Posterior part of rostrum without distinctly elevated crest ; basal spine on male third pereopod long and barbed; disto median projection of petasma with short filament on dorsal and ventral sides; anterior thelycal plates tongue like, lateral plates horse shoe shaped	<i>dobsoni</i>
3.	Ischial spine on first pereopod distinct	4
-	Ischial spine on first pereopod small or absent	6
4.	Disto-medianpetasmas projections directed forwards convoluted, greatly swollen and lateral thelycal plates with raised lateral ridges, each with a posterior inwardly curved triangular plate, anterior plate of thelycum long a deeply groove	
	Disto-median petasmas projections directed antero-ventrally anterior thelycal plate tongue like.....	5
5.	Lateral thelycal plates with salient and parallel ear shaped lateral ridges; disto median petasmas projections hood-like.....	<i>monoceros</i>
	Lateral thelycal plates without lateral ridges; disto-median petasmas projections not hood-like	<i>kutchensis</i>

6.	Branchio-cardiac carina feeble or ill-defined, anterior end not exceeding posterior third of carapace; distal margin of anterior thelycal plate convex to indistinctly triangular; petasma with laminose and strongly diverging disto-median projections, disto lateral projections directed antero-ventrally; anterior thelycal plate flask-shaped, distal end with three tubercles of subequal size, lateral plates kidney shaped..... <i>moyebi</i>	
-	Branchio-cardiac carina distinct, extending from posterior margin of carapace almost to hepatic spine; anterior thelycal plate longitudinally grooved, wider posteriorly than anteriorly; disto median petasmas projections crescent shaped, leaning on disto lateral projections and concealing them partly or completely..... <i>affinis</i>	

Key to species under the genus *Parapenaeopsis*

1	Epipods present on first and second pereopods.....	2
.	Epipods absent on first and second pereopods.....	3
2	Telson with pair of fixed apical spines; atleast distal half free portion of rostrum unarmed.....	3
	Telson without fixed subapical spines, with or without lateral movable spines; distal third or less part of rostrum edentulous..... <i>hardwickii</i>	
3	Petasma long with disto lateral projections slender, horn like, slightly curved directed anterior ventrally with ventro external openings; telson 4 pairs of fixed distal spines..... <i>stylifera</i>	
.	Petasma long with disto lateral projections slender, horn like, slightly curved directed laterally with external openings; telson with one or two pairs of fixed spines..... <i>coromandelica</i>	

Key to species under the genus *Penaeus*

Adrostral carina and groove do not extend up to epigastric tooth; antennal crest very prominent ending above middle of hepatic carina, hepatic carina horizontally straight; fifth pereopod without exopodite..... <i>monodon</i>
Adrostral carina and groove beyond epigastric tooth; antennal crest very prominent ending above posterior third of hepatic carina, hepatic carina inclined antero ventrally; fifth pereopod with small exopodite..... <i>semisulcatus</i>

Identification of the family Palaemonidae

Classification of the Family Palaemonidae

Subphylum	Crustace	Palaemonids are commonly called as freshwater
Class	Malacostraca	prawns. The important genera under this family are
Subclass	Eumalacostraca	<i>Palaemon</i> and <i>Macrobrachium</i> . Many species of
Order	Decapoda	prawns under the genera complete their life cycle in
Suborder	Pleocyemata	estuaries. The two genera could be identified based
Superfamily	Palaemonoidea	on the key below

Carapace with antennal and Branchiostegal spines; mandible with palp, eyes pigmented; propodus of pereopod 5 with transverse rows of setae on the distal part of posterior margin; dactylus of last three pereopods simple Genus <i>Palaemon</i> Weber
Carapace with antennal and hepatic spines; eyes pigmented, propodus of pereopod 5 without transverse rows of setae on the distal part of posterior margin; dactylus of last three pereopods simple Genus <i>Macrobrachium</i> Bate

Key to species under the genus *Macrobrachium* Bate

1.	Carpus of pereopod 2 longer than merus.....	2
	Carpus of pereopod 2 subequal to or shorter than merus.....	8
2.	Rostrum with a distinct basal crest.....	3
	Rostrum without distinct basal crest.....	6
3.	Tip of telson reaching beyond tip of longer posterior spines.....	5
	Posterior spines over reaching tip of telson; distal part of rostrum without dorsal teeth	
4.	Carpus of pereopod 2 in male longer than ½ length of chela, its dactylus nearly as long as palm..... <i>M. rosenbergii</i> (de Man)	
	Carpus of pereopod 2 in male variable in length and proportion to chela, its dactylus shorter than ½ length of palm..... <i>M. villosimanus</i> (Tiwari)	
5.	Basal crest of rostrum shallow; palm of pereopod 2 normal, its dactylus shorter than palm <i>M. lamarreilamarrei</i> (Milne Edwards)	
	Basal crest of rostrum elevated; palm of pereopod 2 aollen, its dactylus longer than palm	

6.	Cutting edges of male 2 nd pereopod with two proximal tubercles and all joints of this appendage pubescent..... <i>M. rude</i> Cutting edges of male 2 nd pereopod with two proximal tubercles and all joints of this appendage non-pubescent.....	7
7.	Rostrum nearly straight with 9-12 dorsal teeth, two of which behind orbit; carpus of male pereopod 2 longer than chela..... <i>M. idella</i> (Hilgendorf) Rostrum curved with 9-12 dorsal teeth, three of which behind orbit; carpus of pereopod 2 shorter than chela..... <i>M. equidens</i> (Dana)	
8.	Pereopod 5 longer than 4; dorsal rostrum with many teeth closely arranged..... <i>M. mirabile</i> (Kemp) Pereopods 4 & 5 subequal in length	9
9.	Dactylus of male pereopod 2 with 4 or more tubercles at regular interval..... <i>M. scabriculum</i> (Heller) Dactylus of male pereopod with 1-2 tubercles..... <i>M. javanicum</i> (Heller)	

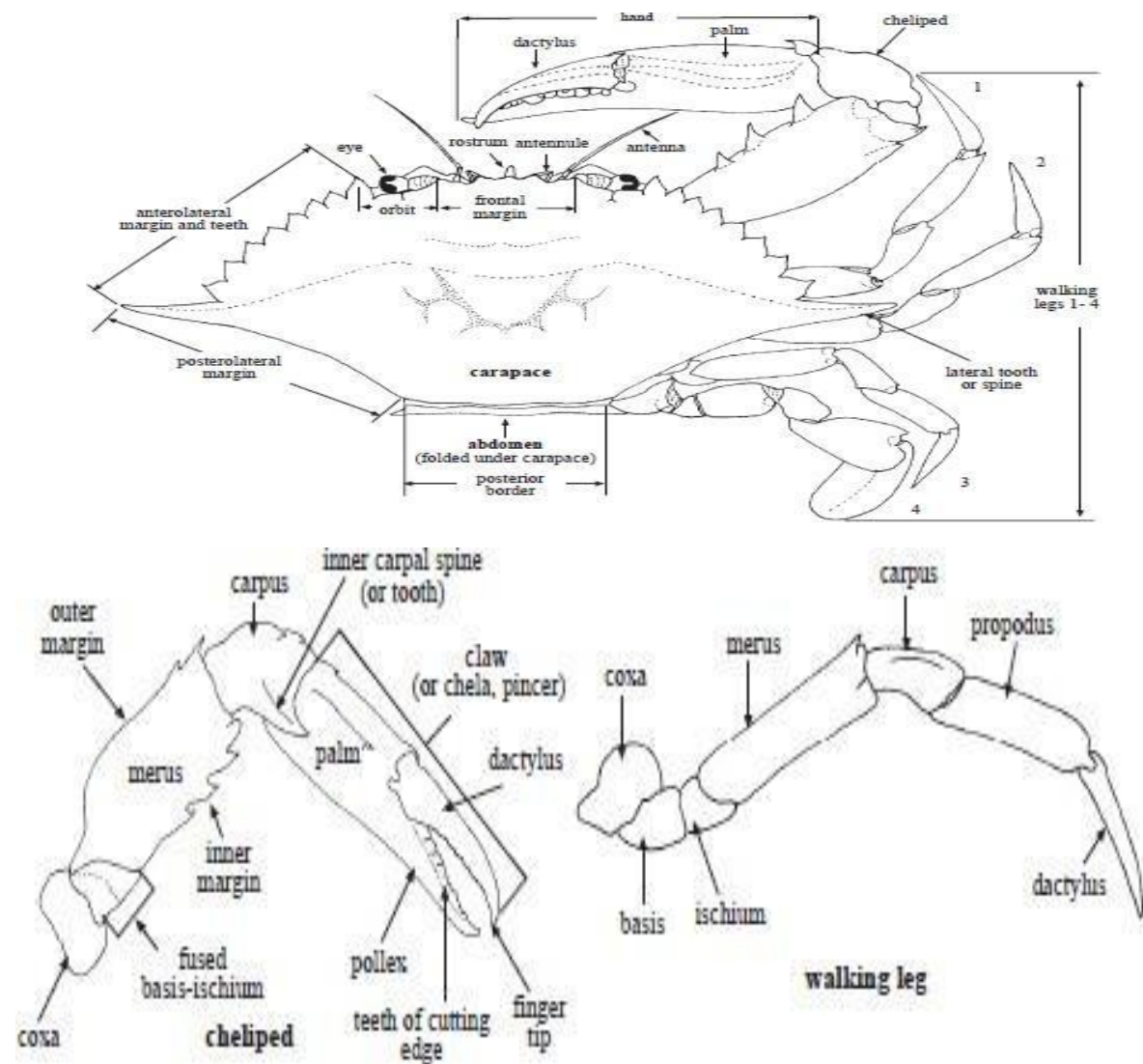
Crabs of commercial importance

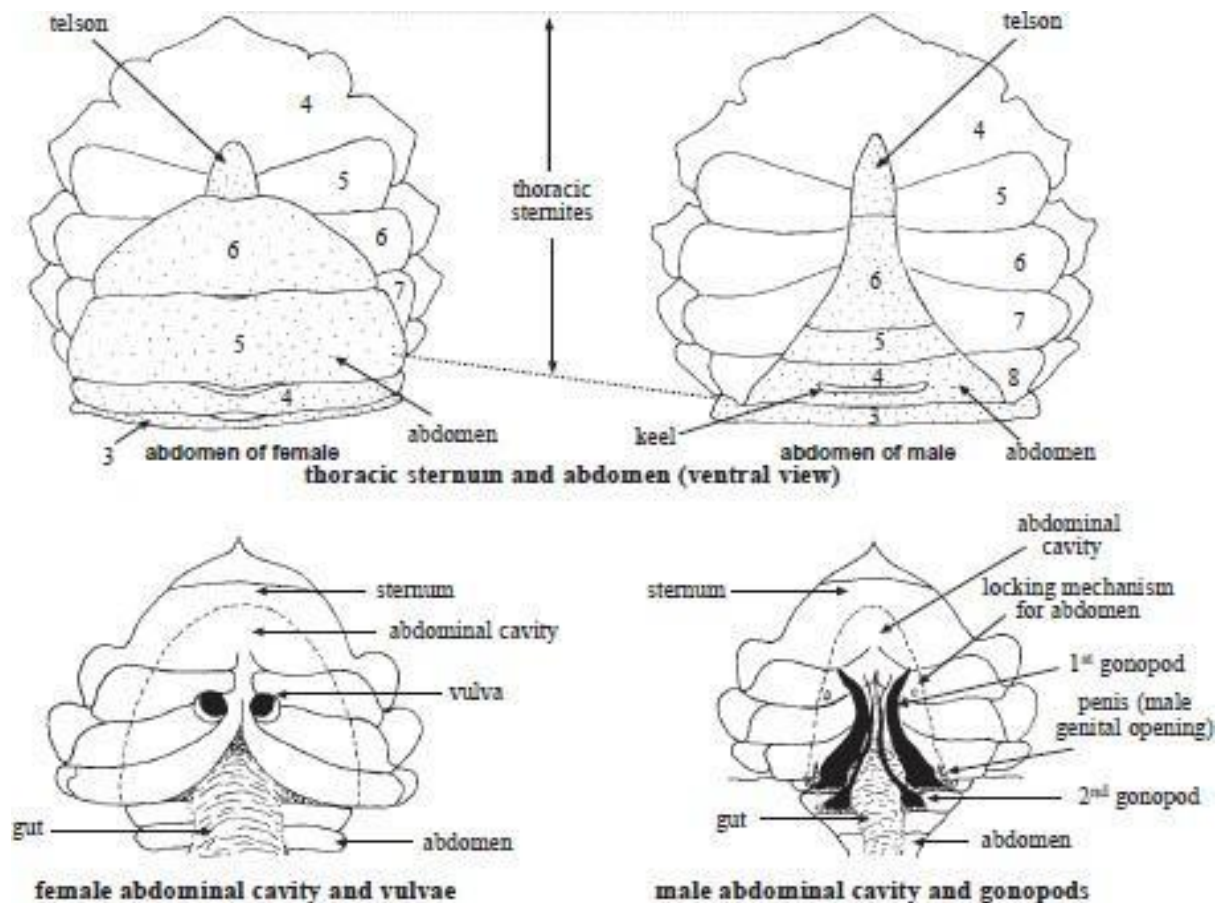
More than 600 species of crabs have been reported from India, of which a few species are commercially important. Many have been confined to sea and a few have invaded into the estuaries, but migrate to sea for breeding. The carapace is high, flattened with the antero lateral margins serrated. Abdomen is highly reduced and this structure is highly dimorphic. Abdominal appendages are also modified sex-wise. (two pairs in males and four pairs in females).

Classification of family Portunidae

Subphylum	Crustacea
Class	Malacostraca
Subclass	Eumalacostraca
Superorder	Eucarida
Order	Decapoda
Suborder	Pleocyemata
Superfamily	Portunoidea
Family	Portunidae

Technical terms: Structure of Carapace and cheliped of a crab





Key for the identification of some of the common species are given below

1.	Antero lateral borders of carapace cut into nine teeth.....	2
-	Antero lateral borders of carapace cut into six teeth..... <i>Charybdis</i>	4
2	Teeth on the antero lateral borders equal sized, green in colour.... <i>Scylla serrata</i>	3
-	Last tooth on the antero lateral borders enlarged in the form of a prominent large long spine..... <i>Neptunus</i>	
3	No spines on the posterior border of the arm of the chelipeds, carapace with three blood red spots..... <i>Neptunussanguinolentus</i>	
	A spine at the far end of the posterior border of the arm of the chelipeds <i>Neptunuspelagicus</i>	
4	First tooth on the antero- lateral borders anteriorly truncated and notched. Sixth abdominal tergum of male with curved and gradually convergent sides. One or two inconspicuous denticles near the far end of the posterior border of the protopodites of the last pair of legs. A brown cross marking on the carapace..... <i>Charybdis cruciata</i>	
-	First tooth on the antero- lateral borders acute, Sixth abdominal tergum of male with its sides parallel or even slightly divergent. Posterior border of the protopodites of the last pair of legs strongly serrated through out. 4 whitish spots on the carapace..... <i>Charybdis lucifera</i>	
	First tooth on the antero- lateral borders acute, Sixth abdominal tergum of male with	

	its sides parallel. Posterior border of the protopodites of the last pair of legs serrated in a larger part of its extent. Legs with annular bands. <i>Charybdis annulata</i>	
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Commercially important lobsters of India

The importance of lobsters in our marine products export trade is only second to that of prawns. The increasing demand of 'frozen lobster tails' has brought the Indian lobster to the limelight. About half a dozen species of spiny lobsters are recorded from the Indian region, belonging to the genera – *Panulirus*, *Palinustus* and *Peurulus*.

Diagnosis of Families

Palinuridae: Moderate to large-sized crustacean. The carapace is rounded (sub-cylindrical) in section, without a distinct median rostrum, ornamented with spines and granules of various sizes: each eye is protected by a strong, spiny frontal projection of carapace (frontal horns). Antennae are long and whip-like, antennules slender each consisting of a segmented peduncle.

Synaxidae: Carapace covered with small rounded granules but without enlarged spines; a small median triangular rostrum present; first pair of legs at least twice as thick as the second; entire body hairy and bright orange or red.

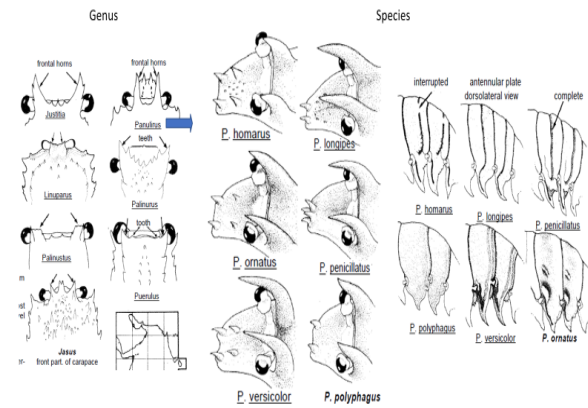
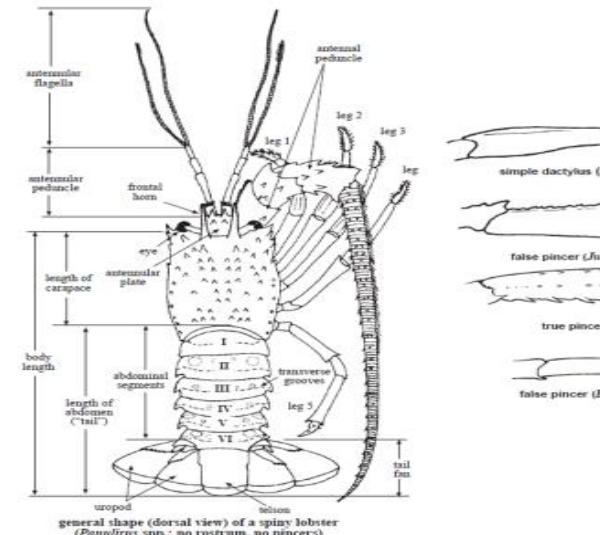
Nephripidae: Body tubular, a well-developed rostrum present; first 3 pairs of legs ending in true pincers, first pair much larger than the others.

Scyllaridae: Body flattened, firm: rostrum rudimentary or absent; first 4 pairs of legs without pincers, antennae plate-like, without pincers, antennae plate-like, without flagellum.

Polychelidae: Body flattened, soft: rostrum absent or rudimentary: first 4 pairs of legs with pincers; the first greatly elongated; antennal whip-like. Deep sea inhabitants.

Classification of family Palinuridae

Subphylum	Crustacea Brunnich, 1772
Class	Malacostraca Latreille, 1802
Subclass	Eumalacostraca Grobben, 1892
Superorder	Eucarida Calman, 1904
Order	Decapoda Latreille, 1802
Suborder	Pleocyemata Burkenroad, 1963
Superfamily	Palinuroidea Latreille, 1802



Key for the identification of 6 species of Lobsters under the genus *Panulirus*

1	Each abdominal segment with transverse groove.....	2
.	Abdominal segments without transverse groove.....	4
-		

2	Anterior margin of abdominal grooves scalloped..... <i>P. homarus</i> (Linnaeus) · Anterior margin of abdominal grooves not scalloped..... -	3
3	Antennular plate with 4 equal principal spines fused at base ... <i>P. penicillatus</i> (Olivier) · Antennular plate with 2 principal spines and some smaller spines behind - <i>P. longipes</i> (Milne Edwards)	
4	Flagellum of exopod of 2 nd maxilliped small or absent..... · Flagellum of exopod of 2 nd maxilliped well developed ,multiarticular - <i>P. polyphagus</i> (Herbst)	5
5	Conspicuous transverse white band posteriorly on each abdominal segment, legs with longitudinal white lines..... <i>P. versicolor</i> (Latreille) · No transverse white band on abdominal segments, but a conspicuous white spot on lateral portion, legs with alternative yellow and black mottling ... <i>P. ornatus</i> (Fabricius) -	

Marine mollusc diversity and conservation in India

09

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The global ecosystem encompasses over 1.75 million distinct species, among which there are 46,000 recognised species of marine molluscs (Bouchet et al. 2016). The phylum Mollusca accounts for around 60% of the total global biodiversity, as stated by Gosliner et al. in 1996. India possesses a diverse range of marine environments, including tidal flats, lagoons, coral reefs, deep sea areas, and islands. The exploration of marine biodiversity in India did not occur till the seventeenth century. India has a coastline that spans 8,129 kilometres and a continental shelf that covers 0.5 million square kilometres. Within its waters, there are 3,370 different species of marine molluscs belonging to 220 families and 591 genera (Ramakrishna and Dey 2010). Among these the bivalves are the most diverse (1100 species), followed by cephalopods (210 species), gastropods (190 species), polyplacophores (41 species) and scaphopods (20 species). There is no consensus among various authors on the total number of marine molluscs from India. Nevertheless, the current knowledge regarding the status of different mollusc species in maritime environments in India is lacking, and their threat status remains unidentified. India is home to five out of the seven classes of molluscs found worldwide, as stated by

Classes in Phylum Mollusca

This phylum can be segregated into seven classes: Aplacophora, Monoplacophora, Polyplacophora, Bivalvia, Gastropoda, Cephalopoda, and Scaphopoda.

Class Aplacophora

Aplacophora, which means "bearing no plates," comprises worm-like organisms that are predominantly found in benthic marine environments. These organisms do not have a shell made of calcium carbonate, but they do have aragonite spicules on their outer layer. Their mantle cavity is basic and they do not possess eyes, tentacles, or nephridia (excretory organs).

Class Monoplacophora

Monoplacophora organisms possess a solitary, helmet-shaped shell that envelops the body. The shell's form and the underlying animal's structure can range from circular to ovate. These animals possess a coiled digestive system, numerous sets of excretory organs, abundant gills, and a pair of gonads. Monoplacophorans were considered to be extinct and were only known from fossil evidence until the identification of *Neopilinagalathaea* in 1952. Presently, scientists have recognised approximately twenty living species.

Class Polyplacophora

Animals belonging to the family Polyplacophora, which means "bearing many plates," are popularly referred to as "chitons." They have a dorsal shell made up of eight armor-like plates. These animals possess a wide, lower foot that is specialised for adhering to rocks and other surfaces, and a mantle that extends beyond the shell in the shape of a belt. The girdle may possess calcareous spines as a means of providing protection against predators. Chitons inhabit several regions across the globe, including cold water, warm water, and tropical environments. The majority of chiton species reside in intertidal or subtidal areas and do not go beyond the photic zone. Certain organisms inhabit the upper regions of the intertidal zone, enduring prolonged exposure to air and light.

Class Bivalvia

Bivalvia is a taxonomic class consisting of aquatic molluscs that have flattened bodies and are protected by a shell composed of two hinged pieces. Bivalves encompass clams, oysters, mussels, scallops, and various other shell-bearing families. Most of them are organisms that extract food particles from the water and lack a distinct head or radula. The majority of bivalves engage in sediment burial on the seabed, while others may rest on the sea floor or affix themselves to rocks or other solid substrates. The bivalve's shell is made up of calcium carbonate and is

comprised of two valves, typically of comparable shape and size. The valves are connected along one edge by a pliable ligament which, in combination with interlocking "teeth" on each valve, creates the hinge.

Class Gastropoda

The class Gastropoda, also known as "stomach foot," comprises various well-known mollusks such as snails, slugs, conchs, sea hares, and sea butterflies. Gastropoda encompasses both species that possess shells and species with diminished shells. These animals exhibit asymmetry and typically possess a spiral-shaped shell. Shells can exhibit planospiral morphology, resembling a coiled garden hose, as observed in garden snails, or conispiral morphology, resembling a spiral staircase, as observed in marine conches.

Class Cephalopoda

The class Cephalopoda include octopuses, squids, cuttlefish, and nautilus, which are all referred to as "head foot" animals. Cephalopods are a group of mollusks that have a shell, although it is smaller than usual. These organisms have vibrant colours, commonly observed in squids and octopuses, which serves the purpose of camouflage. All members of this class are carnivorous predators and possess beak-like jaws at the front end. Cephalopods exhibit a highly developed neural system and possess eyes, as well as a closed circulatory system. The foot is characterised by lobes and is specialised into tentacles and a funnel, which serve as the means of mobility. Cephalopods achieve locomotion by expelling a jet of water for propulsion. Cephalopods, such as squids and octopuses, secrete sepia or a dark ink, which is expelled towards a predator to facilitate a rapid escape. Octopuses and squid possess suckers on their tentacles. The ctenidia are contained within a spacious mantle cavity that is supplied by blood veins, each of which has its own corresponding heart. The mantle contains siphonophores that enable the exchange of water.

Class Scaphopoda

Scaphopoda, also known as "boat feet," are commonly referred to as "tusk shells" or "tooth shells." This is particularly noticeable when studying Dentalium, which is one of the few extant genera of scaphopods. Scaphopods typically reside underground in sand, with the front entrance exposed to water. These animals possess a solitary conical shell that is open at both ends. The head is underdeveloped and extends from the back end of the shell. These animals lack eyes but contain a radula, as well as

a foot that has been converted into tentacles with a bulbous end, referred to as captaculae. Captaculae function as mechanisms to ensnare and manipulate prey. These animals lack ctenidia.

Scheduled marine molluscs of India

1. *Cassis cornuta* (Linnaeus, 1758)
2. *Charoniatritonis* (Linnaeus, 1758)
3. *Conus milneedwardsi* (Jousseaume, 1894)
4. *Cypraeacassisrufa* (Linnaeus, 1758)
5. *Ophioglossolambis digitata* (Perry, 1811)
6. *Lambismillepeda* (Linnaeus, 1758)
7. *Lambisscorpius* (Linnaeus, 1758)
8. *Harpagochiragra* (Linnaeus, 1758)
9. *Harpagoarthriticus* (Roding 1798)
10. *Turbo marmoratus* Linnaeus, 1758
11. *Tudiclaspirillus* (Linnaeus, 1767)
12. *Staphylaealimacina* (Lamarck, 1810)
13. *Leporicypraeamappa* (Linnaeus, 1758)
14. *Talpariatarpa* (Linnaeus, 1758)
15. *Pleuroploca trapezium* (Linnaeus, 1758)
16. *Harpulinaaarusiaca* (Lightfoot, 1786)
17. *Dolomenaplicatasibbaldi* (G.B. Sowerby II, 1842)
18. *Lambistruncata* ([Lightfoot], 1786)
19. *Rochianilotica* (Linnaeus, 1767)

Bivalves

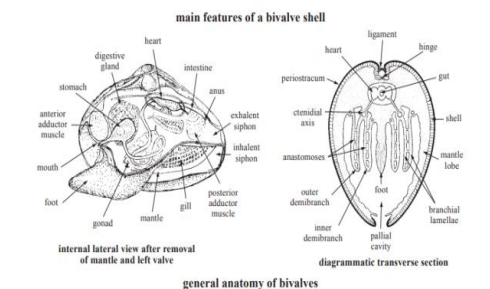
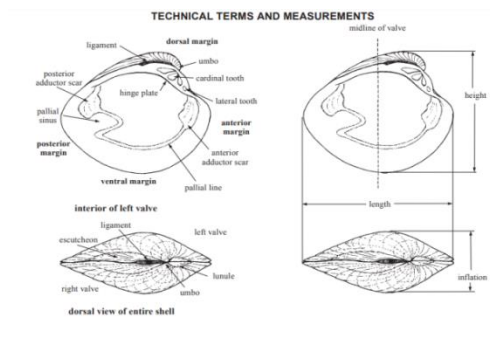
1. *Hippopus hippopus* (Linnaeus, 1758)
2. *Tridacna maxima* (Roding, 1798)
3. *Tridacna squamosa* (Lamarck, 1819)
4. *Placuna placenta* (Linnaeus, 1758)

Cephalopods

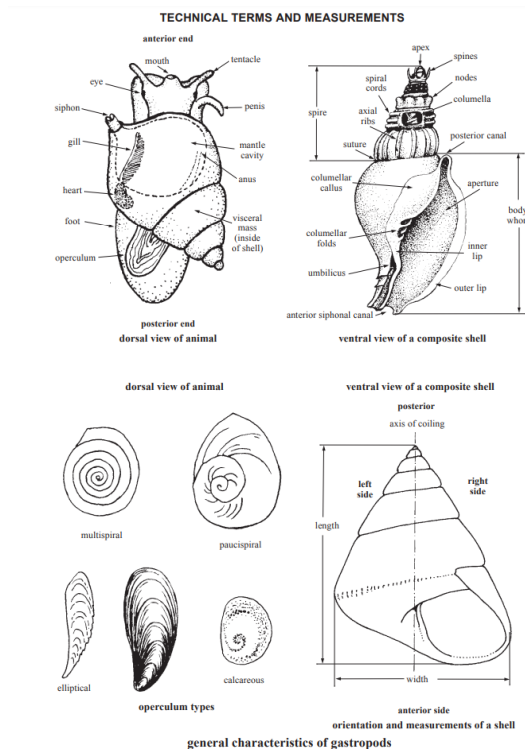
1. *Nautilus pompilius* (Linnaeus, 1758)

Scheduled marine molluscs of India

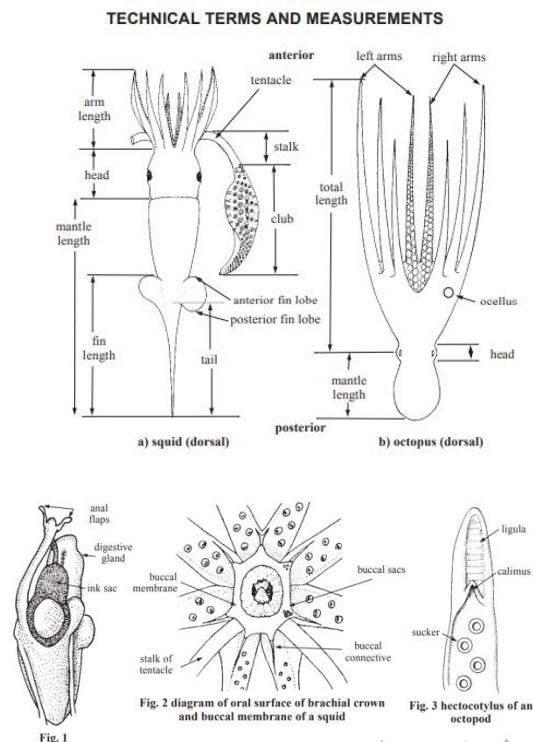




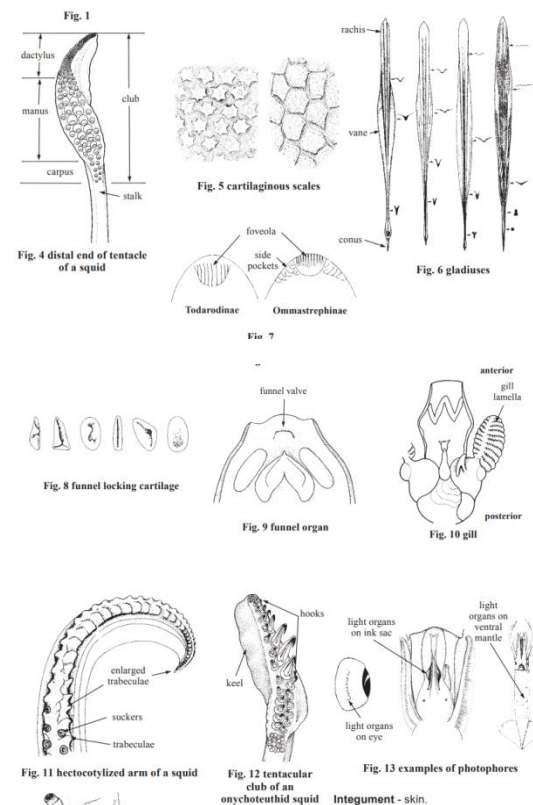
Courtesy:FAO identification guide for fishery purpose

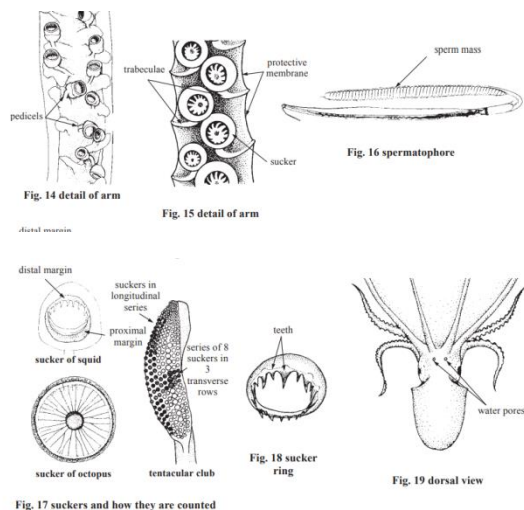


Courtesy:FAO identification guide for fishery purpose



Courtesy:FAO identification guide for fishery purpose





Courtesy:FAO identification guide for fishery purpose

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Echinoderm diversity and its conservation

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The Phylum Echinodermata, an exclusive marine phylum comprising approximately 7,000 living species and 13,000 fossil species, is found from the intertidal area to the deep sea bed. This unique group of animals has a skeleton made of calcium carbonate in the form of calcite inside their bodies and a unique watervascular system that helps them eat, move around, and do other things. As larvae, they have bilateral symmetry, and as adults, they have more or less noticeable pentiradial symmetry. Echinoderms have no head or brain, but they do have a central nerve ring that surrounds the mouth.

Echinoderm Diversity

Five extant classes of echinoderms are universally recognised: Asterozoidea, Ophiurozoidea, Echinozoidea, Holothurozoidea, and Crinozoidea.

Class Asterozoidea (sea stars, starfish)

The world's oceans are known to have 2100 species of sea stars. Sea stars are one of the most familiar echinoderm species and an important predator species in the marine ecosystem. They are in a size range as small as a few centimetres to a metre in diameter. Most of the seastars have five arms, but some have as many as 50. The crown of thorns is an important starfish that is known to cause considerable damage to living coral reefs the world over.

The mouth of the seastar is located at the bottom, and while feeding, the mouth is everted outside on the food, secreting the digestive enzymes on the food, and this digested food is taken inside while retracting the stomach. The sexes in seastars are separate, and fertilisation takes place outside in the water. Some seastars are known to brood the eggs until they hatch.

Class Ophiurozoidea (brittle stars, serpent stars, basket stars)

There are about 2000 extant species of ophiuroids in the world's oceans. As their name implies, brittle stars are extremely fragile. This class is one of the most numerous species of

echinoderms among all. Brittle stars are nocturnal animals that feed on suspended organic matter and microzooplankton using their tube feet. In brittle stars, the sexes are also separate, and external fertilisation depends on the mercy of nature.

Class Echinozoidea (sea urchins, sand dollars, and heart urchins)

There are nearly 800 species found in the seas and oceans of the world. The echinoids are commercially important organisms. A considerable aquaculture operation of sea urchins is taking place in order to harness the gonad, which is a delicacy in countries like Japan and France. The echinoid lacks a distinct arm-like structure, but the body is covered by the calcium carbonate test, which is armoured with spines. The tube feet and spines on the globular test help in the movement of the echinoids. Echinoids feed on the bottom organic material and plant material using their teeth, the "Aristotle lantern," located on the oral side of the test. The five anal pores are situated on the aboral surface of the test. A sand dollar is a flat, cake-like organism with soft, thin hair around its test. In sand dollars, the tube feet are projected through the porous petal-like structure, and these tube feet help in respiration.

Class Holothurozoidea (sea cucumbers, beche de mer)

There are approximately 1500 species of shallow-water holothuroids found in the tropical shallow seas around the globe. They are soft with leathery outer skin and lie on the sea bottom on their sides. The mouth is surrounded by up to 30 tentacles on one end, and the anus is situated on the opposite end. The tentacles around them secrete mucus to capture planktonic organisms, which are often wiped off by them. When sea cucumbers are disturbed, they evert their intestine through their anus, but they are regenerated within a few weeks. In most seacucumbers, the sexes are separate but some are hermaphrodites. Sea cucumbers are commercially important organisms. Sea cucumbers are one of the important ecosystem functionaries and maintain the health of the reef ecosystem. The product of sea cucumber is called Beche-de-mer, which is a delicacy in south east Asian countries. However, in India there is

a ban on the collection and processing of these organism under the 1972 wild life protection act.

Class Crinoidea (sea lilies, feather stars)

Among the 650 species of living crinoids, 100 are stalked crinoid and 550 are feather stars. This group of organisms is very different from other echinoderms by having their mouth and anus on their upper surface in an open disc. Crinoids are filter feeders, using their arms, which range from 5 to 200 in some cases.

Sl.No	Class	No. of species in Gulf of Mannar (James, 1988)	Total echinoderm diversity in India (Sastri, 1988)
1	Crinoidea	9	65
2	Asterioidea	26	158
3	Ophiuroidea	19	152
4	Echinoidea	19	113
5	Holothuroidea	22	163

Echinoderm exploitation and conservation issues

Echinoderms are gaining popularity with aquarists and account for about 17% of the global trade. More and more people around the world are collecting echinoderms for commercial purposes, which puts these strange invertebrates in danger. This adds to the worry about the continued loss of marine resources around the world, especially the effects of overfishing on the structure and function of whole ecosystems (Botsford et al. 1997). Of the five extant classes of echinoderms, only sea urchins and sea cucumbers are heavily exploited (Kelly, 2005). Sea urchins and sea cucumbers are under high commercial fishing pressure, and various aspects of their biology are likely to compound the impact of overexploitation of wild populations. Some species of sea urchin and sea cucumber are extremely long-lived, which tends to be an indicator of uncertainty in reproductive success (Ebert & Southon 2003). In addition to overfishing, the emerging global trade in the collection of echinoderms for home aquaria, souvenirs, and biomedical products is at a critical stage, and certain species of echinoderms are now listed as threatened species. fishery for *Asterias rubens* in Denmark (Sloan 1985). The Chinese have imported sea cucumbers for over 1000 years from India, Indonesia, and the Philippines, but traders began gathering them from a wider area in the eighteenth and nineteenth centuries (Conand & Byrne 1993).

			2007)
1	Crinoidea	9	65
2	Asterioidea	26	158
3	Ophiuroidea	19	152
4	Echinoidea	19	113
5	Holothuroidea	22	163

Table.1 Comparison of echinoderm faunistic diversity from the Gulf of Mannar

Current conservation measures

Current controls of the management of echinoderm fisheries include closed seasons during times of spawning; gear restrictions; designation of no-take, marine-protected areas; daily catch limits; minimum legal size; prohibition of night fishing for nocturnal species; and restrictions on the use of scuba for harvesting (Toral-Granda 2006). Rotational fishing has also been suggested as an appropriate harvest strategy for fisheries that occur on sessile and sedentary species, primarily because it allows higher spawning stock abundance than does an annual harvest strategy (Humble 2005). One way to reduce the commercial exploitation of wild echinoderm stocks is to develop laboratory culture methods to produce individuals for commercial purposes, and this is being done to supply the food market (Kelly et al. 1998).

Conservation measures practiced in India

In India, nearly 200 species of sea cucumbers are found in coral reef colonies, of which 22 are found in the Gulf of Mannar and Palk Bay regions. Out of the 22 species, *Holothuriacabra* (sandfish), *Holothuriaspiniifera*, *Holothuriaatra*, and *Actinopygaechinites* were exploited and exported in large numbers to Singapore, where they were distributed to Taiwan, China, and Japan, where they are utilised for the preparation of soups, which are considered delicacies. The indiscriminate exploitation for this lucrative trade would have resulted in overexploitation, leading to the endangering of the species in the

wild. The Union Ministry of Environment and Forests imposed a fishing ban on sea cucumbers smaller than 75 mm in length in 1982 as a result of numerous conservation-related issues. Subsequently, in 2002, a blanket ban on collection and trade of sea cucumber was imposed by listing this organism in the Schedule I category of the Wildlife Protection Act of 1972. Schedule I contains the list of the most endangered species and gives them the highest level of protection. The Forest Department/Wildlife Crime Control Bureau

(WCCB) reports sporadic instances of illegal sea cucumber trade and a number of instances of sea cucumber confiscation along the Gulf of Mannar in spite of this ban. However, the livelihood issues of fishermen involved in sea cucumber fishing, incidental catches of sea cucumber in fishing gear, and the problems emerging due to the confiscation of illegal sea cucumbers continue to be major issues in the Gulf of Mannar region.



Sea star *Astropecten indicus* from the trawler Discards from Mangalore coast



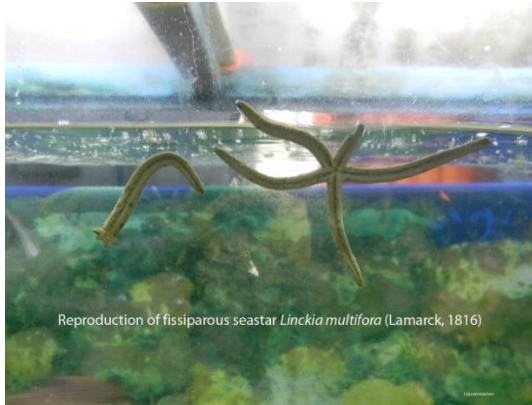
Sea star *Protoreasterlinckii* from Gulf of Mannar



Sea star *Pentacasteraffinis* from Gulf of Mannar



Sea star *Pentacastercumingii* from Gulf of Mannar



sea star *Linckia multifora* (Lamarck, 1816)

from Gulf of Mannar



Pin cushion star *Culcitaschmidiana* (Retzius, 1805)

from Gulf of Mannar



Test of sea urchin *Echinolampas ovata*

from Gulf of Mannar



Test of sea urchin *Lovenia elongata*

from Gulf of Mannar



Test of sea urchin *Temnoplureus toreumaticus*

from Mangalore coast



Test of irregular sea urchin (Sand dollar) *Clypeaster spinus* from Mangalore coast



Sea urchin *Stomopneustes variolaris*
from St. Mary's Island off Malpe,
South Canara coast



Test of irregular sea urchin
Echinodiscus auritus from Gulf of Mannar



Sea cucumber *Holothuria leucospilota*
from St. Mary's Island off Malpe, South Canara
coast



Sea cucumber *Holothuria scabra* from the Palk Bay-
Dhanushkodi waters.

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Elasmobranch diversity

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The cartilaginous fish, comprising sharks, rays, skates, guitar fishes and chimaeras have captured the imagination of scientists and enthusiasts alike. From the majestic great white shark to the graceful manta ray, each species contributes to the rich tapestry of marine biodiversity, making elasmobranchs a captivating subject of study and conservation. Elasmobranchs are a subclass under the class Chondrichthyes, which differ from bony fishes (Osteichthyes) in having a cartilaginous skeleton instead of calcified bones. Chondrichthyes is an evolutionary old taxon with the earliest ancestors appearing in the Devonian period about 400 million years ago. Chondrichthyes comprises subclass Elasmobranchii (sharks, rays, skates and guitarfishes) and subclass Holocephali (Chimaeras). Elasmobranchs inhabit diverse marine environments worldwide, from shallow coastal waters to deep oceanic trenches, totaling over 869 extant species, including about 400 sharks and the remaining being skates, rays and guitarfishes. These cartilaginous fish occupy various habitats, spanning from nearshore to abyssal depths, from the equator to the poles, and even some in freshwater and hypersaline waters, with a higher concentration in tropical and temperate marine waters. As exploration of deep-sea environments advances, more elasmobranch species are likely to be discovered, enriching our understanding of their biodiversity. Taxonomy undergoes continual revisions, leading to better clarity on the relationships and identities of organisms. In the case of elasmobranchs, species may be reclassified, merged with others, or renamed, contributing to an evolving understanding of their phylogeny and evolutionary history. Such revisions ultimately enhance our comprehension of how these fascinating creatures have evolved over time.

Class :Chondrichthyes

Kingdom Animalia
Phylum Chordata
Class Chondrichthyes
Subclasses Elasmobranchii, Holocephali

Common characteristics of cartilaginous (Chondrichthyes) fishes

- Cartilaginous skeleton which is calcified giving the appearance of bone
- Cranium (or skull) to protect brain and sense organs of the head
- Vertebral column fundamentally structured around a notochord supported by vertebral centra
- Skeleton of the pelvic fins modified into paired claspers in males
- Usually snout is pre-oral with the nostrils on the ventral surface
- Teeth usually not fused to jaws and replaced serially
- Lungs/swim bladder absent
- Intestinal spiral valve present
-

Subclass Elasmobranchii

Common characteristics of Elasmobranchs

- Upper jaws not fused to the cranium, can be protruded. Lower jaw is a single element on each side
- Gill openings 5-7 pairs, no operculum
- Body covered with placoid scales (dermal denticles), teeth are modified placoid scales
- Teeth arranged in successive rows that continuously replace each other in a conveyor belt-like manner

Living members of the Subclass Elasmobranchii come under the division Neoselachii which comprises the subdivisions Selachii (modern sharks) and Batoidea (skates, rays and guitarfishes)

- Selachii include two superorders viz., Squalomorphii and Galeomorphii. Squalomorphii includes less derived sharks, such as dogfish sharks,

while Galeomorphii includes most of the living sharks, such as bull sharks, tiger sharks, and hammerhead sharks

- Within Squalomorphii (lack anal fin), there are 3 orders, the Squatiniformes (angel sharks), the Pristiophoriformes (sawsharks) and the Squaliformes (dogfish sharks)
- Galeomorphii, characterized by the presence of an anal fin, encompasses five orders: Heterodontiformes (bullhead sharks), Orectolobiformes (carpet sharks), Lamniformes (mackerel sharks), Carcharhiniformes (ground or requiem sharks), and Hexanchiformes (six- and seven-gilled sharks and frilled sharks)
- Batoidea contains four orders: Rhinopristiformes (saw fishes, wedge fishes and guitar fishes), Myliobatiformes (stingrays, whip rays, eagle rays, devil rays and relatives), Rajiformes (skates) and Torpediniformes (electric rays and numb fishes).

Subdivision Selachii (Modern sharks)

Sharks are perhaps the most well-known members of the subclass Elasmobranchii, ranging in size from small species like the dwarf lanternshark to giants like the whale shark and the great white shark.

Common features of Sharks:

- Upper eyelids that can move freely, gill openings positioned on the sides of head, distinct pectoral fins not attached to sides of the head
- Typically have a streamlined fusiform (bullet-shaped) body, although some species exhibit a flattened ray-like shape
- Five pairs of gill openings, although there are species with six or seven pairs
- Majority possess two dorsal fins, although a few species have only one. Certain groups of sharks have dorsal fins with spines along their leading edges
- Well-developed caudal fin

Subdivision Batoidea (Skates, rays and guitar fishes)

Distinguishing features:

- Flattened in shape and have expanded pectoral fins that give them a wing-like appearance.

- Pectoral fins are connected to both the back of the skull and the body, expanding significantly to create a body disc
- Gill openings are positioned beneath their flattened body
- Majority of species feature diminutive dorsal and caudal fins, with numerous species entirely lacking these fins
- Dorsal fins do not possess spines
- Anal fin absent
- Eyes as well as spiracles typically positioned on top of the head
- In a few blind electric rays, the eyes are obscured by skin and are not easily distinguishable
- Species identification relies on characteristics such as colouration, shape of the body disc and tail, structure of the nasal passages and mouth as well as the arrangement and shape of dermal thorns and denticles

Subclass Holocephali (Chimaeras)

Distinguishing characteristics of chimaeras:

- Upper jaw joined and fused to the underside of skull
- Gills protected by operculum, and only single gill opening
- Skin devoid of denticles
- Teeth glued together into plate-like structures, often resembling a beak
- Tail elongated and slender

Extant Chimaeras are categorized into three families: Callorhynchidae (plough-nose chimaeras), Rhinochimaeridae (long-nose chimaeras), and Chimaeridae (short-nose chimaeras)

Species reported from Indian waters: *Neoharriotta pinnata* (Scklefin chimaera) and *Hydrolagus africanus* (African chimaera).

Classification of Sharks (Selachii) in orders

Squatiniformes (Angel Sharks, Sand devils)

Flat body, mouth at front, no anal fin, ovoviviparous

Pristiophoriformes (Sawsharks)

Long snout, mouth underneath, no anal fin, gill slits on sides of the body, spiracles present; ovoviviparous (litters of 7 to 17 large pups)

Squaliformes (Dogfish and bramble/cookiecutter sharks)

Short snout, no anal fin; ovoviviparous, 1 or 2 or over 20 young ones in a litter.

Hexanchiformes (Frilled and cow sharks)

Anal fin present, 1 dorsal fin, 6 or 7 gills on each side of the head, ovoviviparous

Heterodontiformes (Bullhead sharks and horn sharks)

Anal fin present, 5 gill slits, 2 dorsal fins, dorsal spines. Only living sharks with dorsal fin spines and anal fins both present, oviparous, producing eggs in unique, large spiral flanged egg cases,

Orectolobiformes (Carpet sharks including the wobbegong, nurse, bamboosharks, blind, zebra, and whale shark)

Anal fin, 5 gill slits, 2 dorsal fins, no fin spines, mouth in front of the eyes, oviparous or ovoviviparous

Lamniformes (Mackerel sharks, including the basking, goblin, megamouth, great white, crocodile shark, thresher, porbeagles, sandtiger and mako sharks)

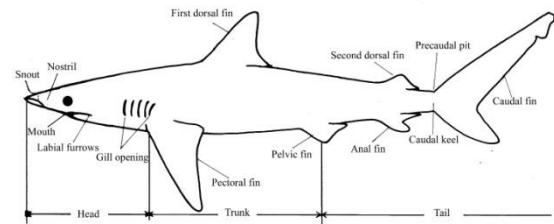
Anal fin, 5 gill slits, 2 dorsal fins, no fin spines, mouth behind the eyes, no nictitating eyelids, ovoviviparous

Carcharhiniformes (Ground sharks including catsharks, swellsharks, houndsharks, weasel sharks, requiem, tiger and hammerhead sharks)

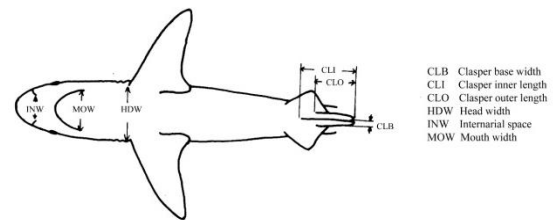
Anal fin, 5 gill slits, 2 dorsal fins, no fin spines, mouth behind the eyes, nictitating eyelids, viviparous or ovoviviparous

Morphology and morphometry of sharks

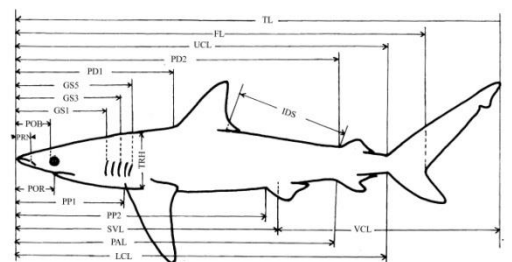
Sharks are categorized according to their external features like body shape, snout length, and fin proportions, as well as internal characteristics such as tooth arrangement and count. Among these, total length (TL) is commonly used in shark taxonomy as it serves as a baseline for measuring other proportional dimensions. Pre-caudal length (PCL) and fork length (FL) are sometimes employed as substitutes for TL in specific cases, providing additional data to analyze shark morphology.



Lateral view of shark illustrating external body parts

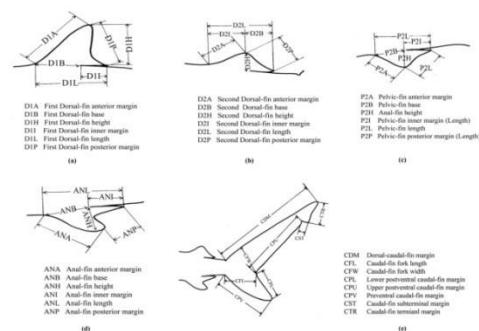


Ventral view and measurements

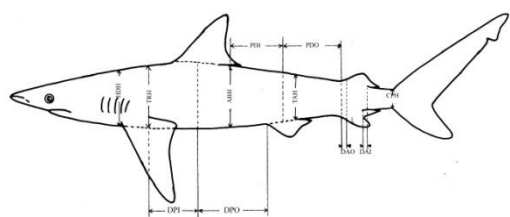


FL	Fork length	PD1	Pre-first dorsal-fin length	SVL	Snout-vent length
GS1	Snout to first gill slit opening	PD2	Pre-second dorsal-fin length	TL	Total length
GS3	Snout to third gill slit opening	POB	Preorbital length	TRI	Trunk length
GS5	Snout to fifth gill slit opening	POR	Preopercular length	UCL	Upper precaudal-fin length
IDS	Interdorsal width	PP1	Prepelvic-fin length	VCL	Vent caudal-fin length
LCL	Lower precaudal-fin length	PP2	Prepelvic-fin length		
PAL	Prenarial length	PRN	Prenarial length		

Main longitudinal measurements

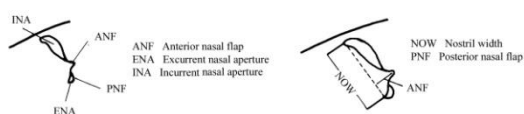


Measurements of (a) first dorsal, (b) second dorsal, (c) pelvic, (d) anal and (e) caudal fins

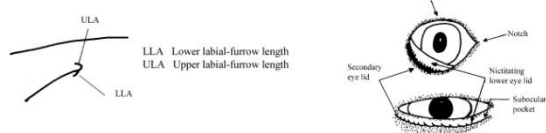


ABH	Abdomen height	HDH	Head height
CPH	Caudal-fin peduncle height	PDI	Pelvic-fin midpoint first dorsal-fin insertion
DAI	Second dorsal-fin insertion anal-fin insertion	PDO	Pelvic-fin midpoint second dorsal-fin origin
DAO	Second dorsal-fin origin anal-fin origin	TAH	Tail height
DPI	First dorsal-fin midpoint pectoral-fin insertion	TRH	Trunk height
DPO	First dorsal-fin midpoint pelvic-fin origin		

Other common measurements

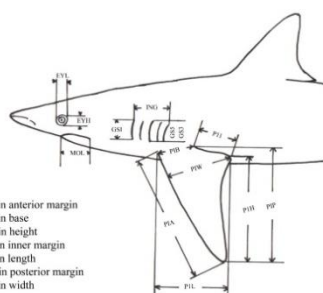


Nostrils

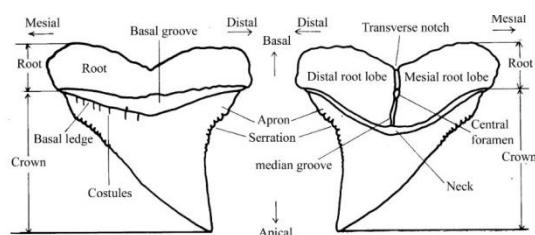


Mouth corner

Eye



Head and pectoral fin measurements



Tooth parts of sharks

Taxonomy and diversity of sharks in Indian waters

Order : Carcharhiniiformes

Shark species from the families Carcharhinidae, Sphyrnidae, Scyliorhinidae, Pentanchidae, Triakidae, Hemigaleidae, Proscyllidae, and Pseudotriakidae within the Carcharhiniiformes order are known to inhabit Indian waters.

Family : Carcharhinidae (Requiem sharks)

The largest and most significant family of sharks in tropical fisheries. They typically lack spiracles (except for *Galeocerdo*); have internal nictitating eyelids and elongated, arched mouths that extend beyond their eyes. Teeth generally blade-like, varying in size from small to large and often broader in the upper jaw, while the lower jaw teeth are more cuspidate and less compressed. Precaudal pit present. Two dorsal fins and an anal fin present, with the first dorsal fin base notably positioned ahead of the pelvic fin bases. Midpoint of the first dorsal fin base always lies in front of the origins of the pelvic fins. They have five gill slits, with the last one to three situated above the pectoral fin, and do not possess gill rakers. Reproduction is typically viviparous, involving a yolk sac placenta, and litter sizes vary from 1 or 2 to as high as 135, although the tiger shark is an ovoviviparous exception to this.

Family : Sphyrnidae (Hammerhead sharks)

These sharks have hammer-like lateral extensions on their heads, with circular eyes positioned at the outer edges. Eyes feature internal nictitating eyelids, and they lack spiracles and labial furrows. Precaudal pit present, have two dorsal fins, with distinctive high and pointed first dorsal fin. Base of the first dorsal fin is shorter than that of the caudal fin and positioned in front of the origins of pelvic fins. Second dorsal fin and anal fins are notably smaller than the first dorsal fin. Mode of reproduction is by viviparity.

Family : Scyliorhinidae (Catsharks)

These small sharks feature a slender, elongated body with catlike eyes, often elongated and possibly with rudimentary nictitating eyelids. They possess two small dorsal fins without spines, and an anal fin. Base of the first dorsal fin is either opposite or behind the bases of the pelvic fins. These sharks lack pre-caudal pits, and their caudal fin lacks a prominent ventral lobe or dorsal margin undulations. They have five gill slits, with the last two positioned behind the origins of the pectoral fins. Additionally, they

possess spiracles and numerous small teeth, each with a single central cusp and sometimes one or more cusplets on each side near the centre of the mouth. Intestines possess spiral valve, and they do not have lateral keels or precaudal pits on the caudal peduncle.

Family : Pentanchidae (Cat sharks)

Small sharks with slender to moderately stout bodies; eyes horizontal oval; rudimentary lower eyelids; spiracles present; five gill slits last two over the pectoral fin; small, numerous teeth; intestine with spiral valve; origin of first dorsal over or behind pelvics; second dorsal and anal fins relatively large; second dorsals smaller to larger than first dorsal; tail strongly symmetrical with little or no lower lobe, its top edge straight, sometimes with denticles.

Family: Triakidae (Hound sharks)

Small to medium-sized sharks, characterized by horizontally oval eyes equipped with nictitating eyelids. Their mouths are long, angular, or arched, extending past the front ends of eyes, and they have moderate to very long labial furrows. Their anterior nasal flaps are not typically slender or barbel-like. These sharks have two moderately to large dorsal fins without spines, with the first dorsal fin base located well ahead of the pelvic fin bases. Anal fin is smaller than the second dorsal fin and has a concave rear edge. They lack a precaudal pit, and their caudal fin lacks a prominent ventral lobe or strong undulations on its dorsal margin. They possess spiracles and intestine with a spiral valve.

Family: Hemigaleidae (Weaselsharks)

Margin of the dorsal fin is wavy or undulated, there is a precaudal pit, internal nictitating membrane, small spiracles, moderately long labial furrows, and a spiral valve in the intestine.

Family : Proscyllidae (Finbackcatsharks)

Nictitating eyelids of these sharks are poorly developed, and their spiracles are notably large. Posterior teeth on their dental bands have a comb-like arrangement, and their labial furrows are either very short or entirely absent, only visible at the mouth corners if they are present.

Family: Pseudotriakidae (False catsharks)

Eyes are elongated and slit-like, featuring underdeveloped nictitating eyelids. They also possess large spiracles and an exceptionally high number of tooth rows, with the posterior teeth displaying a comb-like structure. First dorsal fin is elongated, low, and keel-like in appearance.

Species reported from Indian waters: Order Carcharhiniformes

Family	Genus	Species	Common name
Carcharhinidae	<i>Carcharhinus</i>	<i>C. longimanus</i>	Oceanic whitetip shark
		<i>C. albimarginatus</i>	Silvertip shark
		<i>C. dussumieri</i>	Whitecheek shark
		<i>C. wheeleri</i>	Blacktail reef shark
		<i>C. amblyrhynchus</i>	Grey reef shark
		<i>C. sorrah</i>	Spot-tail shark
		<i>C. falciformis</i>	Silky shark
		<i>C. melanopterus</i>	Black-tip reef shark
		<i>C. leucas</i>	Bull shark
		<i>C. limbatus</i>	Black-tip shark
		<i>C. altimus</i>	Bignose shark

		<i>C. amboinensis</i>	Pigeye shark
		<i>C. brevipinna</i>	Spinner shark
		<i>C. macroti</i>	Hardnose shark
		<i>C. amblyrhynchoides</i>	Graceful shark
		<i>C. obscurus</i>	Dusky shark
		<i>C. hemiodon</i>	Pondicherry shark
	<i>Rhizoprionodon</i>	<i>R. acutus</i>	Milk shark
		<i>R. oligolinx</i>	Grey sharpnose shark
	<i>Prionace</i>	<i>P. glauca</i>	Blue shark
	<i>Scoliodon</i>	<i>S. laticaudus</i>	Spadenose shark
	<i>Galeocerdo</i>	<i>G. cuvier</i>	Tiger shark
	<i>Triaenodon</i>	<i>T. obesus</i>	Whitetip reef shark
	<i>Loxodon</i>	<i>L. macrorhinus</i>	Slit-eye shark
	<i>Lamiopsis</i>	<i>L. temminckii</i>	Broadfin shark
	<i>Negaprion</i>	<i>N. acutidens</i>	Sicklefin lemon shark
Sphyrnidae	<i>Sphyrna</i>	<i>S. lewini</i>	Scalloped hammerhead
		<i>S. mokarran</i>	Great hammerhead
		<i>S. zygaena</i>	Round headed hammerhead
	<i>Eusphyra</i>	<i>E. blochii</i>	Wing-head shark
Scyliorhinidae	<i>Cephaloscyllium</i>	<i>C. silasi</i>	Indian swellshark
	<i>Atelomycterus</i>	<i>A. marmoratus</i>	Coral catshark
	<i>Bythaelurus</i>	<i>B. hispidus</i>	Bristly catshark
Pentanchidae	<i>Apristurus</i>	<i>A. investigatoris</i>	Broadnose catshark
	<i>Halaelurus</i>	<i>H. quagga</i>	Quagga catshark
Triakidae	<i>Iago</i>	<i>I. omanensis</i>	Bigeye hound shark
		<i>I. mangalorensis</i>	Mangalore hound shark
Hemigaleidae	<i>Chaenogaleus</i>	<i>C. macrostoma</i>	Hooktooth shark
	<i>Hemigaleus</i>	<i>H. microstoma</i>	Sicklefin weasel shark
	<u><i>Paragaleus</i></u>	<u><i>P. longicaudatus</i></u>	Slender weasel shark
	<i>Hemipristis</i>	<i>H. elongata</i>	Snaggletooth shark
Proscyllidae	<i>Eridacnis</i>	<i>E. radcliffei</i>	Pygmyribbontailcatshark
	<i>Proscyllium</i>	<i>P. magnificum</i>	-
Pseudotriakidae	<i>Planonassus</i>	<i>P. indicus</i>	Eastern dwarf false catshark

Order Lamniformes

Shark species belonging to the families Alopiidae, Lamnidae, Megachasmidae, Pseudocarchariidae and Odontaspidae of the order Lamniformes are known to occur in Indian waters

Family Alopiidae (Thresher sharks)

These sharks possess long, curved, asymmetrical caudal fin, dorsal lobe is almost as long as the rest of the body and a short ventral lobe. Pectoral fins are long and narrow. They have large eyes, a small mouth, and short gill openings, with the last two above the base of the pectoral fin. Precaudal pit present. Ovoviviparous and exhibits uterine cannibalism.

Family Lamnidae (Mako sharks)

These large sharks have pointed snouts and spindle-shaped bodies, with elongated mouths

housing large, blade-like teeth. Their gill slits extend widely laterally to the mid-dorsal surface, and they lack gill rakers. They possess long pectoral fins and tall dorsal fins, accompanied by small, pivoting second dorsal and anal fins. Notably, they exhibit large lateral keels and prominent precaudal pits on the caudal peduncle. Caudal fin slunate. These sharks follow an ovoviviparous reproductive strategy, lacking a yolk sac placenta, and demonstrate uterine cannibalism.

Family Pseudocarchariidae (Crocodile sharks)

These medium-sized sharks possess a spindle-shaped body, remarkably large eyes without a nictitating membrane. Their gill slits are notably long, extending onto the dorsal surface of the head. Mouth is large and parabolic, positioned ventrally on the head, and holds protrusible teeth

that are large and lanceolate. Anterior teeth are narrow, whereas the lateral teeth are compressed and blade-like. They have small and low dorsal fins, with the second dorsal fin being less than half the size of the first but larger than the anal fin. Their pectoral fins are small, broad, and

rounded, while the pelvic fins are large. A weak lateral keel and precaudal pits are present on the caudal peduncle. Their fins are outlined in white, sometimes with small white spots on the body and a white blotch located between the mouth and gill slits.

Family Megachasmidae (Megamouthsharks)

These sharks have an elongated head, approximately as long as its trunk, with a notably large terminal mouth. Snout is short and broadly rounded, and the gill opening is

moderately long but does not extend onto the dorsal surface of the head. Last two gill slits are positioned over the base of the pectoral fin. They have small teeth arranged in numerous rows.

Family Odontaspidae (Sand sharks)

Caudal peduncle without lateral keels, marked by a distinct pit on its upper surface but none on the lower surface. Their teeth are sizable, slender, and characterized by smooth edges. Lower eyelid lacks a nictitating membrane. Their development is ovoviviparous.

Species reported from Indian waters: Order Lamniformes

Family	Genus	Species	Common name
Alopiidae	<i>Alopias</i>	<i>A. uperceliosus</i>	Big eye thresher
		<i>A. vulpinus</i>	Thin tail thresher
		<i>A. pelagicus</i>	Pelagic thresher
Lamnidae	<i>Isurus</i>	<i>I. oxyrinchus</i>	Shortfin mako
		<i>I. paucus</i>	Longfin mako
Pseudocarchariidae	<i>Pseudocarcharias</i>	<i>P. kamoharui</i>	Crocodile shark
Megachasmidae	<i>Megachasma</i>	<i>M. pelagios</i>	Megamouthshark
Odontaspidae	<i>Carcharias</i>	<i>C. taurus</i>	Sand tiger shark
	<i>Odontaspis</i>	<i>O. ferox</i>	Smalltooth sand tiger

Order: Squaliformes

Species from the families Echinorhinidae, Squalidae, Centrophoridae, Etmopteridae and Somniosidae within the Squaliformes order have been recorded in Indian waters.

Family Echinorhinidae (Bramble sharks)

First dorsal fin starts behind the origin of the pelvic fin, and there are no anal fins. Dorsal fins are spineless and positioned far back, situated behind the origins of the pelvic fins. Body and fins have large scattered thorn-like denticles, which vary in size from small to very large. These denticles are widely spaced, with bases that are not star-shaped. Some of these larger

denticles are fused in groups. Development is ovoviviparous, and does not possess a yolk sac placenta.

Family Squalidae (Dogfish sharks)

Body relatively low and cylindrical in cross-section, featuring two dorsal fins that may or may not have spines. Origin of the first dorsal fin is located in front of the pelvic fins. Denticles on this species range from small to moderately large. Caudal fin may or may not have a subterminal notch. Reproduction ovoviviparous (aplacental viviparity), and can give birth to anywhere from one or two to over 20 young ones in a litter.

Family Centrophoridae (Gulper sharks)

These sharks have grooved spines on both dorsal fins, with larger teeth on the lower jaw than on

the upper jaw. They lack precaudal pits or lateral keels on the caudal peduncle. Their reproductive strategy is ovoviviparous, where embryos depend solely on yolk for nutrition.

Family Etmopteridae (Lantern sharks)

These bioluminescent sharks are typically small to medium-sized and inhabit deep oceanic waters. Lanternsharks are cylindrical in cross-section and feature elongated snouts, two dorsal fins each with a sharp spine at the front, tiny light organs usually scattered along the belly and lower sides, large spiracles, and a subterminal notch on the caudal fin.

Family Somniosidae (Velvet dogfishes/Sleeper sharks)

Typically, these sharks feature a broad head with a short, flat snout. Their upper teeth are small and needle-like, contrasting with the broader and flatter lower teeth. Five pairs of gill slits and large spiracles. Both the first and second dorsal fins are relatively low and small compared to the shark's body. Fin spines can be found on both dorsal fins across all genera except for *Scymnodalatias* and *Somniosus*.

Species reported from Indian waters: Order Squaliformes

Family	Genus	Species	Common name
Echinorhinidae	<i>Echinorhinus</i>	<i>E. brucus</i>	Bramble shark
Squalidae	<i>Squalus</i>	<i>Squalus lalandei</i>	-
Centrophoridae	<i>Centrophorus</i>	<i>C. moluccensis</i>	Smallfin gulper shark
		<i>C. uyato</i>	Little gulper shark
		<i>C. atromarginatus</i>	Dwarf gulper shark
		<i>C. granulosus</i>	Gulper shark
		<i>C. squamosus</i>	Leafscale gulper shark
		<i>C. lusitanicus</i>	Lowfin gulper shark
		<i>C. zeehaani</i>	Southern dogfish
	<i>Denia</i>	<i>D. profundorum</i>	Arrowhead dogfish
Etmopteridae	<i>Etmopterus</i>	<i>E. pusillus</i>	Smooth lantern shark
	<i>Centroscyllium</i>	<i>C. ornatum</i>	Ornate dogfish
Somniosidae	<i>Centroselachus</i>	<i>C. crepidater</i>	Longnose velvet dogfish
	<i>Zameus</i>	<i>Z. squamulosus</i>	Velvet dogfish

Order: Orectolobiformes

Sharks representing the families Rhincodontidae, Stegostomatidae, Ginglymostomatidae and Hemiscyllidae of the order Orectolobiformes have been reported from Indian waters.

Family Rhincodontidae

This shark has a wide, flat head with a snub-nosed snout and a large mouth almost at the tip. Teeth are numerous but smaller in size. External gill slits are exceptionally large, while inside the mouth cavity, there are filter screens within the internal gill slits. Gills openings are also very sizable, and the fifth gill slit is notably distinct from the fourth. Gill rakers are elongated. Caudal peduncle features prominent lateral keels, and the caudal fin has a robust ventral

lobe, though it lacks a pronounced terminal lobe and subterminal notch. Reproduces through viviparity, giving birth to hundreds of offsprings

Family Stegostomatidae(Zebra sharks)

These sharks are of moderate size, featuring a relatively small and subterminal mouth. External gill slits are small, and the eyes are positioned laterally on the head, lacking movable upper eyelids. Notably, it has large spiracles, and nostrils with short, pointed barbels. One striking characteristic is its unusually long caudal fin, almost equal in length to the rest of the shark's body. Typically, this caudal fin lacks a strong ventral lobe but has a prominent terminal lobe and subterminal notch. On the caudal peduncle, there are no lateral keels or precaudal pits.

Family Ginglymostomatidae (Nurse sharks)

Distinctive characteristics of nurse sharks include a short, wide, and blunt snout; oval-shaped eyes positioned behind the mouth; a pair of large barbels below the snout; a groove between each nasal opening and the corner of the mouth; a small mouth that opens transversely, located slightly below the snout; five gill slits, with the last two situated very close together and positioned above the pectoral fins. They have two relatively close-set dorsal fins of similar size located towards the rear half of the body, and a relatively short, strongly asymmetric tail with a minimal lower lobe and no keels on the tail base.

These small and slender sharks are identifiable by their nasoral grooves and short nasal barbels. Their small transverse mouth is located in front of the eyes, and they have large spiracles positioned below the eyes. No lateral skin flaps on their heads. Possess two dorsal fins without spines, with the second dorsal fin origin well ahead of the first dorsal fin. Anal fin is low, keel-like, and rounded, with its origin situated well behind the origin of the second dorsal fin. A narrow notch separates the anal fin from the lower caudal origin. These sharks have a long precaudal tail and a caudal peduncle lacking lateral keels or precaudal pits. Their reproductive method is oviparous, and they lay their eggs in small oval egg cases.

Famil: Hemiscyllidae(Bamboo sharks)**Species reported from Indian waters: Order****Orectolobiformes**

Family	Genus	Species	Common name
Rhincodontidae	<i>Rhincodon</i>	<i>R. typus</i>	Whale shark
Stegostomatidae	<i>Stegostoma</i>	<i>S. fasciatum</i>	Zebra shark
Ginglymostomatidae	<i>Nebrius</i>	<i>N. ferrugineus</i>	Tawny nurse shark
Hemiscyllidae	<i>Chiloscyllium</i>	<i>C. griseum</i>	Grey bamboo shark
		<i>C. indicum</i>	Slender bamboo shark
		<i>C. plagiolum</i>	White spotted bamboo shark
		<i>C. arabicum</i>	Arabian carpet shark
		<i>C. hasselti</i>	Hasselt's bamboo shark
		<i>C. punctatum</i>	Brown banded bamboo shark
		<i>C. burmensis</i>	Burmese bamboo shark
	<i>Hemiscyllium</i>	<i>H. ocellatum</i>	Epauvette shark

Order: Hexanchiformes

Sharks representing the family Hexanchidae under the Order Hexanchiformes have been reported to occur in Indian waters.

Family Hexanchidae (Six/Seven gill sharks)

Hefty sharks with wide head, mouth situated on the underside and having six rows of blade-like,

comb-shaped teeth on each side. Possess a single dorsal fin and a short, sturdy caudal peduncle. Distance from the dorsal fin's insertion to the upper caudal origin is roughly equal to or slightly longer than the length of the dorsal fin base. Ovoviviparous, delivering litters ranging from 22 to 108 pups.

Species reported from Indian waters: Order**Hexanchiformes**

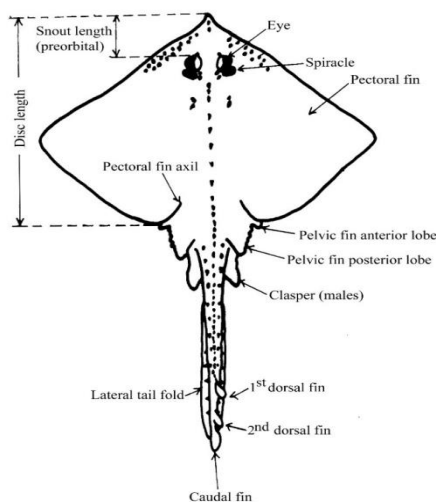
Family	Genus	Species	Common name
Hexanchidae	<i>Hexanchus</i>	<i>H. griseus</i>	Bluntnose sixgill shark
	<i>Heptranchias</i>	<i>H. perlo</i>	Sharpnose seven gill shark

Taxonomy and diversity of Batoids

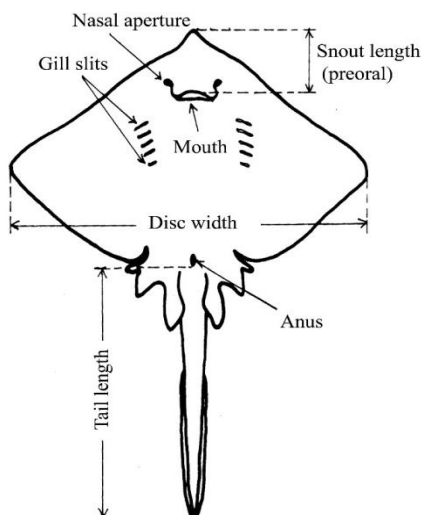
Common characteristics of Batoids:

- Gill openings positioned on the ventral side
- Eyes and spiracles situated on the upper side of the head
- Large pectoral fins that connect to the side of the head
- Absence of anal fin
- Pavement teeth, for crushing prey

Morphology and morphometry of Batoids



Dorsal view illustrating body parts and measurements of skates



Ventral view illustrating body parts and measurements of skates

Classification of Batoids

The classification of Batoids remains debatable, with much yet to be understood about the evolutionary relationships and lineages. Skates, rays, and guitarfishes are commonly acknowledged as a monophyletic group, however, depending on the classification, they can be listed as belonging to four different orders viz., in the division Batoidea under subclass Elasmobranchii, and occasionally they are all listed under one order Rajiformes instead of under separate orders.

Subdivision :Batoidea

Order Rhinopristiformes

Order Myliobatiformes

Order Rajiformes

Order Torpediniformes

Order: Rhinopristiformes

Species representing the families Pristidae, Rhinidae and Rhinobatidae of the order Rhinopristiformes have been documented in Indian waters.

Family: Pristidae (Saw fishes)

Body is similar to that of a shark, with a depressed head and a snout that extends into a long, flat blade containing teeth on each side. There is one pair of long barbels present. Two distinct dorsal fins and a caudal fin, with no dorsal fin spines and anal fin absent. Spiracles are large.

Family Rhinidae (Bow mouth guitar fishes and Wedge fishes)

Body shape is a blend between that of a shark and a skate, with a large, bilobed caudal fin. Origin of the first dorsal fin is positioned over or in front of the pelvic fins. In bowmouth guitarfish, the snout and anterior part of the head are broadly rounded, whereas in wedge fishes, they are angular and wedge-shaped, often featuring a deep or shallow indentation that separates them from the origin of the pectoral fin.

Family Rhinobatidae (Guitar fishes)

Body shape intermediate between that of sharks and skates, having a stout tail that is not distinctly separated from the body. Snout wedge-shaped and varies in length but is not elongated into a blade and does not feature lateral teeth.

Possesses two clearly defined dorsal fins and a caudal fin that lacks bilobed structure. First dorsal fin originates behind the pelvic fins. Body covered in denticles, which emerge from a row along the back midline. Notably, the tail does not have a spine.

Family Glaucostegidae (Giant guitar fishes)

Flattened, spade-like to wedge-shaped disc and a robust, depressed shark-like trunk. Snout is typically long, with tips that can vary from acute or bluntly rounded to protruding forward as a large, bulbous lobe. Eyes are generally small and

widely separated, while the spiracles are small with 1-2 variably developed folds. Skin covered with fine denticles, sometimes with small thorns confined to a row along the mid-line of the body and small patches near the eyes, shoulders, and occasionally on the snout (more pronounced in young ones). Long-based pelvic fins are positioned laterally, behind the disc. Two similarly-shaped, upright dorsal fins that are well separated, with the first positioned well behind the tips of the pelvic fins. Caudal fin is small and directed posteriorly, without a ventral lobe.

Species reported from Indian waters: Order Rhinopristiformes

Family	Genus	Species	Common name
Pristidae	<i>Anoxypristis</i>	<i>A. cuspidata</i>	Pointed/Narrow sawfish
	<i>Pristis</i>	<i>P. microdon</i>	Large-tooth sawfish
		<i>P. pristis</i>	Common sawfish
		<i>P. zijsron</i>	Longcomb/Green sawfish
Rhinidae	<i>Rhina</i>	<i>R. ancylostomus</i>	Bowmouth guitarfish/shark ray
	<i>Rhynchobatus</i>	<i>R. australiae</i>	Bottlenose wedge fish/White spotted wedge fish
		<i>R. djiddensis</i>	Giant Guitarfish/Whitespotted wedge fish
	<i>Rhynchobatus</i>	<i>R. laevis</i>	Smoothnose wedge fish
	<i>Rhynchobatus</i>	<i>R. palpebratus</i>	Eyebrow wedge fish
Rhinobatidae	<i>Rhinobatos</i>	<i>R. lionotus</i>	Smoothback guitarfish
	<i>Rhinobatos</i>	<i>R. annandalei</i>	Annandale's guitarfish/Bengal guitarfish
	<i>Rhinobatos</i>	<i>R. punctifer</i>	Spotted guitarfish
	<i>Acroteriobatus</i>	<i>A. variegatus</i>	Stripenose Guitarfish
Glaucostegidae	<i>Glaucostegus</i>	<i>G. granulatus</i>	Granulated/Sharpnose guitarfish
		<i>G. obtusus</i>	Widenose Guitarfish
		<i>G. typus</i>	Giant guitarfish
		<i>G. thouin</i>	Clubnose guitarfish
		<i>G. halavi</i>	Halavi guitarfish

Order: Torpediniformes

Electric rays/numb fishes from the families Torpedinidae, Narcinidae and Narkidae within the order Torpediniformes have been found to occur in Indian waters.

Family Torpedinidae (Electric rays)

Torpedo rays are characterized by their flat and disc-shaped bodies, featuring caudal fins of varying lengths. They have thick, fleshy margins around their disc and a strongly arched, wide mouth without labial folds or a peripheral groove. Unlike some species, their jaws are not bound by cartilage. Male torpedo rays possess claspers near the base of their tail. They exhibit ovoviviparous mode of reproduction.

Family Narcinidae (Numb fishes)

These small to medium-sized rays exhibit oval, rounded, or shovel-shaped pectoral discs and stout tails that are either equal to or longer than the disc. Mouth transverse with a prominent groove, while the snout is supported by a broad, trough-shaped rostral cartilage. Jaws highly protrusible, and there is a notable groove around the periphery of the mouth. Nasal curtain typically broader and shorter. Their small teeth have a single moderate cusp. Two prominent dorsal fins of roughly equal size and a large caudal fin.

Family Narkidae (Numb rays)

Pectoral disc is rounded anteriorly; mouth is very small and narrow, with upper and lower grooves. Head is flattened, lacking spiracle lamellae except in the genus *Electrolux*. Their

teeth are either ridged or unicuspidate. One or two dorsal fins or no dorsal fin at all. Caudal fin is significantly larger than the dorsal fin and is approximately of the same size as the pelvic fin.

Species reported from Indian waters: Order Torpediniformes

Family	Genus	Species	Common name
Torpedinidae	<i>Torpedo</i>	<i>T. panthera</i>	Panther electric ray
		<i>T. sinuspersici</i>	Variable torpedo ray
		<i>T. marmorata</i>	Marbled electric ray
Narcinidae	<i>Benthobatis</i>	<i>B. moresbyi</i>	Dark blind ray
	<i>Narcine</i>	<i>N. timlei</i>	Spotted numbfish
		<i>N. brunnea</i>	Brown numbfish
		<i>N. lingula</i>	Chinese numbfish
		<i>N. oculifera</i>	Bigeye numbfish
		<i>N. maculata</i>	Darkfinned numbfish
		<i>N. atzi</i>	Oman numbfish
Narkidae	<i>Heteronarce</i>	<i>H. prabhui</i>	Quilon electricray
	<i>Narke</i>	<i>N. dipterygia</i>	Numbray

Order Rajiformes

Skates of the families Gurgesiellidae and Rajidae under the order Rajiformes have been documented from Indian waters.

Family Gurgesiellidae (Pigmy skates)

The mouth features an exceptionally thin and flexible rostral cartilage; pelvic fin is deeply notched, characterized by finger-like lobes and these lobes are mostly of equal size

Family Rajidae (Skates)

The snout is slender and pointed, while its mouth is wide, sometimes covered by a fleshy nasal flap. The rostral cartilage is mostly firm. Its pelvic fin usually has two lobes, with a deep or weak incision, and the anterior lobe tends to be shorter than the posterior lobe. May have up to two dorsal fins but lacks an anal fin.

Species reported from Indian waters: Order Rajiformes

Family	Genus	Species	Common name
Gurgesiellidae	<i>Cruriraja</i>	<i>C. andamanica</i>	Andaman skate/Andaman pygmy
	<i>Fenestraja</i>	<i>F. mamillidens</i>	Prickly pygmy skate/Prickly skate
Rajidae	<i>Dipturus</i>	<i>D. johannisdavesi</i>	Travancore skate
	<i>Orbiraja</i>	<i>O. powelli</i>	Indian ring skate
	<i>Cruriraja</i>	<i>C. andamanica</i>	Andaman leg skate

Order: Myliobatiformes

Rays representing the families Gymnuridae, Dasyatidae, Plesiobatidae, Myliobatidae, Aetobatidae, Rhinopteridae, Hexatrygonidae and Mobulidae falling under the order Myliobatiformes have been recorded from Indian waters.

Family Gymnuridae (Butterfly rays)

Disc considerably broader than it is long, taking on a lozenge shape that is 1.6 times wider than it

is long. Possesses five pairs of gill slits and a very thin, short tail.

Family Dasyatidae (Whiprays)

Disc oval, circular, or rhomboidal in shape, paired with moderately stout to slender, and often elongated whip-like tails that are usually longer than the disc itself. There are no ridge-like skin folds on their tails.

Family Plesiobatidae (Stingrays)

Snout elongated, measuring over six times the diameter of its orbit. Body is broadly angular and fleshy, with a dorsal surface uniformly covered in fine denticles. Tail is short.

Snout characterized by a pair of low, rounded, and broad lobes that are deeply notched in the middle, creating a distinct and recognizable shape.

Family Myliobatidae (Eagle rays)

These rays exhibit a clear distinction between the head and the rest of the disc, with a notable separation. Their internasal curtain lacks notches or indentations, presenting a smooth and continuous structure.

Family Hexatrygonidae (Stingrays)

Greatly elongated and thick snout that is quite prominent. Their body is notably soft and flabby in texture. Has six pairs of gill openings, and the spiracles are positioned widely apart and located behind the eyes.

Family Aetobatidae (Eagle rays)

The snout of these rays features a single convex rostral lobe, providing a distinctive shape. Their internasal flap is deeply notched, forming a noticeable "V" shape

Family Mobulidae (Devil rays/Manta rays)

These rays possess a distinct snout structure that is formed into paired elongated lobes, giving them a unique appearance. Their mouth is broad, lacking a nasal curtain, which adds to their characteristic features.

Family Rhinopteridae (Cow nose rays)**Species reported from Indian waters: Order Myliobatiformes**

Family	Genus	Species	Common name
Gymnuridae	<i>Gymnura</i>	<i>G. poecilura</i>	Longtail butterfly ray
		<i>G. micrura</i>	Smooth butterfly ray
		<i>G. zonura</i>	Zone tail butterfly ray
Dasyatidae	<i>Brevitrygon</i>	<i>B. imbricata</i>	Bengal whipray/Scaly whipray
		<i>B. walga</i>	Dwarf whipray
		<i>Hemitrygon</i>	Bennett's sting ray
	<i>Telatrygon</i>	<i>T. crozieri</i>	Indian sharpnose ray
	<i>Himantura</i>	<i>H. leoparda</i>	Leopard whipray
		<i>H. uarnak</i>	Coach whipray/Reticulate whipray
		<i>H. undulata</i>	Leopard whipray
		<i>H. alcockii</i>	Pale-spot whip ray
		<i>H. fava</i>	Honeycomb whipray
		<i>H. marginata</i>	Black edge whip ray
	<i>Maculabatis</i>	<i>M. arabica</i>	Pakistan whipray
		<i>M. bineeshi</i>	Shorttail whipray
		<i>M. gerrardi</i>	Whitespotted whipray
		<i>M. pastinacoides</i>	Round whipray
		<i>M. microps</i>	Smalleye stingray
	<i>Neotrygon</i>	<i>N. kuhlii</i>	Blue-spotted stingray
		<i>N. indica</i>	Indian ocean blue-spotted maskray
	<i>Telatrygon</i>	<i>T. zugei</i>	Pale edged stingray
	<i>Pastinachus</i>	<i>P. ater</i>	Broad cowtail ray
		<i>P. gracilicaudus</i>	Narrow cowtail ray
		<i>P. sephen</i>	Cowtail ray
	<i>Pateobatis</i>	<i>P. bleekeri</i>	Bleeker's whipray
		<i>P. fai</i>	Pink whipray
		<i>P. jenkinsii</i>	Jenkins' whipray
		<i>P. uarnacoides</i>	Whitenose whipray
	<i>Pteroplatytrygon</i>	<i>P. violacea</i>	Pelagic stingray

	<i>Taeniura</i>	<i>T. lymma</i>	Blue-spotted fantail ray
	<i>Taeniurops</i>	<i>T. meyeri</i>	Blotched stingray
	<i>Urogymnus</i>	<i>U. asperrimus</i>	Porcupine whipray
		<i>U. granulatus</i>	Mangrove whipray
Plesiobatidae	<i>Plesiobatis</i>	<i>P. daviesi</i>	Giant stingray
Myliobatidae	<i>Aetomylaeus</i>	<i>A. maculatus</i>	Mottled eagle ray
		<i>A. milvus</i>	Brown eagle ray
		<i>A. nicholfii</i>	Banded eagle ray
		<i>A. vespertilio</i>	Ornate eagle ray
Aetobatidae	<i>Aetobatus</i>	<i>A. flagellum</i>	Longheaded eagle ray
		<i>A. ocellatus</i>	Spotted eagle ray
Rhinopteridae	<i>Rhinoptera</i>	<i>R. javanica</i>	Javanese cownose ray/Flapnose ray
		<i>R. jayakari</i>	Short tail cownose ray
Hexatrygonidae	<i>Hexatrygon</i>	<i>H. bickelli</i>	Sixgill stingray
Mobulidae	<i>Mobula</i>	<i>M. alfredi</i>	Reef manta ray
		<i>M. birostris</i>	Giant manta ray
		<i>M. kuhlii</i>	Shortfin devilray/Kuhl's devilray
		<i>M. mobular</i>	Giant devilray/Devil fish
		<i>M. tarapacana</i>	Chilean devilray
		<i>M. thurstoni</i>	Bentfindevilray/Smoothtailmobula
		<i>M. eregoodootenkee</i>	Longhornedmobula

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India is endowed with a wide diversity of water resources, which sustain a large fisheries sector in the country. India has a coastline of 8,118 km with an Exclusive Economic Zone (EEZ) stretching over 2.02 million sq. km, and a continental shelf covering 0.53 million sq.km. Fisheries have a very important role for food supply, nutritional security and livelihood in India. The sector is one of the important revenue-earning and employment-opportunity sectors, contributing significantly to the economy of the country. Marine fisheries in India are a shared responsibility between the national and state governments. In a legal and constitutional sense, state governments are responsible for waters inside the 12 nautical mile territorial limit (22 km) while the Government of India (GOI) is responsible for waters between 12 nautical miles and the country's 200 nautical mile (370 km) EEZ.

What is Ichthyology?

Ichthyology is simply the science of studying fishes. Ichthyology has the word *ichthy*, deriving from the Greek word *ixthu*, combining form of *ixthus*, meaning "fish". This includes bony fish, cartilaginous fish and jawless fish. Historically, ichthyologists were naturalists who described fishes they collected. Fish are the most diverse group of vertebrates, with more than one-half of the total vertebrate species. Approximately 33000 living species of fishes were described so far.

Ichthyological diversity in India

Indian fisheries has a long history dating back to Kautilya's Arthashastra, in which fish is described as a food source, and fishing is shown as a well-established industry in India as early as 300 B.C. The ancient Hindus were well-versed in fish habits, and the ancient Hindus acquired significant knowledge on the habit of fishes and the epic on the second pillar of Emperor Ashoka enacting the prohibition of consumption of fish during a certain lunar period which can be

interpreted as a conservation point of view. The early research conducted by Linnaeus, Bloch and

Schneider, Lacepède, Russell, and Hamilton can be linked to the current scientific investigations on Indian fishes. Modern scientific studies on Indian fishes could be traced to the first works by Linnaeus, Bloch and Schneider, Lacepède, Russell and Hamilton. Cuvier and Valenciennes (1828-1849) reported 70 nominal species off Puducherry, Skyes (1839), Gunther (1860, 1872, 1880) and The Fishes of India by Francis' day (1865-1877) and another book Fauna of British India Series in two volumes (1889) describing 1,418 species are the two most fundamental works on Indian fish taxonomy to date. Alcock (1889, 1890) reported 162 species new to science from Indian waters. In the 20th century, the basis of comprehensive investigations on the various families and groups of freshwater fishes was made by Chaudhuri along with Hora and his co-workers. Misra published An Aid to Identification of the Commercial Fishes of India and Pakistan and The Fauna of India and Adjacent Countries (Pisces) in 1976. Jones and Kumaran described about 600 species of fishes in the work Fishes of Laccadive Archipelago. Talwar and Kacker presented a precise description of 548 species under 89 families in his work Commercial Sea Fishes of India. The FAO Species Identification Sheets for Fishery-Western Indian Ocean (Fischer and Bianchi) is yet a valuable guide for researchers. Recently, Talwar and Jhingran published report on 930 inland species of India recognized till date.

Species richness

Of the 33,059 all fish species from the world, India supports of about 2443 marine fishes owing to 7.4% of the total marine fish resources. Of the overall fish diversity known from India, the marine fishes make up 75.6 percent, containing 2443 species belonging to 927 genera, under 230 families of 40 orders. By revising the new descriptions and additions, the overall number of fish species of India was of the tune of 2492 species belonging to 941 orders, 240 families. Among the fish diversity-rich areas in the marine waters of India, the Andaman and Nicobar archipelago exhibits the highest number of species, 1431, followed by the east coast of India with 1121 species and the west coast with 1071. A list of 1785 species is prepared based on the data of FishBase, FAO species identification

sheets of Western Indian Ocean Area 51 and Eastern Indian Ocean Area 57 (Table 1). We recognize since 91 species of endemic marine fishes to exist in the coastal waters of India. As of now, about 50 marine fishes known from India fall into the vulnerable category as per the IUCN Red List, and about 45 species are Near-Threatened and on the track to vulnerability. But, hardly this species (10 elasmobranchs, 10 seahorses and one grouper) are listed in Schedule I of the Wildlife (Protection) Act, 1972 of the Government of India.

In the global context, approximately 36088 valid marine and freshwater species under 515 families and 5213 genera (Nelson, 2006; Fricke et al. 2021). A stable naming and indexing system is essential for global communication about organisms and this system is maintained by the International Code of Zoological Nomenclature. The species are named according to the protocol set by Linnaeus' binomial nomenclature system (Engelhoff, 2009). The identification and description of fish species is important not only for taxonomy and systematics but also for natural history and ecology studies, fishery management, tracking the dispersal patterns of eggs and larvae, estimations of recruitment and spawn areas, and food product authentication (Anderson et al. 2007; Fischer, 2013).

Fish Taxonomy. -what is it? Is everyone a Taxonomist?

Taxonomy is basically the science of correctly naming species. The term has often been confused with fish identification, which basically refers to the use of the latest taxonomic information to identify fishes. The job of the Fish Taxonomist is to name and classify species in a way that makes it easier for fisheries scientists, and other "users", to correctly identify fish species during their work. In other words, fish taxonomy is practiced by very few, whereas fish identification is practised daily by many people.

Why do we need fish collections in fish taxonomy?

Any researcher who wishes to make an in depth study of the taxonomy, anatomy of fishes, reproductive biology or feeding habits of a particular species, needs to learn the details of the fish and its skeleton. This saves the time, expense, and conservation issues associated with capturing fresh specimens. For many species, capturing fresh specimens is often difficult or impossible, such as those which migrate, are found in the deep sea or are endangered. The

collection serves much as a library, with specimens being loaned and returned. Unlike a library however, the collection becomes more valuable after specimens have been studied and returned.

Fish biodiversity

The Indian fish fauna is divided into two classes, viz., Chondrichthyes and Osteichthyes. The Chondrichthyes are represented by 131 species under 67 genera, 28 families and 10 Orders in the Indian region. The Indian Osteichthyes are represented by 2,415 species belonging to 902 genera, 226 families and 30 orders

Classification and Diversity **(eprints.cmfri.org.in/12911/)**

Class Actinopterygii-the ray finned fishes

Numerically, actinopterygians are the dominant class of vertebrates, comprising nearly 99% of the over 30,000 species of fish. Traditionally actinopterygians have been divided into the subclasses Chondrostei and Neopterygii. Neopterygii, in turn, have been divided into the infraclasses Holostei and Teleostei.

Important characters of the class are:

- Scales ganoid, cycloid, or ctenoid
- Spiracles usually absent
- Pectoral radials attached to the scapulo-coracoid complex except in Polypteriformes
- Interopercle and branchiostegal rays usually present.

Infraclass Teleostei Teleost are the most species rich and diversified group of all the vertebrates.

Class: Pisces

Elasmobranchs: The elasmobranchs consists of sharks, sawfishes, rays, skates and guitar fishes. Many elasmobranchs have been included in the WLP list as per those included in CITES List. (dealt in detail elsewhere).

Some major Orders are given here

Order Atheriniformes: Commonly called silversides, the order includes at least 354 species in six families in 2 suborders. They are found worldwide in tropical and temperate marine and freshwater environments; they often live in dense schools and is pelagic in coastal and off shore environments, entering turtle grass beds in the evening.

Order: Anguilliformes (Apodes)

The Order Anguilliformes, or true eels, contains 20 families and about 820 species. Species are usually elongate and slender, with single dorsal and anal fins that are continuous with the caudal fin (if present) in most species. All species lack pectoral fins and skeleton while some groups lack pectoral fins. Scales are usually absent, or if present, are cycloid and embedded in skin. All have leptocephalus larvae. Most true eels are predators and belong to one of three families Congridae (Conger eels), Muraenidae (Moray Eels) and Ophichthidae (snake eels and worm eels). Some species are excellent food fish and form the basis of very important commercial fisheries.

Order Aulopiformes

Includes includes 5 families; commercially important Lizard fishes and green eyes

Family Chlorophthalmidae-Greeneyes

Large eye with teardrop-shaped pupil and distinctive lensless space anteriorly. A hermaphroditic species.

Family Synodontidae-Lizardfishes

These are generally small with a slender cylindrical body and head that superficially resemble those of lizards. They have a dioecious mode of reproduction. Worldwide, four genera with about 57 species have been recorded. In India 22 species have been reported in three genera *Harpadon*, *Saurida*, *Trachinocephalus* and *Synodus*.

Order Batrachoidiformes

Family Batrachoididae (Toadfishes)

Two species recorded from India

Order Beloniformes

Four families with with nine species infive genera are recorded from India. Some major families are

Family Belonidae (Needlefishes)

Needlefishes have slender, stream-lined bodies, and very long jaws filled with very sharp teeth. They are voracious predators and feed mostly on small fishes. In most species, the upper jaw only reaches its full length in adulthood, so the juveniles have a half-beak appearance, with an elongated lower jaw, but a much smaller upper one. During this stage of their lifecycle, they eat plankton, switching to fish once the beak fully develops. Needlefish reproduce through mating and lay eggs. The male usually rides the female on the waves as they mate

Family Exocoetidae (Flyingfishes)

Elongate bodied fishes with cylindrical shape, flattened ventrally in some species. Head short. Snout blunt. Worldwide, five subfamilies with 52 species in 8 genera has been reported. Represented in Indian waters by 18 species in 6 genera.

Family Hemiramphidae (Halfbeaks)

Elongate fishes with a prolonged lower jaw and a short triangular upper jaw. Spines absent in fins. Represented in Indian waters by 17 species in 7 genera.

Order Beryciformes

The Order has 7 families with 29 genera and 144 species. All species are marine. Four families represented in Indian waters. Family Berycidae (Alfonsinos) Dorsal fin without notch, with 4-7 spines increasing in length from first to last, and 12-20 soft rays. 2 genera with about 9 species.

Family Holocentridae (Squirrelfishes, soldierfishes)

Species with a long dorsal fin with spiny portion and soft rayed portion divided by a notch. Holocentrids (squirrelfish and soldierfish) are vocal reef fishes whose calls and sound-producing mechanisms have been studied in some species only. Worldwide, eight genera with 78 species has been reported. In India, 18 species in 4 genera have been recorded.

Order Clupeiformes

Herrings are certainly among the most valuable commercial fishes in the world, being important food fishes in many countries and serving as a chief source of fish meal for animal feeds. The Order Clupeiformes include anchovies, herrings, sardines, shads, gizzard shads, wolf herrings and their relatives. The current classification by Nelson (2006), divided the Clupeoidei into four families: the Engraulidae with two subfamilies with 139 species in 16 genera, the Pristigasteridae with two subfamilies and 37 species in 9 genera, the Chirocentridae with 2 species in one genus and the Clupeidae with five subfamilies with 216 species in 66 genera.

Clupeoids

This is a large group consisting mostly small to moderate sized fishes belonging to several families, genera and species and accounts for more than quarter of the fish catch. The clupeid fishes are grouped under four families (Clupeidae, Engraulidae, Pristigasteridae and Chirocentridae) and seven subfamilies. The main

groups included under these families include the sardines, anchovies, herrings, shads and sprats.

Clupeoid's species have a complete covering of easily shed cycloid scales on the body (except Chirocentridae) and can be easily identified in the field with the absence of spines in the fins, single short dorsal fin (11 to 23 finrays), situated usually near the midpoint of the body (except in *Chirocentrus*), small pelvic fins, short or moderate anal fins and a forked caudal fin (except rhomboid in *Coilia*). The body is usually fusiform, sometimes almost round in cross-section (*Dussumieria*, *Etrumeus*, also *Engraulis*), but more often compressed, sometimes highly compressed (Chirocentridae, some Pristigasteridae). Typically, there is a pelvic scute with ascending arms just in front of the pelvic fins (absent in Chirocentridae, W-shaped in the Dussumieriinae, and a series of similar scutes in front of the pelvic fins and behind them, but absent in the Dussumieriinae, some Pellonulinae, *Engraulis*). Mouth is either terminal or superior. Small conical teeth are typically present in the jaws and on the vomer, palatines and endo- and ectopterygoids but some or all may be absent, or the jaws may bear canine teeth (Chirocentridae).

Order Elopiformes

The order Elopiformes includes two small families of medium to large-sized fishes found in coastal marine, estuarine and freshwater environments. Fishes have well-developed gular plates, i.e. extra bones in the throat between the lower jaws, found only in some primitive bony fishes. Elopomorphs all have ribbon-shaped leptocephalus ("pointed head") larvae. The Atlantic Tarpon is a highly prized gamefish that reaches a length of 2.5 m and a mass of 150 kg. Albuliform bonefishes are also popular gamefishes that occupy sandy flats in shallow tropical waters. Two families with two species are recorded from India.

Order Lampriformes

These oceanic fishes are pelagic feeders that stay well above the sea floor, and normally occur in waters 100–1000 m deep. They are typically brightly coloured as adults, often with brilliant crimson fins. Lampriforms have highly variable body forms, but they are generally laterally compressed. Some are rounded in lateral view, while others are very elongated. Two families and 4 species from India

Order Lophiiformes

The order Lophiiformes is a group of marine fish that includes anglerfish and frogfish. The order contains about 322 species in 16 families in three

suborders and includes Anglerfish, Handfish, Frogfish

Order Myctophiformes

Myctophiformes consists of two families of deep-sea marine fish, including the highly abundant lanternfishes (Myctophidae) with over 30 genera and some 252 species and the blackchins (Neoscolopelidae) which contain six species in three genera. Large adults of *Neoscolopelus* are usually benthopelagic below 1 000 m, but subadults mostly in midwater between 500 and 1 000 m in tropical and subtropical areas.

Order Notacanthiformes

The word Notacanthiformes comes from the Greek words *noton* meaning back and *akantha* meaning thorn, and the Latin word *forma* (shape). This is an order of deep-sea ray-finned fish and includes the families Halosauridae and Notacanthidae with 27 species in 6 genera and 2 families. They are elongated and eel-like, but are not related to true eels. They are found in deep waters on the continental slope, typically in depths greater than 500 m.

Order Ophidiiformes

Ophidiiformes is an order of ray-finned fish that includes the cusk-eels, pearlfishes, viviparous brotulas, and others. Members of this order have small heads and long slender bodies. They have smooth scales or no scales, a long dorsal fin and an anal fin that typically runs into the caudal fin. Three families with 93 genera have been recognised.

Order Osmeriformes

The Osmeriformes belong to the superorder Protacanthopterygii, which also includes pike and salmon. They are one of the three major subdivisions of the class Actinopterygii, which is the most advanced of the bony fishes. The Osmeriformes spawn in freshwater, except for the Argentinoidei, Osmeruseperlanus, and perhaps one or two salangids. Osmeriformes are small to mid-sized slender fish, their maxilla is usually included in the mouth's gape, and most of them have an adipose fin. Order Osmeriformes contains two suborders, six families, some 20 genera, and about 93 species.

Order Perciformes

The Perciformes are the largest order of percomorphs, with 148 families and 9300 species, including most marine and freshwater fishes inshore and shallow-water zones. The order Perciformes includes a large proportion of the total species of fish. These fishes usually have

two dorsal fins, of which the first is spiny. Their pelvic fins are usually located under or in front of the pectoral fins. This morphologically diverse order is divided among about 20 suborders.

Family Acanthuridae (Surgeonfishes, tangs, unicornfishes)

Includes two subfamilies with 19 species from India

Family Serranidae

The sea basses and groupers are the most important of the more than 400 species of the family Serranidae. They are usually robust with large mouths, small teeth, ctenoid scales, and either a round or a truncate caudal fin. Most species live in shallow tropical or subtropical seas, but a few occur along temperate shores or in fresh water. Most are predatory on other fishes or invertebrates. 52 species of groupers are recorded from Indian waters.

Family Lutjanidae

The snappers of the family Lutjanidae include about 250 species. Most are large, voracious, and brightly colored fish of shallow tropical or subtropical seas. They have large mouths with canine teeth, robust bodies, ctenoid scales, and usually truncate or forked caudal fins. Most are highly valued for either food or sport, and some for both. Around 42 species are recorded from India.

Family Lethrinidae Commonly called pigface breems, they are benthic feeders, consuming invertebrates and small fishes. Some species have molariform teeth which they use to eat shelled invertebrates, such as molluscs and crabs. Lethrinids are an important component of some commercial, artisanal and recreational fisheries and

Family Leiognathidae

Commonly called slipmouths, they are common in shallow coastal waters and tidal creeks. They feed on benthic invertebrates. They can be used in the preparation of soups rich in calcium.

Order Carangiformes

Around 158 species are recorded in Carangiformes, in 36 genera and 5 families. The order includes Coryphaenidae, Echeinidae, Istiophoridae, Nematiidae, Rachycentridae, Xiphiidae, Carangidae.

Family Carangidae

Carangids are yet another vast group consisting of several families, several genera and species. Six families are included under Carangiformes and the family Carangidae is the largest of them and includes jacks, pompanos, jack mackerels,

runners, scads. The important features used to identify carangids are the presence of two preanal spines, scutes on the body and scalation in the breast area. It forms an important fishery along the Indian coast with most of the species being commercially valuable and exploited by several gears. Some species are popular in sport fishing. Three species have been successfully bred and being cultured.

Order Scombriformes

Scombriformes is an order of bony fish containing nine families which were classified under the suborders Scombroidei and Stromateoidei. This group includes different species of pelagic fish (the mackerels, tunas, bonitos) mostly from the family Scombridae, all being very important and favored food fishes with very high domestic as well as export demand. They are found in both temperate and tropical seas, mostly living along the coast or offshore in the oceanic environment.

Mackerel species typically have stream lined body, vertical stripes on their backs and deeply forked tails, two separate dorsal fins and finlets following the dorsal and anal fins. Forked caudal fin, with a slender ridged base is another characteristic feature. The first (spiny) dorsal fin and the pelvic fins are normally retracted into body grooves.

Fishes are medium to large sized; all undertake either short distance long distance migrations. Smaller mackerel are forage fish for larger predators, including larger mackerel. Sport fishermen value the fighting abilities of the king mackerel.

Barracudas

The barracudas are considered as one of the most predatory fishes in the marine system. With a wide distribution in warm- temperate waters is represented by several species. They can be easily identified by the scaled slender body, two well-separated dorsal fins with the anterior fin having five spines, and the posterior fin having one spine and 9 soft rays. The posterior dorsal fin is similar in size to the anal fin and is situated above it. The lateral line is prominent and extends straight from head to tail. The spinous dorsal fin is placed above the pelvic fins and is normally retracted in a groove. The caudal peduncle is stout and the fin is moderately forked, a jutting lower jaw, and a large mouth with many large, sharp teeth. Their gill covers have no spines and are covered with small scales. They are popular as sport fishes, and also valued as food. *Sphyrna*, is the only genus in the

family Sphyraenidae and included several species. *S. putnamae*, *S. obtusata*, *S. jello*, *S. forsteri*, *S. barracuda*, *S. arabiansis* are the dominant species in India.

Order Istiophoriformes

These are a group of highly migratory pelagic fishes characterised by prominent bills, or rostra and popularly referred to as billfishes. They are found in all oceans, although they usually inhabit tropical and subtropical waters and highly valued as gamefish by sports fishermen. They include sailfish and marlin, which make up the family Istiophoridae, and swordfish, sole member of the family Xiphiidae.

Order Pleuronectiformes

Commonly called flatfishes, this is a diverse group with many forming a great part of the commercial fishery in Atlantic and Pacific waters, but with little information from the tropics where they sometimes go as discards and bycatch. Nearly 65 species recorded from Indian waters with major families being Psettodidae with a single genus and species, Cynoglossidae and Soleidae. The other families are only zero contributors to fishery.

Order Tetraodontiformes

The Tetraodontiformes are represented by 10 extant families and at least 349 species overall; most are marine and dwell in and around tropical coral reefs, but a few species are found in freshwater streams and estuaries. Prominent families include the Balistidae (Triggerfishes), Diodontidae (Porcupinefishes), Molidae (Molas or Ocean Sunfishes), Monacanthidae (Filefishes), Ostraciidae (Boxfishes), Tetraodontidae (Puffers), Triacanthidae (Triplespines), Triacanthodidae (Spikefishes).

Documentation of biodiversity has become a very important aspect in view of the climatic and anthropogenic influences on the habitat. The fish diversity of any regime has great significance in assessment of the habitat and also contributes to the sustainable management of the resources.

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Diversity and ecology of coral reef fishes

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Coral reefs are mainly found in tropical regions of the world and cover approximately 284300 sq.km or 0.1% of the world oceans. However, they harbor about 25% of the marine fish fauna.

The Indo-Pacific harbours about 92% of the reefs. The major reef areas of the world are as below:

The Golden Triangle region in Southeast Asia: The reefs surrounding Thailand, Malaysia, Indonesia, Philippines, Papua, New Guinea, Sumatra, Java, Andaman and Nicobar harbor 32% of world coral reefs and the greatest diversity of marine life. They are considered as the crucible of evolution and diversification of coral reef fishes.

The Great Barrier Reef: Located off the east coast of Australia in the Coral Sea, it is the world's most extensive coral reef system, encompassing over 2,900 individual reefs and 900 islands, stretching for an impressive 2,500 kilometers and covering an area of 216236 sq km.

Red Sea Coral Reef: This 1900 km long reef is located between Africa and Asia and borders the countries of Israel, Egypt and Djibouti.

Chagos-Laccadive Ridge: Consisting a chain of atolls from Seychelles to Lakshadweep, Maldives, Chagos and Diego Garcia this region in the Western Indian Ocean harbours

The Greater Caribbean Reefs: These include several reef formations from *Florida Reef Tract* to the *Great Mayan Reef* or the Mesoamerican Barrier Reef System which stretches from the coast of Mexico to Belize and Guatemala upto the Honduras (1126 km reef; the largest in the Western Hemisphere) and the *Andros Barrier reef* along with several fringing reefs of the Caribbean islands in the Coral Sea.

The New Caledonian Barrier Reef: Situated around the Grand Terres island in the South Pacific this 1500 km reef is the third largest in the world after the Great Barrier Reef and the Great Mayan Reef.

An estimated 6000-8000 species of fishes inhabit the coral reefs of the world. The fish fauna of the Indo-Pacific reefs is significantly different from that of the western tropical Atlantic or the Greater Caribbean.

Indian diversity

A total of about 2810 species of fishes inhabit the coral reef regions of India though not all are strictly coral reef fishes. Considering only those fishes closely associated with coral reefs alone, the currently known diversity in Andaman and Nicobar is about 166 species, Lakshadweep islands 116, Gulf of Mannar 84 and Gulf of Kutch 42 species. Besides there are around 40-50 species of coral reef fishes reported from fringing reefs along the coastline and coastal islands of India.

Body shape and coloration

The great diversity in colour, shape, size and structure of the coral reef fishes is a function of and adaptation to their niches in the coral reefs. A large number of coral reef fishes have flat, laterally compressed bodies which is an adaptation that gives them distinct advantage in **maneuverability**. Long, strong fins and such a body shape allow them to negotiate crevices and close formations of their coral habitat efficiently. Another important aspect is the **feeding habit** of the coral reef fishes which particularly defines the design of the head, mouth, and teeth. **Camouflage** or **behavioural adaptations** for predator avoidance also reflect on the size, shape and colouration of many coral reef fishes, so also peculiar armature. Coral reefs are crowded environs with the density of fishes being particularly high. Distinctive colouration also facilitates easy **identification** of members of the same species as well as **mate location and selection**. Some species are strikingly coloured to advertise their unpalatability or **toxicity** as visible warning signals.

Common groups coral reef fish fauna in India

Coral reef fishes comprise about 30 families. The most numerous of these on the coral reefs are chaetodontids, pomacentrids, labrids, gobioids, acanthurids and scarids.

Chaetodontids (Butterflyfishes): These typical coral reef fishes have a global diversity of 12 genera and 136 species. The Indian diversity records 31 species. *Chaetodon* is the most common genus, with *Heniochus* and



Forcipiger being others. They are distributed in the Atlantic, Indian and Pacific Oceans with a greater number of species in the Indo-west Pacific. They are bony fishes belonging to the order Acanthuriformes. They are mostly coloured white, bright yellow, and/or orange with black bands or markings and have flattened pancake-like bodies. They have extended, protrusible, tubular mouths with brush-like teeth. Dorsal fins are continuous. Scales are present on dorsal and anal fins. Caudal fins are rounded to emarginate with 15 rays. They are found in heterosexual pairs and feed on coral polyps, small invertebrates, filamentous algae and plankton.

Pomacentrids (Damselfish): Globally this family consists of 30 genera and 419 species. They are found in all tropical seas, mainly the



Indo-Pacific region. The Indian diversity consists of 47 species. *Abudefduf*, *Chromis*, *Chrysiptera*, *Amphiprion*, *Dascyllus*, *Pomacentrus* and *Stegastes* are the common genera. These deep-bodied bony fishes of the order Ovalentaria/misc have small mouths and incomplete or interrupted lateral lines. Anal fins usually have two spines. Males brood benthic eggs. Their larval life is short. They also display aggressive territorial behavior. Most of them are omnivores or planktivores.

Labrids (Wrasses): The global diversity of labrids consists of 70 genera and 562 species. They are found in the Atlantic, Indian and Pacific Oceans. The Indian diversity consists of 55 species. *Halichoeres* and *Thalassoma* are the most speciose genera. These bony fishes belong to the order Eupercaria/misc. Scales are cycloid.



Several labrids change colour between their juvenile and mature phases. They are protogynous hermaphrodites where the initial phase consists of males and females and the terminal phase consists of often brilliantly coloured large dominant males, which females can also transform into. One male dominates several females. Labrids exhibit territorial displays, vigorously defending their areas of the reef. Most have a burrowing habit. They can be either benthic carnivores or planktivores.

Acanthurids (Surgeonfishes): Globally there are 06 genera 84 species inhabiting the Atlantic, Indian and Pacific Oceans. The Indian diversity



consists of 11 species of which *Acanthurus*, *Ctenochaetus*, *Naso*, *Paracanthus* and *Zebrosoma* are the most common genera. Acanthurids belong to the order Acanthuriformes and have deeply compressed bodies, an unnotched dorsal fin and long preorbital bone. The eyes are placed high on the head. They have characteristic sharp caudal spines on the caudal peduncle that are flashed erect when the fish feels threatened and are capable of inflicting scalpel-like injuries giving the family its common name as surgeonfishes. Acanthurids are predominantly

herbivores; some may be planktivores or detritivores or a combination of all these.

Scarids (Parrotfishes): 12 genera and 136 species inhabit the Atlantic, Indian and Pacific



Oceans. The Indian diversity comprises of 05 genera and 17 species. *Scarus* is the most common genus. The fused teeth are akin to parrot-beaks giving them the common name of parrotfishes. The body is covered with large cycloid scales mostly in bright green, blue or pink hues. Scarids are herbivores that scrape algae off coral rocks including dead coral rocks. Like labrids, their initial phase is males or females and terminal phase consists of large males. A single male dominates over several females

Pomacanthids (Angelfishes): The global



diversity of this family encompasses 08 genera and 91 species. They are found in the tropical Atlantic and Indo-west Pacific. The Indian diversity accounts for 09 species. *Apolmichthys*, *Centropyge* and *Pomacanthus* are common genera in this family belonging to the order Acanthuriformes. With their laterally compressed bodies, they live closely associated with the coral formations. Dorsal and anal fins usually have extensions. A strong spine is present on the angle of the preopercle and there are three spines in the anal fin. They have

striking colour patterns with juveniles often having marked colour differentiation from adults. They are mostly planktivores and/or



herbivores and some feed on sessile invertebrates.

Lutjanids (Snappers): 17 genera and 113 species of this family belonging to the order



Eupercaria/misc are represented globally in the Atlantic, Indian and Pacific Oceans. The Indian diversity consists of 38 species. *Lutjanus*, *Aprion*, *Paracaesio*, *Pinjalo* and *Etilis* are common genera. The dorsal fin is continuous or slightly notched. They are typically schooling fish. They feed on crustaceans and fishes; some are planktivorous. Snappers are food fishes.

Muraenids (Moray eels): The global diversity of the family Muraenidae belonging to the order Anguilliformes consists of 16 genera and 211 species distributed in the Atlantic, Indian and Pacific Oceans. The Indian diversity currently consists of 32 species. *Echidna*, *Gymnothorax* and *Uropterygius* are the most common genera. These fishes have a large mouth with canine teeth. The dorsal fin origin is well before the gill opening; anal fin is confluent with the caudal fin. Pectoral and pelvic fins are absent. They are scaleless. They lie in wait in crevices and holes within the coral formations and feed on cephalopods, small fishes and crustaceans.

Caesoinids (Fusiliers): The family Caesionidae belonging to the order Eupercaria/misc consists of 04 genera and 23 species. They are mainly distributed in the Indo-west Pacific. The Indian diversity consists of 12 species with all four genera of present. They have oblong to fusiform bodies, small mouths, large eyes, and deeply forked tail which are all adaptations for a planktivorous diet. Dorsal and anal fins have scales. Scale rows on the body run horizontally. These active schooling fish feed on zooplankton.

Siganids (Rabbitfishes): 01 genera 29 species of this family belonging to the order Acanthuriformes is found in the Indo-Pacific and eastern Mediterranean. The Indian diversity



consists of 12 species. The spines are poisonous. Juveniles form large schools. They are predominantly herbivorous, feeding on algae and seagrass

Epinephelids (Groupers): The 16 genera and 170 species of this family belonging to Perciformes/Serranoidei are found in the Atlantic, Indian and Pacific Oceans. The Indian diversity consists of 06 genera and 42 species. *Epinephelus*, *Athaloperca*, *Cephalopholis*, *Variola*, *Plectropomus* are the genera common in Indian waters. They are protogynous hermaphrodites. All fins are rounded. Carnivorous.

Balistids (Triggerfishes): The 12 genera and 42 species of this family belonging to the order Tetraodontiformes are found in the Atlantic, Indian and Pacific Oceans. The Indian diversity has 11 species. *Balistoides*, *Balistapus*, *Odonus*, *Sufflamen* are the common genera. Skin tough and leathery with large scales forming

distinguishable units. First of the three dorsal spines can be locked erect by the second. Mouth is small and terminal with eight teeth in in outer row of both jaws. Females aggressively guard eggs. Triggerfishes may be diurnal, solitary carnivores feeding on shelled molluscs or sea urchins or planktivores.

Mullids (Goatfishes): These fishes belonging to the order have 06 genera and 100 species distributed in the Atlantic, Indian and Pacific Oceans. The Indian diversity has 03 genera *Upeneus*, *Parupeneus* and *Mulloidichthys* and 16 species. The dorsal fins are located far apart. Two chemosensory chin barbels are used to probe food. They feed on benthic invertebrates and small fishes.

Carangids (Jacks, pompanos, trevallies): A diverse family belonging to the order Carangiformes with 39 genera and 148 species widely distributed in the Atlantic, Indian and Pacific Oceans. The Indian diversity consists of . The first two spines of the three anal fins are separate and placed separately from the third in the abdomen. The caudal fin is deeply forked with slender caudal peduncles, designed for fast swimming. In some species lateral line scales modified into scutes and also in some there are



finlets along the posterior margins of the body. Small cycloid scales render the bodies silvery. Carangids are carnivorous or planktivorous. They are major food fishes.

Scorpionfishes: The order Perciformes/Scorpeinoidei consisting of 20 families has some of the most venomous fishes as its members. They are found in all seas. The family **Scorpaenidae** has 25 genera and 233 species distributed in all tropical and temperate seas and **Synanceiidae (stonefishes)** 9 genera and 40 species and are especially found in lying camouflaged as rocks in coral reefs. Fishes of Scorpanidae have a single dorsal fin and ridges and spines. Dorsal fin is single and deeply notched. Dorsal, anal and pelvic fins have

venom glands. Synanceiidae have a body covered with warts. The sharp needle-like dorsal spines have neurotoxic venom glands at their base.

Diodontids (Porcupinefishes): This family belonging to the order Tetraodontiformes has 7 genera and 18 species distributed in the Atlantic, Indian and Pacific Oceans. The Indian diversity consists of 04 species belonging to *Diodon* and *Cyclithis* genera. There are two fused teeth parrot like in jaw. Body greatly inflatable with ingestion of water. Body is covered with spines which are erected at the time of inflation. Adults found near reefs and the juveniles are pelagic. They are usually found in heterosexual pairs. They feed on hard shelled invertebrates.

Syngnathids (Seahorses): 59 genera 304 species.



Atlantic, Indian and Pacific Oceans. Indian diversity 10 species. *H. trimaculatus*, *H. kuda* and *H. kelloggi* are the common species. Body with tubular snout, bony rings on body and prehensile caudal peduncle. Dorsal, anal, and pectoral fins may be lacking in adults of some species. No pelvic fins are present. Branchiostegal rays are 1-3 and gill openings very small. Basisphenoid and supracleithrum are lacking. Swimming ability is very reduced. Male broods eggs in pelvic pouch and give birth to live young. They feed on minute invertebrates sucked into mouth. They are found in calm shallow regions.

Gobiidae (Gobies): The Gobiidae, or gobies, are the largest family of fish, with over 2,000 described species in more than 200 genera. They are typically small, bottom-dwelling fish with big heads and tapered bodies. They can be found in marine, brackish, and freshwater environments all over the world. One of their most characteristic features is their fused pelvic fins, which form a suction cup that allows them to cling to rocks or other surfaces in strong currents. Gobies are also known for their wide variety of colors and patterns, which can help them camouflage themselves in their environment. Most gobies are carnivores and feed on small

invertebrates, such as worms, crustaceans, and insects. Some species are also known to clean parasites off other fish.

Blenniidae (Combtooth Blennies): The Blenniidae family, are another interesting group of



fish closely related to gobies. Their namesake feature is their specialized teeth. Unlike gobies, blennies have numerous, closely packed teeth that resemble a comb. This toothy apparatus is perfect for scraping algae and other encrusting organisms off rocks and corals. Blennies typically have elongated, slender bodies that allow them to navigate through crevices and tight spaces in rocky reefs, their preferred habitat. Their large eyes provide excellent vision in these often dimly lit environments. Blennies can have a variety of fin shapes and sizes. Some sport long dorsal fins, while others have flamboyant, fan-like pectoral fins used for display or stability. Blennies are almost exclusively marine fish, dwelling primarily in rocky tide pools and coral reefs. They cling to rocks and coral using a combination of their body shape, fins, and sometimes even suction from their mouths. Many blennies are masters of camouflage, able to rapidly change their color and blend in with their surroundings to avoid predators. Blennies can exhibit a range of social behaviors. Some species are territorial and quite aggressive, while others live in small groups or pairs. Certain blennies even form cleaning symbioses with other fish, similar to some gobies.

Elasmobranchs: Around 31 species of elasmobranchs (sharks and guitarfish (21 species) and rays and skates (10 species)) are commonly found in the Indian coral reefs. Some sharks such as *Trienodonobesus* (whitetip reef shark), *Carcharhinus melanopterus* (blacktip reef shark) and *Chiloscyllium indicum* (bamboo shark) are frequently encountered on the reefs.

The unique fish assemblages of the coral reefs form a vibrant and ecologically inter-related

community with structural and behavioural adaptations and occupying every available niche.

Pomacentrids and gobioids are an important prey base in the reef food chain. The acanthurids and scarids along with siganids are vital to keeping algal growth on the reefs in check, preventing them from taking over coral formations, through herbivory. Other reef organisms including the corals are dependent on the fishes for continued ecological sustenance as much as the fishes depend upon them for varied life processes.

Animal interactions on coral reefs have developed as a result of **co-evolution**. Fish species have entered in **symbiotic relationships** with other fishes or reef inhabitants that may be classified into three major categories: **mutualism**, **commensalism** and **parasitism** as part of **Evolutionary Stable Strategies**. Removal of ectoparasites from larger fish by cleaner wrasses, gobies or blennies is a form of **facultative mutualism**. Guarding of the burrows of housekeeper shrimps by shrimp gobies falls under **defensive mutualism**. The mutually beneficial adaptations of sea anemones and clown fish come under the category of **facultative defensive mutualism**. The association between remora and larger elasmobranchs is termed as **commensalism** by some but **parasitism** by others. Sabre-toothed blennies mimic cleaner wrasses for feeding advantages in a case of **aggressive mimicry**.

Fishes also show diverse colour patterns, social behaviour or morphological adaptations as part of **predator avoiding strategies**. Ocelli or stripes on the body to create **predator confusion**, bright warning colours announcing toxicity, **schooling** or **shoaling behaviour**, spines on the body, ability to inflate the body, sheltering among coral formations and **camouflage** are some such adaptations seen among coral reef fishes.

Coral reef fishes belong to the **trophic guilds** of **herbivores**, **omnivores**, **carnivores**, **planktivores**, **detritivores** and **corallivores** with many showing a mixed pattern of feeding as well.

Anthropogenic effects on coral reef fishes and their ecosystem include habitat destruction and trophy hunting as a fallout of tourism, disruption of community structure through commercial fishing, pollution as a result of human population pressure and land runoffs, a marked increase in extreme events, ocean acidification and coral bleaching as a result of climate change and pollution, habitat destruction and

introduction of marine invasives through shipping. Extreme or prolonged disruptions in the ecosystem results in **phase shifts** in the coral reef ecosystem.

The conservation tools that can be implemented for preserving coral reefs and fishes include the creation of marine protected areas, promulgating legislation for individual species, restricted tourism and trade, planned development based on the **Precautionary Principle** in coral reef areas, community participation on conservation and creating public awareness.

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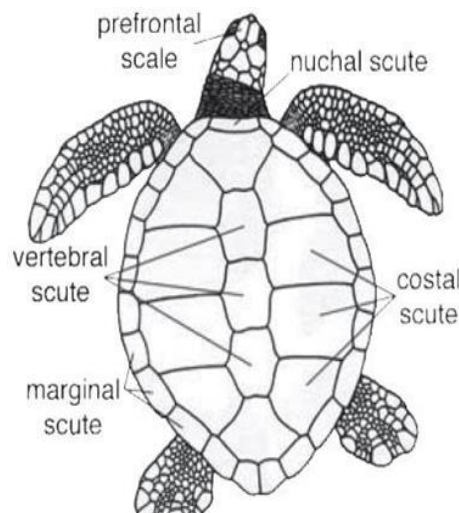
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Sea turtle diversity

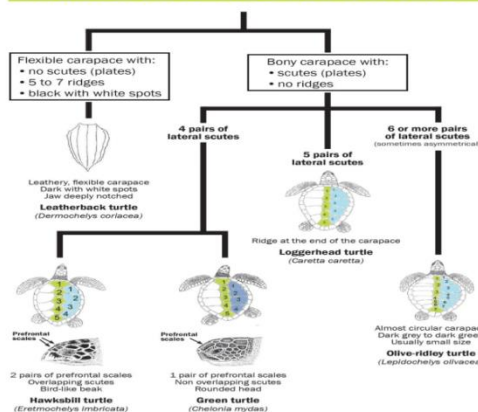
R. Ratheesh Kumar and R. Rahul

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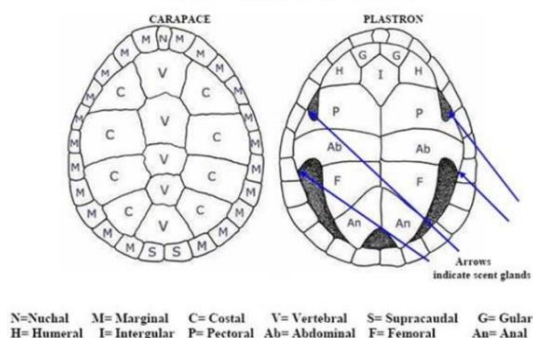
Scientists recognized seven living species of sea turtles globally, which are grouped into six genera under two families. India's coastline is home to five species of sea turtles; olive ridley turtle (*Lepidochelys olivacea*), green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), loggerhead turtle (*Caretta caretta*), and leatherback turtle (*Dermochelys coriacea*). Unfortunately, their population is declining worldwide due to over-exploitation, pollution, habitat degradation, vessel hits, incidental catch, etc. Tamil Nadu and Orissa coasts play vital roles as the major marine habitats for sea turtles in India. All five species of sea turtles were recorded from the Tamil Nadu region. Andhra Pradesh and Tamil Nadu coasts serve as migratory pathways for olive ridleys, while Orissa's Gahirmatha stands as the world's largest rookery. Schedule I of the Indian Wildlife (Protection) Act 1972 safeguards all five sea turtle species, but conservation efforts must intensify emphasizing stakeholder involvement and alternative livelihoods. Turtle Excluder Devices (TEDs) serve as a successful method for mitigating trawling-related mortality in sea turtles. The widespread adoption of TEDs in trawl fisheries, coupled with governmental oversight and enforcement of TED regulations, is crucial for successfully implementing these regulations (Boopendranath *et al.*, 2006). Identification of sea turtle species in Indian waters relies on criteria including carapace lengths, costal scutes, prefrontal scales, and vertebral scutes' shapes. Clear photographs of the carapace and head are recommended in case of accuracy in identification.



MARINE TURTLES IDENTIFICATION KEY



Nomenclature of a Turtles Scutes



Olive ridley (*Lepidochelys olivacea*)

The Olive ridley turtle has a global distribution throughout the tropical waters. These turtles nest on tropical coastlines across the globe, preferentially found along tropical mainland shores and barrier islands, frequently in proximity to river estuaries. Their nesting sites span across the mainland of India, including the Andaman and Nicobar Islands, and to a lesser extent, the Lakshadweep Islands. Adult Olive ridley weighs around 50 kg, featuring a short and wide carapace that is smooth but elevated, forming a distinctive tectiform or tent-shaped structure. The coloration of Olive ridleys is mid to dark olive green, identified by 6 to 9 pairs of

asymmetrical costal scutes, they have a large, triangular head, two claws on each flipper, and a creamy yellow plastron with a pore near the rear margin of infra marginals. Olive ridleys engage in night nesting behavior, laying 1 to 3 clutches per season, each containing 100 to 120 eggs, with an egg size of approximately 4 cm in diameter. The re-nesting interval ranges from 20 to 28 days, and the re-migration interval is typically 1 to 2 years. The nesting track, which is 70 to 80 cm wide and light in color, exhibits asymmetrical oblique marks created by the forelimbs, while the tail drag mark is either absent or not easily noticeable, adding to the unique characteristics of these remarkable turtles.

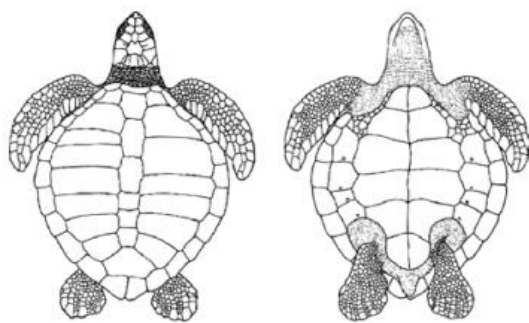


Fig.1. Olive ridley turtle: dorsal (left) and ventral (right) view

(Illustrated in Sea Turtles of India, 2011)



Fig.2. Live Olive ridley turtle (*Lepidochelys olivacea*) sighted in the offshore survey off Maharashtra (Jayasankar et al., 2022)

Green turtle (*Chelonia mydas*)

The Green turtles are found globally in tropical and subtropical waters. The species is renowned for its distinctive characteristics, and they exhibit nesting preferences on tropical beaches, encompassing both mainland and remote islands. They are frequently observed on large, open beaches to small cove beaches, with prominent nesting sites found along the mainland in Gujarat, as well as on beaches throughout the Lakshadweep and Andaman

Islands. Adult Green turtles weigh around 250 kg, featuring a broadly oval carapace with a scalloped margin but not serrated. Their coloration varies, with brown hues and radiating streaks in juveniles, while adults display more variability. The species is recognised by the presence of four pairs of costal scutes, a rounded shape at the anterior of head, and a single claw on each flipper. Hatchlings display a white plastron which gradually turns yellowish as they mature. Additionally, their vertebrates (centrals) are large, preventing the first costal from making contact with the nuchal scute. Green turtles exhibit night nesting behavior, laying 4 to 6 clutches per season, each containing 100 to 120 eggs. The nesting track, measuring 100 to 130 cm wide, exhibits symmetrical diagonal imprints created by the forelimbs, with a tail drag characterized by either a continuous or interrupted line.

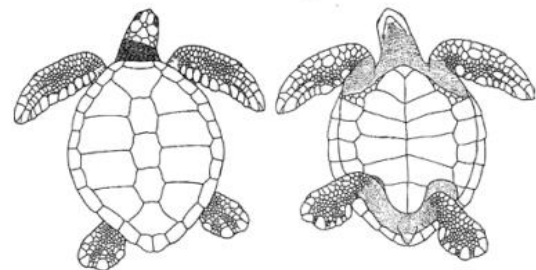


Fig. 3. Green turtle: dorsal (left) and ventral (right) view

(Illustrated in Sea Turtles of India, 2011)

Hawksbill turtle (*Eretmochelys imbricata*)

The Hawksbill turtle has a global distribution and favors nesting on tropical beaches, particularly on remote islands. Hawksbills typically select narrow beaches on islands or mainland shores, often with reefs hindering offshore approaches. Significant nesting sites include Lakshadweep, Andamans, and selected beaches in Nicobar, such as Indira Point in Great Nicobar. Hawksbills often nest under overhanging vegetation, a behavior distinct from ridleys, which prefer open areas. Adult Hawksbill turtles weigh around 150 kg, featuring an oval carapace characterized by a prominently serrated posterior margin and thick, overlapping scutes. Their distinct coloration comprises brown shades boldly marked with amber and brown variegations. The species is distinguished by four pairs of costal scutes with a serrated posterior

border, Hawksbills exhibit a narrow, straight, bird-like beak and possess two claws on each flipper. Their plastron is light yellow to white, and large vertebral (centrals) prevent the first costal from contacting the nuchal scute. Hawksbills display a flexible nesting behavior, choosing both night and day for nesting. They lay 3 to 5 clutches per season, each containing 120 to 150 eggs, with some nests holding up to 180 eggs. The eggs, approximately 3.5 cm in diameter, are laid at intervals of 12 to 14 days. The re-migration interval ranges from 2 to 5 years. The nesting track, measuring 70 to 85 cm wide, is shallow and exhibits asymmetrical (alternating) oblique marks made by forelimbs, while the presence or absence of tail marks varies. Although their tracks may resemble those of ridleys, the beach types they choose for nesting differ significantly.

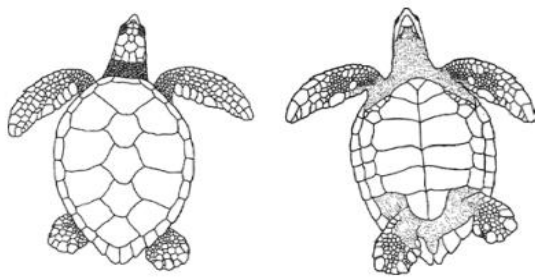


Fig. 4. Hawksbill turtle: dorsal (left) and ventral (right) view

(Illustrated in Sea Turtles of India, 2011)

Loggerhead turtle(*Caretta caretta*)

The Loggerhead turtles are found in tropical waters worldwide. Although it primarily nests in temperate waters, sometimes extending to subtropical and tropical regions. Loggerheads find suitable nesting sites in locations such as Sri Lanka and are not known for nesting in India. These turtles favor extensive mainland beaches or barrier islands for nesting. Adult Loggerheads weigh approximately 200 kg, featuring a moderately broad carapace with a lightly serrated posterior margin in immature. Notably, adults exhibit a thickened area at the base of the 5th vertebra. Their coloration is generally unmarked reddish-brown in subadults and adults. Recognizable by five pairs of costal scutes and a large, broadly triangular head, Loggerheads have two claws on each flipper and a yellow to orange plastron. Unlike some other species, the narrow vertebrates (centrals) allow the first costal to contact the nuchal scute. Loggerheads engage in night nesting behavior, laying 3 to 5 clutches per season, each containing 100 to 120 eggs, with an egg size of

approximately 4 cm in diameter. The re-nesting interval ranges from 12 to 16 days, and the re-migration interval is typically 2 to 3 years. The nesting track, measuring 70 to 90 cm wide and moderately deep, exhibits asymmetrical diagonal marks produced by the forelimbs, typically without the presence of a tail drag mark.

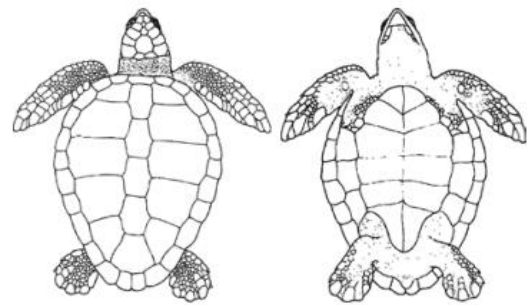


Fig. 5. Hawksbill turtle: dorsal (left) and ventral (right) view

(Illustrated in Sea Turtles of India, 2011)

Leatherback turtle(*Dermochelys coriacea*)

Leatherback turtles have a global distribution spanning all oceans, from sub-arctic to tropical waters. The Leatherback turtle, renowned for its large size, prefers nesting on tropical beaches, especially those with wide expanses, a steep slope, and clear access to deep water devoid of rocks. In India, Leatherback turtles predominantly nest in the Andaman and Nicobar Islands, with primary nesting sites identified at Galathea on the east coast, and various beaches along the west coast of Great Nicobar, Little Nicobar, and Little Andaman Islands. Adult Leatherbacks weigh over 500 kg, boasting an elongated and tapering carapace with seven prominent dorsal ridges. Notably, they lack costal scutes and have a triangular head with two maxillary cusps. Their mostly black coloration is adorned with white spotting, and distinctive pink or bluish spots embellish the base of the neck and flippers. These turtles exhibit unique nesting behavior, with a preference for night nesting, laying 4 to 6 clutches per season, each containing 80 to 100 eggs. The Leatherback turtle's nesting track, measuring 150 to 200 cm wide, is characterized by symmetrical diagonal marks created by the forelimbs and a deep median groove formed by the long tail, making it a fascinating and distinctive species within the marine ecosystem.

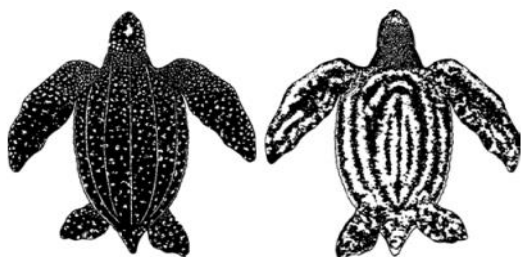


Figure 5. Leatherback turtle: dorsal (left) and ventral (right) view

(Illustrated in Sea Turtles of India, 2011).

Conclusion

Sea turtles, representing ancient marine species, contribute significantly to the health of our oceans. Their nesting habits on tropical beaches worldwide serve as a vital link in the complex web of marine life. Sea turtles are faced with multifaceted threats such as over-exploitation, habitat degradation, and incidental catch, the need for comprehensive conservation efforts cannot be overstated. Legislative measures such as the Indian Wildlife (Protection) Act 1972 provide a legal foundation, but the success of conservation initiatives relies heavily on collaborative endeavors involving various stakeholders, local communities, and dedicated research institutions. Sustained commitment is necessary to address persistent challenges such as habitat degradation, developmental activities, and the high incidence of incidental catch. The collaborative efforts of governmental bodies, non-governmental organizations, and local communities are crucial in ensuring the survival of these ancient creatures and fostering sustainable practices that benefit marine ecosystems and human societies alike. As stewards of our oceans, the responsibility to protect and conserve sea turtles lies in our hands, and the positive outcomes seen in certain regions underscore the potential for impactful change with sustained dedication.

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Marine Macroalgae: Biodiversity from Indian Waters

15

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Marine ecosystems are the largest aquatic ecosystems on our planet, sustaining almost 50% of the overall world's biodiversity. Marine and terrestrial environments rely on various ecosystems, such as intertidal zones, tidal zones, the deep sea, coral reefs, salt marshes, estuaries, lagoons, and mangroves, which are crucial for their sustainability. Algae are autotrophic plants that live mostly in water and come in many different types, from *Chlamydomonas*, *Chlorella* and Diatoms, which are single-celled organisms, to *Fucus* and *Sargassum*, which are multicellular organisms. The classification of marine algae encompasses two primary categories: marine microalgae and marine macroalgae. Marine microalgae, often known as phytoplankton, are exclusively observable with the use of microscopes. Marine macroalgae, also known as seaweeds, seaplants, or aquatic plants, encompass all types of marine algae that are observable without the aid of microscopes (Ranjith et al., 2018).

Forefathers of marine algae research

Carolus Linnaeus, known as the "Father of Taxonomy," coined the term "algae" in 1753, which means "sea weeds" in Latin. Felix Eugen Fritsch, known as the Father of Algology or Phycology, gave the most authentic and comprehensive algal classification. Prof. M.O.P. Iyengar (1886–1966) was an Indian botanist and psychologist who worked on algal structure, cytology, reproduction, and taxonomy. He is known as the "father of Indian phycology" or "father of algology in India".

Taxonomic history of marine algae research in India

In 1672, Hermann made the initial collection of algal specimens from the Indian Ocean. He specifically gathered *Amphiroa*, a type of coralline alga, from the Cape of Good Hope in South Africa. In 1768, J.G. Koenig (1728–1789) conducted a series of comprehensive marine algal collections from the coast of Tranquebar, South India, during his voyage to India under the guidance of a Moravian missionary

(Srinivasan, 1965). Foreign workers led several expeditions to collect seaweed from the Indian coasts during the 18th and 19th centuries. These expeditions included the Galathea expedition (1845-1847), Novara (1857-1859), Preussische (1859-1863), Challenger (1872-1876), Investigator (1890-1892), and Siboga (1899-1900). Nevertheless, the surge in algal research in India occurred just in the late AD's, when Prof. Iyengar (1886–1966) released a publication in 1927 detailing the seaweeds found on Krusadai Island in the Gulf of Mannar. Subsequently, he authored a collection of publications about algal studies. Boergesen (1928–1938) subsequently authored a collection spanning from 1928 to 1938, wherein he documented around 150 taxa, encompassing 5 novel genera and 38 species, originating from the western coast of India, with a special focus on the coastal regions of Bombay and Gujarat (Palanisamy et al., 2020). At the same time, numerous other researchers were actively exploring a variety of marine algae from various parts of the country.

General morphological structure of marine macroalgae/seaweeds:

Macroalgae lack true leaves, stems, and roots, but they have a few common structures with those of terrestrial plants. Their thalloid body consists of a holdfast, stipe, blade, and reproductive structures (Fischer and Hureau, 1985; Carpenter and Niem, 1998).

- **Thallus:** The simple vegetative plant body, no matter the growth form, is undifferentiated into true leaves, stems, and roots.
- **Blades:** The flattened leaf-like portions are called blades, which are either rounded or pointed sheets or filaments. The blades are not true leaves because they lack veins.
- **Frond:** This term used to refer to stipe and blade together; these are either branched or tufted.
- **Gas-filled bladders or floats:** The gas-filled bladders or floats aid the plants in

maximizing sunlight exposure.

- Stipe: a stem-like structure not found in all seaweeds. The stipe allows a place for the attachment of the blades, which in turn provides long and tough support (e.g., Giant Kelp).
- Holdfast: A small, anchor-like, root-like structure that holds the seaweed at the bottom to any substratum.

Macroalgal growth, life history and reproduction

Seaweed typically initiates its life cycle as either a spore or a zygote, or in culture, as propagules or cuttings. After the process of settling and attachment in the substratum, germination, growth, and development occur, ultimately resulting in the formation of an adult or mature plant. This mature plant can then engage in either asexual or sexual reproduction (Lobban et al., 1985). There is a growing body of evidence suggesting that, in addition to external elements such as light and temperature, internal factors such as morphogenetic factors, such as hormones, may play a role in the processes that contribute to the formation and preservation of thallus integrity (Jacobs, 1985).

The life cycle of mature members of green, brown, and red seaweeds involves a recurring pattern of two or three somatic generations that exhibit either isomorphism (having the same morphology) or heteromorphism (having various morphologies). The sporophyte (2N) undergoes meiotic division to generate spores, which then grow into gametophytes (N) to facilitate mitotic gamete production. The process of gamete fusion results in the formation of a zygote, which subsequently develops into a sporophyte, completing the cycle. In certain species of red algae, such as *Gracilaria*, the carposporophyte (2N) is generated within the female gametophyte (N) following the fertilization of an egg by spermatia derived from the male gametophyte. In carposporangia, the carposporophyte generates carpospores (2N) that are then liberated and undergo germination into tetrasporophyte (2N), which in turn produces tetraspores (N) by the process of meiosis. The tetraspores subsequently differentiate into either female or male gametophytes (N), thus concluding the plant's life cycle (Carol, 2006).

Seaweeds have the ability to reproduce or spread in both temporal and spatial dimensions through asexual and sexual mechanisms. The asexual technique can be achieved by two methods: 1) vegetative regeneration from naturally or intentionally created fragments; or 2) the

creation of non-motile or motile spores in structures known as sporangia. The former is referred to as an aplanospore, which is generated within the aplanosporangium, while the latter is known as a zoospore, which is formed within the zoosporangia. Sexual reproduction involves the fusion of gametes derived from either simple or differentiated gametangia. In the case of differentiated gametangia, an antheridium produces male gametes, while an oogonium produces female gametes. Fertile regions can be observed on the surfaces of the thalli in the more sophisticated stages of the red and brown algae. Male gametes, known as spermatia, can be grouped together in cavities called conceptacles. On the other hand, female reproductive organs, such as tetrasporangia, can form separate aggregations called sorus (FAO, 1988).

According to Trono and Fortes (1988), certain specialized branches of spore production are referred to as "receptacles," yet in other cases, certain portions of these branches undergo conversion into fertile structures known as stichidium. Female gametophytes of red seaweeds, such as *Gracilaria* and *Eucheuma*, develop stunted or sessile cystocarps on their surfaces. These cystocarps contain the carposporophyte and are covered by a pericarp.

Seven-kingdom classification of living organisms including macroalgae

Ruggiero et al. (2015) propose a two-superkingdom (prokaryotic and eukaryotic) and seven-kingdom classification with the extension of Cavalier-Smith's six-kingdom schema (Cavalier-Smith, 1998). *Cellular level*: Prokaryota (unicellular): bacteria, e.g., *Staphylococcus*, and Archaea, e.g., *Halobacterium* (Carl et al., 1990). Eukaryota (mainly multicellular, with a few exceptions): Protozoa, e.g., Amoebozoa; Chromista, e.g., diatoms; brown algae; Plantae, e.g., land plants; red or green algae; fungi, e.g., fungus; and Animalia, e.g., fishes, mammals. *Non-cellular level*: Stefan Luketa (2012) created two additional domains (no RNA/DNA-infectious), i.e., prions and viruses.

Taxonomic identification of marine macroalgae

Marine macroalgal taxonomy is a complex field, partly because it is evolving, whereby species and genera are frequently changed, e.g., *Porphyra* to *Pyropia*, *Enteromorpha* to *Ulva*, and *Laminaria* to *Saccharina*. Understanding the cytological properties of seaweeds is crucial for comprehending their fundamental adaptations at this lower level of organization, in addition to

their utility as tools in marine macroalgae taxonomy. However, that classification is based on the combination of several characters (**Table 1**). The categorization of algae at the division level primarily relies on many key criteria, including

- the presence of photosynthetic pigments;
- the availability of food reserves.
- the composition of cell walls; and
- other significant characteristics of the ultrastructure.

Collection and preservation of marine macroalgae

Collection of macroalgae

- Intertidal collection (low tide; 1-2 hours before low tide; description of the site location, topography, etc.).
- Material required: polyethylene bags, knives or scalpels, labeling materials, rubber bands, field notes, long rope (about 50 m long), monopane balance, etc.

Survey methods

- Line/belt transect or quadrat or random sampling or video transect

Sample preservation (Wet/Dry)

- Wet preservation adhering materials (5–10% formaldehyde in seawater should be prepared to preserve the seaweed sample).

Sectioning and staining of marine macroalgal samples

- Sectioning: healthy specimen; rinse specimen - use a sharp scalpel or microtome to cut thin cross-sections of the seaweeds (thin sections - 10µM)
- Staining: A drop of the dye was placed via a glass rod on the section (wait for two minutes for penetration). The dye used are
- Azure II: Red algae: red tones; brown algae: blue tones; and green algae: purple color
- Methylene blue: Blue colour *Acanthophora* spp. forms a purple color.
- Thioflavin: Thioflavin: yellow, sometimes brown; Brown colour - cuticle and epidermal cells.

Table 1. General classification and features of the seaweed major divisions (adapted from FAO, 1988).

S N	Division	Pigments	Plastids	Cell wall	Stored food	General morphology	Reproduction
1	Ulvophyceae/Chlorophyceae	Chl a Chl b	Present	Outer layer - Pectic & Inner layer - Cellulose	Starch	Microscopic - filamentous to coenocytic; to various macroscopic forms	Asexual. Sexual
2	Phaeophyceae	Chl a Chl c Fucoxanthin	Present	Cellulose and alginic acid	Laminarin & mannitol	Freely branched; filaments to macroscopic	Asexual. Sexual
3	Florideophyceae/Rhodophyceae	Chl a Chl d	Present	Cellulose & gelatinous or sulfated galactans such as agar, carrageenan, fucellaran	Floridean starch	Microscopic-filamentous; macroscopic forms	Asexual. Sexual

Keys to major classes - Characters

- 1a Thallus green to yellowish green; chlorophyll b present; zoospores

flagellate generally green; cell wall outer layer pectic and an inner layer cellulose; sometimes calcified; photosynthetic product is starch

. Ulvophyceae/Chlorophyceae (Green algae)

- 1b. Thallus brown or red; chlorophyll b absent; zoospores flagellate or eflagellate.....2
- 2a. Thallus brown to pale brown to reddish brown in color; xanthophyll pigments; chlorophyll a and c present; reserve food mannitol and laminarin zoospores always flagellate

. Phaeophyceae (Brown algae)

- 2b. Thallus red to yellowish red to dark greenish red in color r-phycoerythrin; chlorophyll a & d present; reserve food floridean starch; zoospores always a flagellate

. Florideophyceae/Rhodophyceae (Red Algae)

Green algae

Major pigment is chlorophyll; very common in salinities varying (bays and estuaries, tide pools); simple thallus when compared to other algae. Many forms are filamentous to thin sheets.

Green algae keys to major orders in India (adapted from Oza & Zaidi, 2001).

- 1a. Thallus filamentous, simple or branched; cells usually cylindrical to barrel shaped, multinucleate 2
- 1b. Thallus not filamentous; cells variable in shape, uni- or multinucleate 3
- 2a. Thallus intertwined, forming a mat-like structure Acrosiphoniales (*Acrosiphonia orientalis*)
- 2b. Thallus freely branched, not forming a mat-like structure Cladophorales (*Cladophora glomerata*)
- 3a. Thallus is usually foliose, flat, ribbon-shaped, or tubular 4
- 3b. Thallus, usually siphonous, spongy, or feather-like; rarely foliose; multinucleate 5
- 4a. Thallus foliose, small, up to 30 cm long Ulotrichales (*Monostroma latissimum*)
- 4a. Thallus foliose, tubular or ribbon

shaped, up to 2 m long Ulvales (*Ulva reticulata*)

- 5a. Thallus spongy, cup-like, or matted with clavate to cylindrical vesicles; holdfast rhizoidal or tenaculum type Siphonocladales (*Valoniopsis pachynema*)
- 5b. Thallus feathery to grape like or foliaceous Bryopsidales (*Caulerpa racemosa*)

Brown algae

The major pigment is fucoxanthin; color varies from olive green to dark brown; and yellow-brown pigments mask the color of chlorophyll.

Brown algae keys to major orders in India (adapted from Oza & Zaidi, 2001).

- 1a. The life cycle lacks alternation of generations; the sporophytic phase is absent, represented by only the gametophyte phase.....Fuciales (*Sargassum wightii*)
- 1b. The life cycle exhibits an alternation of generations, represented by both sporophytic and gametophytic phases..... 2
- 2b. Thallus shows apical growth..... 3
- 2b. Thallus shows trichothallic growth.....4
- 3a. Thallus polysiphonous, grows with a single prominent cell Sphacelariales (*Sphacelaria rigidula*)
- 3b. Thallus, not polysiphonous, grows with one to many apical cells, fronds flat, blade-like, non-heterotrichous.....Dictyotales (*Dictyopteris australis*)
- 4a. Thallus heterotrichous, filamentous, rarely pseudoparenchymatous.....Ectocarpales (*Ectocarpus siliculosus*)
- 4b. Thallus non heterotrichous, hollow or sac-like.....Scytosiphonales (*Colpomenia sinuosa*)

Red algae

Major pigments are phycobilins, mostly red rather than green or brown; some have calcium carbonate within their cell walls. Coralline red algae shows smooth or rough encrusting growth on rocks.

Red algae keys to major orders in India (adapted from Oza & Zaidi, 2001)

- 1a. Thallus foliose, filamentous or membranous; cells with stellate chromatophores; protoplasmic connection absent.....Bangiales (*Porphyra kanyakumariensis*)
- 1b. Thallus filamentous-complex, often massive forms, protoplasmic connection present..... 2
- 2a. Auxiliary cells absent..... 3
- 2b. Auxiliary cells present..... 5
- 3a. Gonimoblast filaments intermingled with nutritive filaments.....Gelidiales (*Gelidium micropterum*)
- 3b. Gonimoblast filaments, usually not intermingled with nutritive filaments, develop directly from the fertilized carpogonium or rarely from the hypogynous cell..... 4
- 4a. Central axial cell not visible in the pseudoparenchymatous thallus, carpogonium branches 2-celled.....Gracilariales (*Gracilaria edulis*)
- 4b. Central axial cell visible in the pseudoparenchymatous thallus, carpogonium branches 3-celled Bonnemaisoniales
- 5a. Auxiliary cells form only after fertilization.....Ceramiales (*Centroceras clavulatum*)
- 5b. Auxiliary cell formed before fertilization..... 6
- 6b. Thallus is usually calcified; tetrasporangia develops in conceptacles.....Corallinales (*Amphiroa fragilissima*)
- 6b. Thallus is usually not calcified; tetrasporangia does not develop in conceptacles..... 7
- 7a. Auxiliary cells formed in special accessory branches.....Cryptonemiales (*Grateloupia filicina*)
- 7b. Auxiliary cells are not formed in special accessory branches or branch clusters..... 8
- 8a. Cells formed from the supporting

cell of a carpogonial branch act as the auxiliary cell Rhodymeniales (*Champia parvula*)

- 8b. Intercalary cells of a vegetative filament act as the auxiliary cell.....9
- 9b. Pit plugs are always membranous, spermatangia are large, and gonimoblast filaments develop in upward or downward directions.....Gigartinales (*Catenella impudica*)
- 9b. Pit plugs are always naked, spermatangia are small, and gonimoblast filaments develop in an upward direction only Ahnfeltia Les (*Ahnfeltia plicata*)

Classification of living algae and global diversity of macroalgae

The estimated global algal diversity represents 72500 taxa, of which 50,589 species (10,556 fossil) have already been described. Algal species are represented mainly by four kingdoms (Eubacteria, Chromista, Plantae, and Protozoa), representing sixty-three classes and still growing (Guiry et al., 2024; Guiry&Guiry, 2024). There are fourteen algal phyla, of which seaweeds fall under three major phyla. Chlorophyta (chlorophyta/green algae), Heterokontophyta/Ochrophyta (includes brown algae), and Rhodophyta (Rhodophyta/red algae) come under two major kingdoms, i.e., Chromista and Plantae. Kingdom-wise living algal species and a decadal description of new macroalgal species are given in Tables 2 & 3.

Table 2: Kingdom-wise living algal species (adapted from Guiry et al., 2024)

Kingdom	Genera	Species	Species (%)	Fossil	Living	Extant(%)
Chromista	2932	29,200	47.76	4709	24,778	48.75
Plantae	2858	21,170	34.62	2257	19,105	36.88
Total	7707	61,145		10,556	50,589	

Table 3: Decadal description of new species(adapted from Guiry et al., 2024)

Phylum/class	2012-2022	Average
Chlorophyta	507	51
Phaeophyceae	160	16
Rhodophyta	770	77

Diversity of macroalgae

There are about 12,000 species represented by Chlorophyta (Ulvanophyceae; 22.97% with 2,695 species in 527 genera), Heterokontophyta (Phaeophyceae; 9.11% with 2124 species in 346 genera), and Rhodophyta (Foridophyceae; 94.72% with 7,155 species in 990 genera). The estimated total number of species is between 8000 and 10500; more than 841 species are represented in the Indian waters (Radulovich et al., 2015; Ganesan et al., 2019), exhibiting regional species richness and global diversity patterns. Worldwide, 291 seaweed species are commercially used; due to their cultivation success and biomass value, seaweed is now being

farmed in more than 50 countries (FAO, 2016). Taxonomy, species diversity, and distribution of seaweed have been well studied in the Indian seas (Krishnamurthy and Joshi, 1970; Untawale et al., 1983; Oza and Zaidi, 2001; Sahoo et al., 2001; Rao and Gupta, 2015; Kaliaperumal., 2017). The studies show that the seaweeds were abundant in Gujarat, Tamil Nadu, the Andaman and Nicobar Islands, and the Lakshadweep Islands. Recently, from the Indian waters, 844 species were represented, of which 434 were Rhodophyta, 191 were Ochrophyta, and 216 were Chlorophyta (Mantri et al., 2020). The comparison of earlier reports on Indian macroalgae diversity is given in Table 4.

Table 4: Comparison of earlier report on Indian macroalgae diversity

Checklist	Title	Chlorophyta	Ochrophyta	Rhodophyta	Total
Krishnamurthy & Joshi, 1970	Genera	36	33	98	167
	Species	130	136	256	522
Untawale et al.,	Genera	44	39	120	203

1989	Species	156	141	307	604
Oza and Zaidi., 2001	Genera	43	37	136	216
	Species	216	191	434	841
Sahoo et al.,2003	Genera	45	38	138	221
	Species	184	166	420	770
Rao and Gupta, 2015	Genera	46	50	138	234
	Species	212	211	442	865
Present study	Genera	50	48	157	255
	Species	240	219	475	934

Present Indian macroalgae diversity

The distributional records of valid Indian seaweed species and country-wise seaweed diversity up to March 30, 2022, were extracted from the global AlgaeBase database (<https://www.algaebase.org/>). The results

revealed 934 species of seaweeds, including 240 Chlorophyta (30 families and 50 genera), 219 Ochrophyta (15 families and 50 genera), and 475 Rhodophyta (49 families and 157 genera), were extracted from the database (Table 5). The Rhodomelaceae (Rhodophyta) are the most species-rich family, representing nearly 84 taxa, whereas the brown seaweed, *Sargassum* (more than 100 taxa), is the most diversified genera.

Table 5: Indian macroalgae diversity from AlgalBase Database

Class	Order	Family	Genera	Species
Rhodophyta	22	49	157	475
Ochrophyta	8	15	48	219
Chlorophyta	8	30	50	240
Total	38	94	255	934

Factors influencing marine macroalgal diversity

Environmental Conditions:

- Temperature: Different species thrive in various temperature ranges, influencing their distribution.
- Light Availability: Light intensity and quality affect photosynthesis and growth.
- Salinity: Species exhibit preferences for

- specific salinity levels.

Substrate Availability:

- Substrate Type: Macroalgae exhibit preferences for different substrate types, including rocks, sand, and other macroalgae.
- Substrate Stability: The stability of the substrate influences attachment and

growth.

Nutrient Levels:

- Nitrogen and Phosphorus: Nutrient availability influences macroalgal productivity.
- Eutrophication: Elevated nutrient levels may lead to increased macroalgal growth.

Wave Action and Currents:

- Wave Exposure: Some species are adapted to withstand strong wave action, while others prefer sheltered areas.
- Current: Macroalgae may adapt their forms based on water movement.

Importance of Marine Macroalgae

Seaweeds grow in the intertidal and subtidal regions of the sea and other aquatic bodies. Like land plants, seaweeds form the basis of the marine ecosystem's food chain; the photosynthetic pigments can produce food and form an important primary producer in the marine environment. Seaweeds have been used for food and medicine for over 14,000 years, and many tons of these plants are gathered and eaten (Reed, 1907; Dillehay et al., 2008). Seaweed has become a commercially crucial coastal product as it produces primary metabolites (structural molecules such as proteins, lipids, and carbohydrates) and secondary metabolites as bioactive compounds. They have a more comprehensive application, i.e., human nourishment, livestock feed, agricultural fertiliser, cosmetics, pharmaceuticals, and biotechnological (Leandro et al., 2019). Several seaweeds are considered structuring species in changing the coastal environment by modifying light, sedimentation rates, and hydrodynamics (Sara García-Poza et al., 2020).

Marine Macroalgae- Services and benefits to humans

Seaweeds generate socio-economic benefits and support coastal communities, thereby contributing to environmental benefits, human health, and ecosystem services.

- Environmental benefits and ecosystem services: habitat for marine organisms, bioremediators, mitigation of ocean acidification and climate change, etc.
- Human basic utilities: healthy, low-

calorie food, animal feed and supplements, biofuel, biofertilizer, growth stimulants, etc.

- Industrial uses: bioactive compounds, nutraceuticals, cosmetics, industrial chemicals, etc.
- Socio-economic benefits: livelihood of coastal communities and income generation

Marine Macroalgae Biodiversity Research Gaps and Challenges

- Fixing geographical gaps to entirely record biomass and species diversity
- Strengthening the scientific community's access to data
- Expertise is needed for building capacity and national expertise for constructing an
- integrated taxonomy
- Possibilities to promote seaweed utilisation, cultivation, and sustainable harvesting in India
- Adequate technical and scientific support is required for the national seaweed policy and guidelines.

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Seagrasses of India- an account on diversity

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Seagrasses are marine angiosperms, basically monocotyledons, found submerged fully in coastal and estuarine waters. It is the world's only flowering plant which can sustain in seawater and withstand an incredible ally in the war against climate change.

Adaptations in seagrasses

It is believed to have evolved from land plants with terrestrial like leaves, flowers, seeds, roots and is pioneers in making their food. Unlike terrestrial plants, however, they lack strong stems to hold themselves; instead they are well supported by the buoyancy of the water. Seagrasses are well developed to sustain completely submerged underwater life with internal gas transport and well developed epidermal chloroplasts. Water-borne filamentous pollen grains and ribbon-like leaves of seagrasses which are devoid of stomata are some of the adaptations that help in thriving in aquatic or saline environments. These adaptations help the plants disperse their pollen and survive in challenging conditions.

Distribution of seagrasses

Globally, the seagrass comprises six families encompassing 14 genera of Angiosperms with seven tropical and temperate genera each. The seagrasses are quite evident in all coastal waters except the northern Arctic Circle and Antarctica. The diversity of seagrass flora of Indian context is represented by six genera and 14 species. In India, various seagrass species such as *Enhalus acoroides*, *Halophila ovalis*, *Halophila ovata*, *Halophila stipulacea*, *Halophila beccarii*, *Halophila decipiens*, *Thalassia hemprichii*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Halodule uninervis*, *Halodule pinifolia*, *Halodule wrightii*, *Syringodium isoetifolium* and *Ruppia maritima* have been recorded. The maximum species are recorded from Gulf of Mannar and Palk Bay, Andaman and Nicobar Islands, Lakshadweep, Gulf of Kutch and in patches from all along other coastal and estuarine regions of India.

Classification of seagrasses

Seagrasses are indeed not considered as true grasses. While they share some similarities with terrestrial grasses, they belong to a different

taxonomic group within the angiosperms (flowering plants). Seagrasses are a functional group because they have adapted to live in marine environments, particularly in shallow coastal waters. They provide important habitats for various marine organisms and play a crucial role in coastal ecosystems.

Taxonomic Classification

Kingdom	Plantae
Division	Magnoliophyta
Class	Liliopsida
Subclass	Alismatidae
Order	Alismatales
Family	Hydrocharitaceae Cymodoceae Posidoniaceae Zosteraceae

Hydrocharitaceae Hydrocharitaceae is a flowering plant family broadly called the 'tape-grasses'. The family has 18 freshwater species and 3 marine species. The marine genera are *Enhalus*, *Halophila* and *Thalassia* whereas *Cymodoceaceae* family is called as 'manatee-grass family', the only marine species family with five genera comprising 16 species, mostly occurring in tropical coastal regions. The noted genera under *Cymodoceaceae* are the *Cymodocea*, *Halodule*, *Amphibolis*, *Syringodium* and *Thalassodendron*. *Posidoniaceae* family has a sole genus *Posidonia* which contains 9 species of seagrasses mostly seen in the Mediterranean Sea and southern part of Australia. *Zosteraceae* family is found in the temperate region as well as subtropical waters with two genera, *Zostera* and *Phyllospadix*.

Taxonomic identification of Seagrasses

Globally the seagrass species are called as Eel grass, turtle grass, spoon grass, tape grass and shoal grass etc. The term seagrass arise due to the grassy leaf appearances though some are not like grass at all. The size ranges from few centimeters to 6 meters. Morphologically the seagrass differs with seaweeds in terms of advanced leaves, stem, roots, rhizome, fruits,

flowers and seeds. In actual there is quite differences between different seagrass species. For example, the leaves of seagrasses may appear to be oval shape or fern like in *Halophila*, elongated spaghetti like in *Syringodium* or ribbon like in *Cymodocea*, *Thalassia*, and *Halodule*. The leaves are well protected by leaf base called sheath whereas the round or pointed leaf tip helps in identification of species. In many seagrass varieties, the leaves arise directly from the vertical stem except in *Halophila* species where prominent petioles are observed. The leaves scars are very prominent in seagrasses. The horizontal stem, running parallel to ground are called as Rhizomes of which the Roots arise vertically. The segmentation is very prominent in rhizomes which are called as Nodes/Scars from which vertical stems or directly leaves arise. The distance between two adjacent nodes is known as internodes. Both rhizome and roots (simple or branching) are often found buried in sediment, helping in anchorage, absorbing nutrients as well as stores carbohydrates. In asexual reproduction, the rhizomic extension plays a vital role as it can lead to vast meadow in short lifespan.

Identification keys to Indian Seagrasses

1. A) Leaves cylindrical, round, terete or spaghetti like.....*Syringodium isoetifolium*
B) Leaves ribbon like or flat.....2
2. A) Leaves elliptic in shape, oval, lanceolate or linear-oblong*Halophila*
B) Leaves in whorl like arrangement, black patches, no cross veining.....*H. beccarii*
C) Leaves with presence of cross veining.....3
3. A) Leaves with 12-20 cross-veins.....*H. ovalis*
B) Leaf of 6-8 pairs of cross-veins, hair on both sides, serrated margin.....*H. decipiens*
C) Leaves have 4-7 pairs of cross veining..... 4
4. A) Leaves 2- 6 cm, petioles present, serrated tip, single root at each node....*H. stipulacea*
B) Leaves in pairs, 8 to 12 cross veins, less than 5mm width.....*H. minor*
C) Leaves are linear with 5-10cm length.....5
5. A) Leaves appear to be ligulate.....6
B) Leaves are not ligulated.....8
6. A) Leaf veins are not more than 3.....*Halodule*
i) Leaf tip have irregular serrations, rounded, tip of midrib furcated.....*H. pinifolia*
ii) Leaf tip appears tridentate, tip of midrib not furcated.....*H. uninervis*
iii) Leaves flattened with blunt or forked tips.....*H. wightii*
B) Leaf Veins more than 3.....7
7. A) Leaves appear flat, strap like shaped.....*Cymodocea*
i) Leaf tip is smooth or slightly serrulated, leaf blades are linear*C. rotundata*
ii) Leaf tip is serrated and leaf blades are linear.....*C. serrulata*
8. A) Rhizome are 2-4 mm in diameter, densely organized with filiform laterals; linear falcate leaves, no basal black coloured fibers*Thalassia hemprichii*
B) Rhizome is more than one cm dia, naked roots, linear leaf and basal black fibers present *Enhalus acoroides*

Detailed characteristics of seagrass varieties

1. *Cymodocea rotundata*
 - Leaves appear as plane, strap liked shaped with 2 to 4 mm width
 - Leaf apex is rounded with smooth edged
 - Leaf sheath fibrous, Smooth rhizome
 - Scars appear as a continuous ring pattern in the stem
 - These are very prominent in shallow reefs.
2. *Cymodocea serrulata*
 - Linear shaped leaves, appears as straps,

- with 5-9 mm wide
 - Serrated leaf tip
 - Leaf sheath non fibrous, broadly triangular shaped with a narrow base
 - Leaf Scars are non continuous
 - They are found on shallow sub tidal reefy areas and sand banks
- 3. *Enhalus acoroides***
- The leaves are ribbon like of 30 to 150cm in length
 - Thickness more than 1 cm
 - Leaf edges appears as inrolled
 - Rhizomes are thick, black with thread like roots
 - These are found on shallow, intertidal sand and mud banks
- 4. *Halodule pinifolia***
- Leaf tip rounded, small with a length of 20cm
 - one central vein and two parallel marginal veins
 - central vein get splited into two at leaf tip
 - Rhizome is pale with black fibres at nodes
 - These are found in intertidal sand banks.
- 5. *Halodule uninervis***
- These are larger than *H. pinifolia*
 - Leaf tip is tridentated, pointed not rounded
 - 3 parallel veins with central prominent
 - Rhizome colour is pale with presence of black fibres at nodes
 - Highly preferred by Dugong
 - These are found in shallow or intertidal sand or mud banks
- 6. *Halodule wightii***
- Flat leaves with serrated or forked apex
 - Shoots arises from nodes of rhizome
 - Grows in coastal/marine shallow waters
- 7. *Halophila decipiens***
- Small oval shaped, leaf blade of 1-2.5cm long
 - Leaves have petioles in pairs, leaves have 6 to 8 crossveins
 - Leaf hairs are present on both sides, leaf margins serrated
 - Leaves are longer than its width
 - These are found in more than 10 metres depth

8. *Halophila ovalis*

- Leaves are oval shaped, appear in pairs with the petioles
- Eight or more cross veins are present, margins very smooth
- Leaf surface have no hairs, length 5 to 20mm
- These are the one of the early colonizing species
- These are found in the intertidal – subtidal depths

9. *Halophila minor*

- Up to 8 pairs of cross veins or sometimes less than 8
- Less than 5mm wide leaves
- The leaves are small, oval and appears in pairs
- Leaf sheath is wedge shaped, no leaf hairs present
- Leaf margin is smooth
- These are found in shallow or intertidal sand areas

10. *Halophila stipulacea*

- Leaves elliptical, leaf margin serrated
- Pair of blades extend from each rhizome node on petioles
- Internodes reported a length of 7-50 mm
- Rhizomes are 0.5 to 2cm in diameter

11. *Halophila beccarii*

- Leaves arranged as whorls or clusters of 5 to 10 at a node
- Leaf clusters do not lie flat, finely serrated leaf margin
- Leaves are elongate, midrib present, no cross veins
- Short vertical stems seen

12. *Syringodium isoetifolium*

- Leaves are noodle or spaghetti shaped with pointed tips
- Leaves contain air cavities
- Leaves are 7 to 30 cm in length, inflorescence a cyme
- These are found in shallow subtidal reef area as well as in sand banks

13. *Thalassia hemprichii*

- Tannin cells appear as short black bars in leaf blades
- Rhizome is thick with scars
- Leaf shapes as hooks or are curved
- Leaves range of 10-40 cm long
- These are common in shallow reef areas

14. *Ruppia maritima*

- Leavea are thread like in appearance
- Leaf tips are pointed with serrations
- Inflorescence on a long bunch like stalk
- Fragile rhizome

Reproduction in seagrasses

Seagrasses are capable of reproducing sexually as well as asexually. These flowering plants produce seeds and the water born pollen grains are carried through the water to the female flowers for fertilization. The asexual reproduction occurs via extension of rhizome / roots through new growth thereby the single plant is capable of producing an entire meadow. This asexuality in seagrass leads to quick recovery after being grazed extensively by turtles, dugongs or even disturbed by storms.

Ecosystem Services provided by Seagrass ecosystem

Seagrass ecosystems are considered as highly productive coastal marine environments, boasting coastal productivity. It is the feeding-breeding grounds for fin-fishes, shellfishes, other major invertebrate communities, sea turtles, dugong, coastal and migratory birds etc. Many herbivorous/ detritivorous based food chains do depend on seagrass ecosystems and hence these can be considered as productive pastures of the sea.

Seagrass meadows sequester the atmospheric and dissolved CO₂ as a result of photosynthesis and the carbon will get deposited / stored in the sediment which helps enrichment and conditioning of the coastal waters.

Seagrasses are known as “the lungs of the sea” because of their oxygen releasing into the adjoining water through the process of photosynthesis.

Seagrasses modify the current-wave patterns, traps and stores the sediments and hence effectively filter and leach out the nutrients to the coast and to the deep sea. Thus these seagrasses can be called as biological sentinels or the canaries of coastal areas.

Seagrasses trap fine sediments, thus helping in maintenance of water quality and the suspended solids in the water which increases water clarity. This is due to the highly complex arrangement of roots which stabilizes the bottom substratum as that of land grasses, preventing soil erosion.

Seagrasses are breeding, feeding and nursery grounds of commercially important fin-fishes and shellfishes. The higher productivity of seagrass meadow impacts a positive remark on the coastal fisheries too.

It is also believed that the carbon storage within the seagrasses can affect the pH and increase calcification of coral reefs which mitigates the effects of ocean acidification.

Blue Carbon

Seagrass ecosystem stores carbon in the sediments, known as "blue carbon". It is believed that only 0.1 percent of the sea floor is occupied by the seagrasses, but are capable of sequestering 11 per cent of the carbon which is buried in the seabed and thus are able to absorb 83 million tonnes of carbon (83 gC/m² /yr translating to global storage rates between 27 and 40 TgC/yr) from the atmosphere annually which is 35 times faster than tropical rainforests. On a mathematical fact, it is estimated that One acre of seagrass meadow sequester 740 pounds of carbon per annum (83 grams of carbon per sq.m per year) which is equal to the amount emitted by a fuel driven car travelling around 6,212 kilometers.

Threats to seagrasses

Globally, research on seagrasses indicated that meadows are vanishing at an alarming rate from the coastal areas at the rate of 110 sq km per year due to the impact of anthropogenic activity. The main reasons for declining of seagrass are urban/port development, agriculture activities, urbanization in coastal areas, dredging, berthing and anchoring of boat, Netting/Trawling, pollution, sedimentation, excessive nutrients, storms, disease outbreak, and overgrazing by herbivores.

Conservation of seagrasses

Seagrasses are very sensitive ecosystem and are much susceptible to any natural or anthropogenic stresses. As these provide extreme levels of ecosystem services, the seagrasses can be considered as indicators of pollution. Loss of seagrass habitats leads to ultimate decline of associated flora and fauna thus results in the decline of overall ecosystem productivity. It is high time to take earnest measures to protect, conserve and manage these seagrass ecosystems so as to sustain these sensitive critical marine habitats for future generations.

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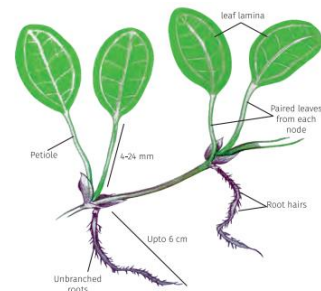
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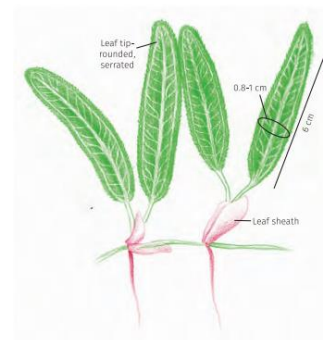
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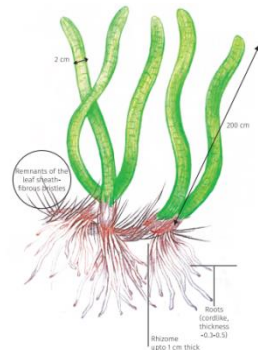
Halophila ovata



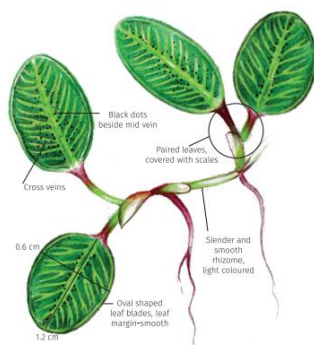
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Images of Seagrass Varieties of India

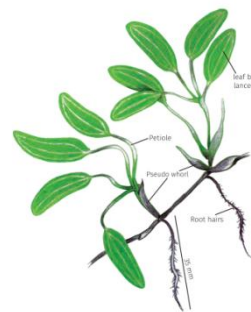
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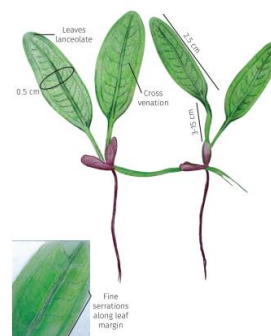
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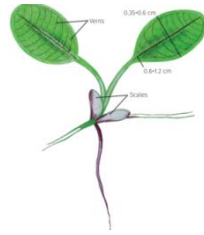
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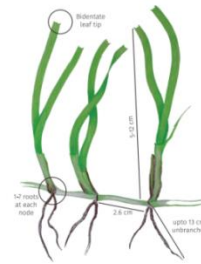
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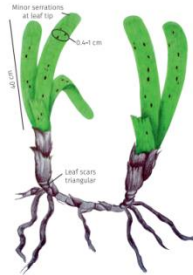
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Halophila minor



Halodule wrightii

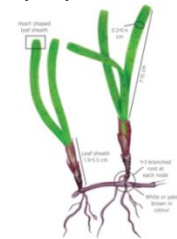


Thalassia hemprichii



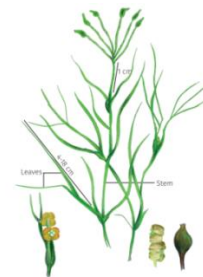
Syringodium isoetifolium

Family Cymodoceaceae

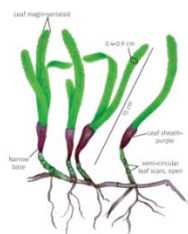


Cymodocea rotundata

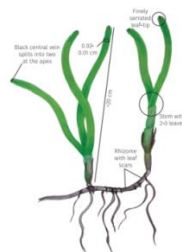
Family Ruppiaceae



Ruppia maritima



Halodule uninervis



Halophila pinnifolia

(Images from Pande et al, 2021)

Mangroves of Karnataka Importance and Identification

Bindu Sulochanan

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Mangroves are vital coastal ecosystems that provide a variety of benefits to both people and environment. They are salt-tolerant and distributed along coastlines, lagoons, estuaries, rivers or deltas in over 120 tropical and subtropical nations and forms less than 1 percent of all tropical forest. In 2020 it was estimated that mangroves areal extent is 14.8 million ha (FAO, 2023). Mangrove coverage in the nations Indonesia, Brazil, Nigeria, Mexico and Australia account for 47 percent in the world (FAO, 2020).

Mangrove ecosystem services include fuel, fodder, non-wood forest products, carbon sequestration, biodiversity conservation, coastal disaster mitigation, etc. But in spite of these, mangrove ecosystem is often converted to other uses, including aquaculture, agriculture, urban development and other related infrastructure. Land subsidence due to climate change and increasing salinity fluctuations due to reduced river flow also contribute to the reduced diversity of mangroves. It is estimated that within a period of two decades from 2000 around 677 thousand ha of mangroves were lost, which was partially offset by the expansion of 393 thousand ha of mangroves, resulting in net loss of 284 thousand ha (FAO, 2020). Indian mangroves form 3% of South Asia (ISFR, 2019) with an aerial extent of 4975 km². East Coast of India has the maximum mangrove coverage of 57% followed by 23% in the west coast, and 20% in Andaman and Nicobar Islands (Venkataraman and Wafar, 2005).

Adaptations

Morphological adaptations of mangroves to survive the tidal variations include aerial roots, salt excretion glands and vivipary of seeds (Tomlinson, 1986). The aerial roots assist in respiration and anchorage (Fig.1) especially in waterlogged soils and enhance the plants ability to adapt to salinity changes in the ecosystem (excess salt is excluded by the roots and leaves); propagules are also adapted to tidal dispersal by

seedvivipary and excellent methods of nutrient retention(Ball, 1988; Hogarth, 2015).

The mangroves diversity varies according to the ecosystem depending largely on the climate, salinity, topography, also the structure and composition of soil of the area. In very high saline areas patches of dwarf and tree having irregular and distorted growth pattern can be observed while favourable conditions for certain species forests with canopies exceeding 40 m in height (FAO, 2007) can be observed as in the Sundarbans. The perennial rivers Ganges, the Meghna and the Brahmaputra of India and Bangladesh, bring with it rich nutrients and forms the Sundarbans delta. In arid zones, the diversity is often limited and irregular canopy can be observed as in Karnataka where nutrient flow occurs mainly during monsoon. These mangroves still play a major role in the ecosystem as well as for the economy of the local people.



Fig. 1 Modifications of root in mangroves A Buttress B Prop roots C Cone roots D Pneumatophores E Cable roots and feeding roots

Importance

Mangrove forests support many marine species which also include some of the endangered and threatened species as they form the breeding and feeding ground and provide shelter and cool oxygenated water (FAO, 2020). Especially, the Sundarbans mangrove ecosystem shelters, a number of mammals and reptiles. This also includes the endangered Bengal tiger (*Panthera tigris*). A number of migratory bird species also rely on mangroves as wintering and roosting

sites, as was sighted along Karnataka Coast. Thus, mangroves provide a key habitat and support a number of endemic, restricted-range and migratory bird (Fig. 2).



Fig. 2 A. Black kite *Milvus migrans*. B. Indian Shag *Phalacrocorax fuscicollis*. C. Indian pond heron *Ardeola grayii*. D. Median Egret *Mesophoyx intermedia*. E. Great cormorant *Phalacrocorax carbo*. F. Black-Crowned Night-Heron *Nycticorax nycticorax*.

It is estimated that mangroves store 12 billion metric tons of carbon dioxide world wide and when these systems are damaged, they emit their stored carbon back into the atmosphere, where it contributes to climate change (Cawood 2023). In India the ecosystem services of mangroves are region specific due to their diverse nature, which

includes tourism, water filtration; it is estimated that 2 to 5 hectares of mangroves may treat effluents of 1 ha of aquaculture, supports more than 3000 species of fishes, regulates climate; as carbon storage potential is 3-5 times higher than that of the tropical forest, supports livelihood of 120 million people directly or indirectly, is a source of fuel and timber and offers coastal protection (www.insightsonindia.com).

Diversity in Karnataka

Rao and Suresh (2001) and Chandran et al. (2012) have reported the occurrence and distribution of eumangrove species such as *Rhizophora mucronata*, *R. apiculata*, *Acanthus ilicifolius* (Fig. 3), *Avicennia alba*, *A. marina*, *A. officinalis*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *Lumnitzera racemosa*, *Excoecaria agallocha*, *Kandelia candel*, *Sonneratia alba*, *S. caseolaris*, *Aegiceras corniculatum* and *Ceriops decandra* along the estuaries of Karnataka.



Fig. 3 A. *Acanthus ilicifolius* B. *B. gymnorrhiza* C. *Sonneratia alba* D. *S. caseolaris*

Field guide to key features for identification of Eumangroves

Sl No:	Family	Species	Key features
1	Acanthaceae	<i>Acanthus ilicifolius</i> L.	Pneumatophores rarely present, A woody shrub, with some what green succulent branches, Holly-leaves perennial spike with white to mauve flowers. Pair of stipular spines at the base of leaves and also a pair of bracteoles beneath each flower
2	Combretaceae	<i>Lumnitzera racemosa</i> Wild.	Pneumatophores absent, Leaves clustered at the end of branches, alternate leaves have notched apex bearing a small gland/Hydathode, white flowers in short axillary racemes, Multi-stemmed to columnar trunk
3	Euphorbiaceae	<i>Excoecaria agallocha</i> L.	Exudes milky latex, abaxial surface of leaves with greyish scales. Bark with longitudinal rows of lenticels, Knobby serpentine root system, with white lenticels on the knobs acting like pneumatophores

4	Myrsinaceae	<i>Aegiceras corniculatum</i>	Pneumatophores absent, Multi-stemmed or columnar trunk, Flowers stalks, several in number, fruits cylindrical, curved and acute 3 cm long and 0.5 cm dia
5	Rhizophoraceae	<i>Bruguiera cylindrica</i> (Roxb.) Wight.	Geniculate pneumatophores, cable roots, Flowers not solitary in axis Peduncles 3 flowered
6	Rhizophoraceae	<i>Bruguiera gymnorrhiza</i> Merr.	Geniculate pneumatophores, cable roots, Flowers solitary in axil, Petals with 3-4 hairs at the top, viviparous fruit, 10-25cm long, leaf scars 3, distinct, usually horse-shoe shaped vascular bundles
7	Rhizophoraceae	<i>Ceriops decandra</i> (Griff.) Ding Hou.	Pneumatophores curiously shaped, feeding roots, cable roots and anchoring roots present, stem flanged or buttressed with short plate like protruberances. Petals divided into fringe like lobes. Fruits with spreading calyx lobes. Hypocotyl club shaped, angular to 30 cm long.
8	Rhizophoraceae	<i>Kandelia candel</i> (L.) Druce.	Pneumatophores absent, tree bushy form with aerial roots in close assembly from stem and branches, white flowers in axillary pendunculate, dichotomously branched cymes. Fruit 1 celled, 1 seeded grit with the persistent reflexed calyx lobes. Propagule viviparous, bark reddish brown
9	Rhizophoraceae	<i>Rhizophora apiculata</i> BL.	Pneumatophores absent, multiple leaf scar, Branching stilt roots, cyme with 2 sessile, flowers on thick peduncles under leaf or the leaf with or without black dot, Fruits like an inverted pear, hypocotyl curved at the apex
10	Rhizophoraceae	<i>Rhizophora mucronata</i> Poir.	Pneumatophores absent, multiple leaf scar, leaves ending with apiculum. Branching stilt roots, Flowers in recurved stalk, style is absent or very short
11	Sonneratiaceae	<i>Sonneratia alba</i> J. Smith	Pneumatophores present, feeding roots, cable roots and anchoring roots present, stipules absent in leaf, branches swollen at nodes, readily breaking. Flowers large 6-8 oblong sepal lobes. Stamens numerous, long
12	Sonneratiaceae	<i>Sonneratia caseolaris</i> (L.) Engl.	Pneumatophores present, feeding roots, cable roots and anchoring roots present, leaves have at the tip hydathodes, Flakey bark, brownish in colour
13	Verbenaceae	<i>Avicennia alba</i> Bl.	Pneumatophores 15-20 cm long, tree height 10m-15m, bark grey, leaf dark green or black shining

			above, flower 3-6 mm, yellow, fragrant, arranged in axillary or terminal spikes, peduncle 2.5-3.5cm long branched. Fruits compressed capsule ovoid or ellipsoid slightly curved at the apex. Seed solitary.
14	Verbenaceae	<i>Avicennia marina</i> (Forsk.) Vierh.	Pencil like pneumatophores feeding roots, cable roots and anchoring roots present, Gnarled spreading tree, leaves grey dense hairy on abaxial surface. Fruit velvety like, an unopened almond in shape, not acuminate or beaked at the tip.
15	Verbenaceae	<i>Avicennia officinalis</i> L.	Pneumatophores plenty tree height 8m. salt excreting glands on leaf. Flower 1cm long, fruit green almond shaped

Conclusion

Along Karnataka Coast it was observed that mangroves prefer silty and clayey soils or mixtures of these soils. Monsoon brings with it large amount of clay, silt and sand from upstream catchment areas especially due to the present rapid land use changes. Hence, when the tide dominates during reduced runoff the sand gets deposited naturally. Climate change impacts, receding shoreline and rapid change in land use plan are some of the factors influencing the water and soil quality and thereby impacting the diversity of mangroves in the estuaries of Karnataka. In connection with this sensitizing the administrators as well as the local population regarding the uses of mangroves is very essential. CMFRI has also conducted awareness campaign (Fig.4), but much more needs to be done especially by assessing the sources of pollution and thereby understanding the species wise factors which aid in sustaining the diversity of the region.

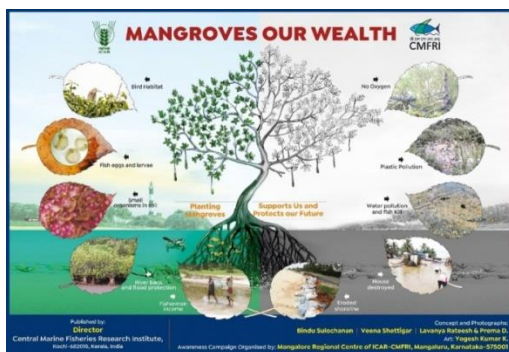


Fig.4 Awareness poster on mangroves protection and conservation

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Marine Mammal Diversity in Indian Waters

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Marine mammals are aquatic vertebrates within the class mammalia, characterized by being warm-blooded, breathing air through lungs, utilizing fins and flippers for locomotion, and producing milk to nurture their offspring. They are into four taxonomic groups: **cetaceans** (whales, dolphins, and porpoises), **sirenians** (manatees and dugong), **pinnipeds** (walrus, seals and sea lions), and **fissipeds** (polar bear and sea otters). While cetaceans and sirenians remain exclusively in water throughout their lives, other marine mammals may come ashore intermittently for various reasons during specific stages of their life cycle¹.

Marine mammals play a vital role as keystone species within the marine ecosystem, and the decline in their population can trigger a ripple effect throughout the food web, ultimately impacting human communities. With their widespread distribution, large body size, and predatory behaviour, marine mammals significantly shape marine food webs and influence the structure and functioning of marine ecosystems. These organisms inhabit a diverse range of environments including tropical, subtropical, temperate, and polar oceans and seas, as well as estuaries and the connected seas of major rivers worldwide. Notably, marine mammals exert considerable influence on the behaviour and life history characteristics of both prey species and predators, contribute to nutrient storage and recycling, and modify habitats within their ecosystems.

In recent years, marine mammals have encountered various threats to their survival.

These include accidental fatalities among coastal populations caused by becoming entangled in fishing gear, colliding with powered vessels, and becoming trapped in water regulation devices. Additionally, pollution, ocean acidification, infectious diseases, harmful algal blooms, disturbances from seismic activities and ocean warming poses significant stressors to these organisms⁴.

Conservation and sustainable management of marine mammals is crucial for maintaining and restoring their distribution, abundance, and diversity, thereby ensuring a healthy ocean. Taxonomy serves as a fundamental tool in this endeavor, as it helps identify the units of conservation based on population structure and, ultimately, species designation. By understanding the taxonomy of marine mammals, conservation efforts can be better targeted towards protecting specific populations and species, ultimately contributing to the overall health of the oceanic environment.

Marine mammals comprises 21 families (with 8 being monotypic) and a total of 135 recognised species worldwide, organised into four taxonomic groups: cetaceans (such as whales, dolphins, and porpoises), sirenians (including manatees and dugongs), pinnipeds (encompassing seals, sea lions, and walruses), and marine fissipeds (consisting of polar bears and sea otters). According to the International Union for Conservation of Nature (IUCN), 25% of these species are classified as threatened. Without proper management and conservation measures, many of these species are at risk of extinction (IUCN, 2009).

Marine mammal diversity of the world

Order	Infraorder	Parvorder	Family	No. of Species
Carnivora (38)	Arctoidea (3)	Ursida	Ursidae	1
		Mustelida	Mustelidae	2
	Pinnipedia (35)		Otariidae	15
			Odobenidae	1
			Phocidae	19
Artiodactyla (92)	Cetacea (92)	Mysticeti (15)	Balaenidae	4
			Neobalaenidae	1
			Eschrichtiidae	1
			Balaenopteridae	9
		Odontoceti (77)	Physeteridae	1
			Kogiidae	2
			Ziphiidae	23
			Platanistidae	2
			Iniidae	1
			Lipotidae	1
			Pontoporiidae	1
			Monodontidae	2
			Delphinidae	37
			Phocoenidae	7
Sirenia (5)			Trichechidae	3
			Dugongidae	2
Total				135

Marine mammal diversity of India

In the Indian seas, marine mammals consist of cetaceans and sirenians, totaling 28 species. This accounts for nearly 25 percent of the world's marine mammals and approximately 8 percent of all mammalian fauna documented in India. Among these, the sirenina group is represented solely by the species *Dugong dugon*. All the marine mammal species in India are listed under

Schedule I of the Wildlife (Protection) Act of 1972.

Taxonomy of marine mammals

The identification of marine mammals involve various methods, including morphology-based classical taxonomy, acoustic detection through

comparison of sound frequencies, and modern techniques such as molecular identification. Molecular methods utilize DNA barcoding (such as COI and 16s rRNA), mass spectrometry (specifically collagen peptide mass fingerprinting), and environmental DNA (eDNA) analysis using droplet digital PCR. Next-Generation Sequencing (NGS) is frequently employed to study present cetacean populations, enabling the recovery of full mitochondrial genomes, genomic Single Nucleotide Polymorphisms (SNPs), and even complete nuclear genomes. This aids in developing more sophisticated models of evolutionary systematics and population histories. Current molecular research on cetaceans globally encompasses various areas, including DNA barcoding, eDNA analysis, whole genome sequencing⁷, mitogenomics, and molecular identification of market samples. However, despite the success of molecular approaches in identifying marine animals, they are often costly, and obtaining fresh tissue samples can be challenging. As a result, researchers commonly rely on morphology-based visual identification methods.

Marine mammal specimens can be identified using various morphological characteristics, such as the body shape, body colour, colouration pattern, head shape, flipper shape, dorsal fin's shape and position, caudal fluke's shape, the ratio of the outer margin of the flipper to the total body length, throat grooves' extent, teeth count and blow hole position. In visual surveys, the blow pattern is a crucial feature for species identification. Photographs of dorsal fins and flukes aid in the identification of individual cetaceans through a technique known as photo-identification. This method is practically useful for studying pod size, structure, and species composition. Conducting repeated photo-sessions from the geographical location over an extended period helps monitor resident and migratory populations, as well as reproductive success. Identifying species at sea presents unique challenges compared to those on land. Even under ideal conditions, observers often have brief sightings of a splash, blow, dorsal fin, head, flipper, or back, often from a considerable distance¹.

Order: Artiodactyla

Infraorder: Cetacea

- All cetaceans possess a similar streamlined body structure
- The blow hole, consisting of one nostril in odontoceti and two in mysticeti, is located

on the top of the head

- Propulsion is achieved through the up and down movement of tail, which ends with a flattened paddle like cartilaginous fluke
- Telescoping in skull refers to a restructuring process that pushes the nasal passages posteriorly in the cetacean skull¹⁵
- They have a well-developed blubber layer that envelops their bodies.
- Unique boneless structures, such as tail flukes and dorsal fins or ridges, have evolved in cetaceans.

Parvorder: Mysticeti (baleen whales)

- This group includes the largest animal on the planet. Antarctic blue whale, weighing up to 181 tonnes (equivalent to approximately 33 elephants) and reaching lengths of up to 98 feet
- Paired nostrils or blowholes are longitudinal slits located at the top of the cranium, resulting in a V-shaped blow
- the wing like movement of their flipper helps in the propelling the body
- Presence of baleen (keratinaceous baleen plates (or "whalebone")) instead of teeth in their mouths, used to filter planktonic organisms from the water
- The family Balaenopteridae represents Indian baleen whales

Key characteristics for whale identification

- Shape of head
- Dorsal fin characteristics (shape and position)
- Body coloration and patterns
- Colour of baleen plates
- Number of ventral (throat) grooves
- Flipper length and shape
- Ratio of girth to length
- Ratio of head length to body length

Family: Balaenopteridae

- Members of this family, commonly known as rorquals, include the largest animals to ever exist.
- In Indian waters, the Balaenopteridae family encompasses 6 species distributed across 2 genera: Balaenoptera and Megaptera.
- With the exception of the humpback whale, other members possess a streamlined body adorned with long pleats extending from the snout tip to as far back as the navel on the ventral

surface.

- Lunge feeding is an intense, rapid, and active feeding technique. Their anatomical structure enables them to accelerate to high speeds before opening their jaws wide and expanding their throats to engulf large quantities of water during feeding.
- The baleen plates of Balaenopteridae species are moderately sized and possess fine fringes. Variations in density, fringe diameter, plate number, and width-to-length ratio serve as diagnostic characteristics among species.
- Dorsal fins are positioned behind the midpoint of the back, typically at around $2/3^{\text{rd}}$ to $3/4^{\text{th}}$ of the total body length.
- Pleated throat grooves are distinctive features that differentiate Balaenopteridae species from other whales.

***Balaenoptera musculus* (Linnaeus, 1758)** Blue whale



- Dorsal fin: Very small, approximately 1% of body length, positioned at $3/4$ of total length.
- Baleen plates: Each side contains 260 to 400 black baleen plates with black bristles, with all three sides of each plate roughly equal in length.
- Body color: Bluish or light grey body color with grey patches on the dorsal surface.
- Ventral grooves: 60-80 ventral grooves extending near to the navel.
- Maximum body length: 33 meters.
- Adult sizes: Most adults measure between 23 to 27 meters, while newborns measure about 7-8 meters.
- IUCN status: Endangered.

***Balaenoptera physalus* (Linnaeus, 1758)** Fin whale



- Head shape: V-shaped from above, pointed at the tip.
- Mouth ridges: A ridge on the upper side of the mouth and another prominent ridge between the dorsal fin and fluke.
- Baleen plates: 260 to 480 grey baleen plates with white streaks on the side.
- Coloration: Asymmetrical head coloration (left side grey, much of right side white); back is dark with light streaks; belly is white.
- Dorsal fin: Tall and falcate (curved), positioned farther forward on the caudal peduncle.
- Ventral grooves: 50-100 ventral grooves extending up to the navel.
- Maximum size: Adults reach a maximum size of 27 meters in the southern hemisphere and 24 meters in the northern hemisphere.
- IUCN status: Vulnerable.

***Balaenoptera borealis* Lesson, 1828** Sei whale



- Rostrum: Pointed, snout slightly down, and turned at the tip.
- Pectoral fins: Relatively short, comprising only 9%–10% of body length, and pointed at the tips.
- Ventral pleats: 32 to 60 in number, with the longest extending past the flippers but well short of the navel.
- Baleen plates: 300 to 380 pairs of black baleen plates with many whitish bristles, each less than 80 cm long.
- Flippers: All dark in color.
- Median ridge: A single median ridge present.
- Maximum body length: 19.5 meters.

IUCN status: Endangered.

Balaenoptera edeni Anderson, 1878 Bryde's whale



- Head shape: Pointed with three prominent ridges on the dorsal side of the rostrum.
- Ventral pleats: 40 to 70 ventral pleats extending to the umbilicus.
- Baleen plates: 250 to 370 slate-grey baleen plates per side, with white to light grey fringes.
- Head coloration: Symmetrical.
- Dorsal fin: Tall and well-falcate (curved).
- Body coloration: Dark gray on the dorsal profile and light ventrally. The tip of the lower jaw is dark.
- Maximum body length: 14 meters.
- IUCN status: Least Concern.

Balaenoptera acutorostrata Lacepede, 1804
Common Minke whale



- Head shape: Sharply pointed and V-shaped with a prominent ridge on the upper rostrum.
- Dorsal fin: Tall and falcate, located at two-thirds of the body length.
- Body coloration: Dark grey with shades on the lateral side of the body.
- Throat grooves: 50-70 throat grooves extending just past the flippers.
- Baleen plates: 231 to 360 cream-colored baleen plates with coarse bristles per side, less than 21 cm long. They are mostly white or yellowish-white, sometimes with a dark margin along the outer edge. Often, conspicuous white bands are present on the upper surface of the flippers.
- Maximum body length: 9 meters.
- IUCN status: Least Concern.

Megaptera novaeangliae (Browski, 1781)
Humpback whale



- Body shape: Robust and stocky.
- Head features: Covered with knobs, with a prominent cluster of knobs at the tip of the lower jaw. Prominent tubercles near the lips and chin.
- Flippers: Elongated, comprising one-fourth to one-third of the body length, with knobs on the leading edge.
- Dorsal fin: Small and usually located at the top of an obvious hump.
- Coloration: Black and dark grey.
- Ventral grooves: 14-35 ventral grooves extending beyond the navel.
- Baleen plates: 270 to 400 black to olive-brown baleen plates with grey bristles per side, each less than 80 cm long.
- Flukes: With irregular trailing edges.
- Maximum body length: 16 meters.
- IUCN status: Least Concern.

Parvorder: Odontoceti (Toothed whales)

- Represented by 6 families in India.
- Generally small to medium-sized cetaceans, except for sperm whales, with males capable of growing at least 18 meters in length.
- Presence of teeth throughout life.
- Single blow hole.
 - An asymmetrical skull with
 - Concave profile
 - Sternum with 3 or more parts
 - Complex system of nasal sacs
 - Fatty organ in the forehead area called the melon
- Capable of echolocation to
 - Navigate
 - Find food
 - Avoid predators

Family: Physeteridae (sperm whales)

- The sperm whales are the largest toothed cetacean.

- There is a low dorsal hump, followed by a series of crenulations.
- Has a large head with a squarish profile, a narrow underslung lower jaw, and functional teeth only in the lower jaw (which fit into sockets in the upper jaw).
- Caudal flukes are triangular and very thick.
- Blowhole located at the left front of the head.
- Head is divided into sections called the “junk” and the spermaceti organ or “case”.
- Spermaceti organ: A large oil-filled reservoir located within the head.
- Capable of very deep and long dives.

***Physeter macrocephalus* (Linnaeus, 1758) Sperm whale**



- Head: Squarish and large, comprising 20 to 30% of the body length.
- Lower jaw: Narrow.
- Flippers: Short and broad.
- Dorsal hump: Small, thick, and round, followed by a series of crenulations along the midline.
- Teeth: 18-26 pairs of teeth present only in the lower jaw, fitting into sockets in the upper jaw.
- Body coloration: Black to charcoal grey, with white lips and inside of the mouth.
- Throat grooves: 2-10 short throat grooves present.
- Blowhole: S-shaped blowhole located at the left side of the front of the head.
- Maximum size: 18 meters.
- IUCN status: Vulnerable.

Family: Kogiidae

- Blunt squarish head not exceeding 15% of the body length, with a very short rostrum.
- Blowhole is not located at the front of the head.

- Dorsal fin is larger than the sperm whale.
- 8 to 16 long, thin, and sharply pointed homodont teeth in each side of lower jaw, fitting into sockets in the upper jaw.
- Similar to sperm whales, Kogiidae also possess spermaceti in their head.
- Body size is typically less than 4 m.

***Kogia breviceps* (Blainville, 1838) Pygmy sperm whale**



- Lower jaw: Tiny underslung lower jaw.
- Head: Small and squarish.
- Dorsal hump: A hump on the dorsal side between the blowhole and dorsal fin.
- Dorsal fin: Well-curved and set behind the midpoint of the body.
- Flipper: Set near to the head.
- Throat creases: Generally absent; dorsal fin is short (< 5% of body length).
- Snout to blowhole distance: Greater than 10.3% of the total length.
- Teeth: 12 to 16 (rarely 10 to 11) sharp fang-like teeth in each half of the lower jaw.
- Maximum body length: 3.5 meters.
- IUCN status: Least Concern.

***Kogia sima* Owen, 1866 Dwarf sperm whale**



- Lower jaw: Tiny underslung lower jaw.
- Head: Triangular or squarish.
- Dorsal hump: No hump on the dorsal side between the blowhole and dorsal fin.
- Dorsal fin: Tall and slightly falcate.
- Throat grooves: A pair of short throat grooves.
- Flipper: Small with a blunt tip, positioned near the head.

- Teeth: Sharp fang-like 7-12 pairs of teeth present on the lower jaw.
- Snout to blowhole distance: Greater than 10.2% of the total length.
- Maximum body length: 2.7 meters.
- IUCN status: Least Concern.

Family: Ziphiidae

- Beaked whales are medium size cetaceans (4 to 13 m length).
- Have a pronounced beak in general.
- Relatively small dorsal fin set far back on the body.
- Small flippers that fit into depressions on the sides.
- A pair of converging grooves under the throat, with the notch is absent in the tail fluke.
- Not more than 1 or 2 pairs of exposed teeth in the lower jaw, found in males only.
- The blubber of these whales is predominantly composed of wax ester, which is a unique characteristic of this family.

Indopacetus pacificus Longman's beaked whale



- Body: Large and robust.
- Head: Bulging foreheads and moderate tube beaks.
- Teeth: Beak with a single pair of oval teeth at the tip of the lower jaw.
- Dorsal fin: Large and falcate, located behind the midpoint of the body.
- Flukes: Broad with straight trailing edges.
- Flippers: Small and blunt.
- Throat grooves: A pair of V-shaped grooves on the throat.
- Coloration: Umber brown to bluish.
- Maximum size: 6 meters.
- IUCN status: Least Concern.

Ziphius cavirostriscuvier, Cuvier 1823 -Cuvier's beaked whale



- Body: Slender and relatively robust compared to other beaked whales.
- Head: Short relative to body size, with a poorly distinct beak.
- Forehead: Smoothly sloping, slightly concave in front of the blowhole.
- Coloration: Light rusty brown with a lighter area around the head.
- Mouth: Mouth line gently slopes upwards.
- Flippers: Small and rounded.
- Throat grooves: Single paired V-shaped throat grooves.
- Dorsal fin: Small falcate dorsal fin set near to the hind end of the body.
- Teeth: A single pair of teeth directed forward and upward at the tip of the lower jaw, exposed only in adult males.
- Maximum body length: 6 meters.
- IUCN status: Least Concern.

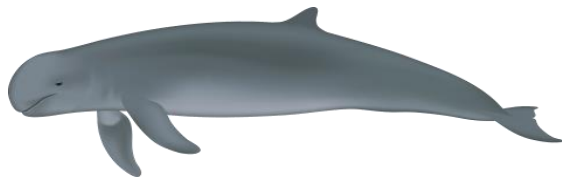
Key characteristics for identification of dolphins

- Shape and location of dorsal fin.
- Shape of flipper.
- Shape of head.
- Colour and pattern of body.
- Teeth count.

Family: Delphinidae

- Delphinids range in size from 1 to 10 meters. Many small to medium sized odontocetes of various forms have been lumped together in this group, and so the family has been referred to as "taxonomic trash basket".
- Most delphinids share the following characteristics
 - Inhabit marine environments.
 - Typically have a noticeable beak.
 - Conical teeth.
 - A large falcate dorsal fin, which is set near the middle of the back.

Orcaella brevirostris (Gray, 1866) Irrawaddy dolphin



- Body: Moderately robust.
- Head: Blunt and bulbous with no beak and a straight mouthline.
- Dorsal groove: Present between the neck and the falcate dorsal fin.
- Dorsal fin: Set just behind the midpoint of the body.
- Neck: Indistinct neck crease.
- Blowhole: U-shaped and open towards the front.
- Coloration: Gray on the dorsal and lateral sides with a white belly.
- Teeth: 8 to 19 pairs present in the upper jaw and 11-18 in the lower jaw.
- Maximum size: 2.4 meters.
- IUCN status: Endangered.

***Orcinus orca* (Linnaeus, 1758) - Killer whale**



- Body: Robust and spindle-shaped.
- Dorsal fin (Male): Very tall and straight, often erect or triangular.
- Dorsal fin (Female): Slightly shorter and falcate, with a pointed or round tip.
- Eye patches: White oval-shaped patches behind the eyes.
- Saddle patch: A light gray saddle patch behind the dorsal fin.
- Flipper: Large and oval-shaped with blunt tips.
- Coloration: Peculiar black and white coloration, including post-ocular patches, a white lower jaw, white ventrolateral field, and a light gray saddle patch behind the dorsal fin.
- Teeth: 10 to 14 pairs of large oval teeth in each jaw.
- Maximum body length: 8 meters.
- IUCN status: Data Deficient.

***Pseudorca crassidens* (Owen, 1846) False killer whale**



- Body: Long, slender, and cigar-shaped.
- Head: Rounded and overhanging melon with no discernible beak.
- Dorsal fin: Moderate height with a rounded tip.
- Flipper: Slightly curved with a distinct hump on the leading edge located near the midpoint of the back.
- Coloration: Predominantly dark grey or black.
- Teeth: 7 to 12 pairs of large teeth in each half of both jaws.
- Maximum body length: 6 meters.
- IUCN status: Near Threatened.

***Peponocephala electra* (Gray, 1846) Melon headed whale**



- Body: Moderately robust.
- Head: Triangular and sharply pointed bulbous.
- Beak: Extremely short and indistinct, may be present in younger animals.
- Cape: Faint cape that dips low below the tall and falcates dorsal fin.
- Lower jaw: Lip of the lower jaw is white.
- Coloration: Body is charcoal gray to black with a white urogenital patch.
- Teeth: 20-25 pairs of teeth per side of each jaw.
- Flippers: Sickle-shaped with sharply pointed tips.
- Maximum body length: 2.75 meters.
- IUCN status: Least Concern.

***Feresa attenuata* (J. E. Gray, 1874) Pygmy killer whale**



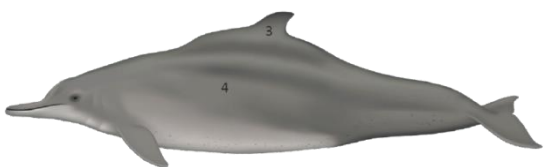
- Head: Short and rounded.
- Body coloration: Dark gray to black on the cape with a sharp change to lighter gray on the sides.
- White patches: White patches on the belly and lips of the jaw white.
- Dorsal fin: Rounded-tipped.
- Teeth: Higher teeth count, with approximately 48 teeth, consisting of 22 on the upper jaw and 26 on the lower jaw.
- IUCN status: Least Concern.

***Sousa chinensis* (Osbeck, 1765)** Indo-Pacific humpback dolphin



- Body: Robust, typically grey with bluish, cream, or pink tinge, and a light belly.
- Beak: Long and well-defined, with no distinct crease.
- Dorsal fin: Small and wide, based on a mid-dorsal hump.
- Dorsal ridge: Absent.
- Color change: Light-colored calves become grey or brown as adults.
- Teeth: 31-39 pairs in the upper jaw and 29-38 pairs in the lower jaw.
- Maximum size: Up to 2.5 meters.
- IUCN status: Vulnerable.

***Sousa plumbea* (G. Cuvier, 1829)** Indian Ocean humpback dolphin

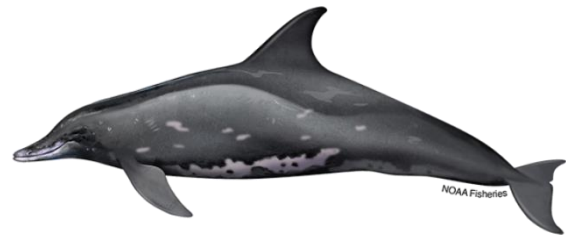


- Body: Robust.
- Beak: Long and well-defined.
- Dorsal fin: Small, sits on a dorsal

hump.

- Color: Brown/grey, sometimes with white/pink on the dorsal fin.
- Teeth: Upper jaw has 33-39 teeth in each tooth row, while the lower jaw has 31-37 teeth.
- Maximum size: Up to 2.8 meters.
- IUCN status: Endangered.

***Steno bredanensis* (Lesson, 1828)** Rough toothed dolphin



- Body: Robust, dark grey to black above and white below, with many scratches and spots.
- Head: Long and conical.
- Beak: Long, with no distinct crease between the melon and the beak.
- Cape: Dark grey cape below the slightly falcate dorsal fin.
- Coloration: Belly, lips, and lower part are white with spots.
- Flippers: Very large and set farther back.
- Teeth: 19 to 28 slightly wrinkled teeth in each half of both jaws.
- Maximum body length: 2.5 meters.
- IUCN status: Least Concern.

***Grampus griseus* (Cuvier, 1812)** Risso's dolphin



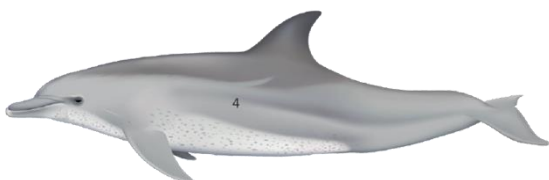
- Body: Robust.
- Head: Blunt head with no beak and a vertical crease on the front of the melon.
- Dorsal fin: Very tall, slender, and dark, falcate with a pointed tip.
- Mouthline: Slopes upwards.
- Teeth: 2 to 7 pairs of teeth at the front of the lower jaw only, with 1 to 2 pairs in the upper jaw. Teeth may be absent or extensively worn.
- Coloration: Body is grey to white, covered with scratches and splotches in adults, while young ones are relatively unmarked.
- Flippers: Long, pointed; sickle-shaped.
- Maximum body length: 3.8 meters.
- IUCN status: Least Concern.

***Globicephala macrorhynchus* Gray, 1846** Short-finned pilot whale



- Head: Bulbous and round, with sloping mouth lines and a short or no prominent beak.
- Flipper: Long and sickle-shaped.
- Teeth: 7 to 9 pairs of short, sharply pointed teeth present.
- Dorsal fin: Round and broad-based, situated near the fore end of the body.
- Coloration: Black in color with a white cape below the dorsal fin.
- Size: Adults grow up to 5 meters
- IUCN status: Least Concern.

***Tursiops aduncus* (Ehrenberg, 1833)** Indo-Pacific bottlenose dolphin



- Body: Moderately robust.
- Beak: Short, set off by a distinct crease.
- Dorsal fin: Tall, slightly falcate, and broader.

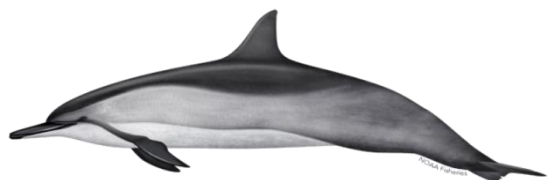
- Coloration: Gray body with a white belly. Prominent black spots or flecks on bellies.
- Teeth: 20 to 26 teeth in each half of the upper jaw, and 18 to 24 in the lower jaw.
- Maximum body length: Up to 2.7 meters.
- IUCN status: Near Threatened.

***Stenella attenuata* (Gray, 1846)** Pantropical spotted dolphin



- Body: Fairly slender.
- Beak: Long and slender, with a white tip separated from the melon by a distinct crease.
- Flipper: Slender and strongly curved.
- Stripe: Dark stripe from gape to flipper.
- Dorsal fin: Narrowly curved falcate dorsal fin with a pointed tip.
- Coloration: Body heavily spotted, with a dark grey band between the eye and the apex of the melon. Adults may have light to extensive spotting and grey bellies, with spotting sometimes absent.
- Teeth: 34 to 48 teeth in each jaw.
- Maximum size: 2.1 meters.
- IUCN status: Least Concern.

***Stenella longirostris* (Gray, 1828)** Spinner dolphin



- Body: Slender.
- Beak: Long and slender, with a black tip.

- Dorsal fin: Erect and triangular or slightly falcate, located in the mid-body region.
- Coloration: Dark grey cape followed by light grey sides and a white belly.
- Stripe: Dark strip present between the eye and the origin of the flipper.
- Teeth: 40 to 62 very fine, sharply pointed teeth per tooth row.
- Maximum size: 1.8 meters.
- IUCN status: Least Concern.

- Beak: Deep crease present between beak and melon.
- Dorsal fin: Tall and slightly falcate, with a distinctive V shape present below.
- Stripe: Extends from chin to origin of flipper.
- Flipper: Recurved and pointed at tips.
- Coloration: Dark back and white belly. Tan to buff thoracic patch and light grey streaked tail stock from an hourglass pattern that crosses below dorsal fin.
- Teeth: 47 to 67 sharp and pointed teeth in each jaw; palate with two deep longitudinal grooves.
- Maximum size: 2.4 meters.
- IUCN status: Data Deficient.

***Stenella coeruleoalba* (Meyan, 1833)** Striped dolphin



- Snout: Moderate, black in color.
- Beak: Moderate length, with a distinct crease between the melon and beak.
- Stripes: Prominent dark stripes from the eye to the anus and from the eye to the flipper.
- Coloration: Black to dark grey on the back, white on the belly. Light grey spinal blaze extending to below the dorsal fin (not always present).
- Palatal grooves: Shallow palatal grooves are often present.
- Teeth: 40 to 50 pairs of slender and pointed teeth present in each jaw.
- Maximum size: 2.4 meters.
- IUCN status: Least Concern.

***Delphinus capensis* (Gray, 1828)** Long-beaked common dolphin



- Rostrum: Elongated.

Family: Platanistidae

- Includes the extant susu and the bhulan of the Ganges and Indus rivers, respectively.
- Long forceps like beak, with front teeth that extend outside the closed mouth.
- Blowhole is a longitudinal slit.
- Instead of a true dorsal fin a short dorsal ridge is present.

***Platanista gangetica* (Roxburgh, 1801)** Ganges River dolphin



- National aquatic animal.
- Body: Tan, chocolate brown, or light blue, with a lighter or pinkish belly.
- Blowhole: Slit-like, single blowhole.
- Beak: Long, with sharp and pointed teeth protruding outside the closed mouth at the front half.
- Teeth: 26 to 39 teeth in each row.
- Dorsal fin: Rectangular, ridge-like.
- Maximum size: Up to 2.5 meters.
- IUCN status: Endangered.

Family: Phocoenidae

- They are small cetaceans generally coastal in distribution with no prominent beak.
- Streamlined body and two limbs that are modified into flippers.
- Spade-shaped teeth distinguished from the conical teeth of dolphins.

- The Dorsal fin is either short and triangular or absent.
- These exhibit sexual dimorphism where the females are larger than males.

***Neophocaena phocaenoides* (Cuvier, 1829)** Finless porpoise



- Forehead: Round and rises steeply from the snout tip, devoid of a beak.
- Dorsal Fin: True dorsal fin is absent, replaced by a narrow dorsal ridge covered in thick skin bearing several lines of tiny tubercles.
- Bumps: Tiny bumps on the dorsal side behind the forehead.
- Body Color: Grey or black, with a lighter belly.
- Teeth: 15 to 22 teeth present in each jaw.
- Flipper: Large, with rounded tips.
- Fluke: Fluke with a concave trailing edge.
- Maximum Size: 1.7 meters.
- IUCN Status: Vulnerable.

Order: Sirenia

- These are herbivorous groups of marine mammals.
- Robust fusiform body with tough and thick skin bearing short hair.
- They have heavy bones that act as ballast to counteract the buoyancy of their blubber.
- 2 nostrils present on top or at the front of a thick muzzle.
- External ear pinnae are absent.
- Forelimbs modified as flippers and hind limbs are absent.
- Horizontally flattened tail; and dense and swollen bones.

Family: Dugongidae

- There is only one extant species in the family.
- Flattened tail is broadened into flukes which are similar to cetaceans.
- Rostrum is deflected downwards, with the presence of erupted tusks in males.
- Absence of nails on the flippers.

***Dugong dugon* (Muller, 1776)**

Sea cow or dugong



- Habitat: Found in the Indo-Pacific region.
- Body Shape: Streamlined body shape resembling cetaceans.
- Nostrils: Valve-like nostrils on top of the snout.
- Teeth: Incisors present in the form of tusks.
- Head: Muzzle deflected downward, ending in a "rostral disk" with short and dense bristles.
- Dorsal Fin: Absent.
- Skin: Smooth skin sprinkled with short hairs.
- Flippers: Paddle-shaped flippers containing no nails.
- Tail: Split into flukes, with a median notch; tail stock laterally compressed into a peduncle.
- Maximum Size: 3.3 meters.

IUCN Status: Vulnerable.

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Plastics are materials that consist of varieties of synthetic or semi-synthetic organic compounds. They are malleable and can be moulded into solid objects of various shapes and sizes. Currently, plastics have become indispensable materials used in many sectors of our day-to-day life, like automotive, agriculture, health, construction/building, packaging, and textiles (Plastics Europe, 2017). Most meet only single-use needs; hence, a substantial proportion comprises 54% of the global mass of anthropogenic waste is constituted by plastic (Hoellein et al., 2014). The convenience offered by these materials comes at a significant cost to the environment.

Polymer is the major ingredient in plastic. Among the varieties, the marine litter is dominated by polypropylene (PP), polyethene (PE), polyvinyl chloride (PVC), polyurethane (PUR), poly terephthalate (PET), and polystyrene (PS), which together comprise approximately 80 per cent of total plastics production (PlasticsEurope 2017). Usually, the discarded plastics, whether in the form of single-use items or larger debris, find their way into water bodies, where they persist and degrade into microplastics over time. This process is accelerated by environmental factors such as sunlight, waves, and microbial action, releasing tiny particles that permeate oceans and waterways.

About 5.25 trillion pieces of plastic debris have been estimated in the ocean and about 2,69,000 tons float on the surface waters (Nammalwar, 2020). The first reports of plastic litter in the oceans are in the early 1970s (Coe and Rogers, 1996). Collected plastic waste is disposed of in landfills or incinerated to generate electricity in many countries. The widespread use of plastic materials and inadequate waste management practices have led to the pervasive contamination of marine ecosystems. Plastic pollution directly threatens marine life and presents potential risks to human health through the food chain. Thus, plastic is considered the latest threat to the sustainable health of the ocean and its inhabitants and, indirectly, the livelihood of dependent mankind.

Sources of plastic pollution in the sea

The major portion of marine plastic litter is terrestrial in origin, like riverine discharge or from coastal effluents. In contrast, only a minor contribution is from marine sources like discharges from shipping and fishing activities (~25% of the total terrestrial discharge) (Li, et al., 2016). Aquatic ecosystems are interconnected with the terrestrial environment; therefore, changes in one system impact another (Lebreton et al., 2017). Thus, the perception of the sources of plastic and microplastic pollution in the sea is crucial for developing effective strategies to mitigate their impact on marine life and ecosystems.

Primary Sources of Plastic Pollution in the sea:

1. Single-Use Plastics:

Single-use plastics, such as bags, bottles, and packaging, contribute significantly to marine pollution. These items are designed for short-term use but remain in the environment for many more years. Improper disposal and inadequate waste management systems allow these plastics to enter rivers and oceans.

2. Fishing Gear:

Deserted, lost, or thrown away fishing gear, commonly known as ghost nets, poses a severe threat to marine life. These nets, made of durable synthetic materials, continue to trap and entangle marine organisms, leading to injury or death. The breakdown of these materials also contributes to the microplastic load in the ocean.

3. Industrial Discharges:

Industrial processes release large amounts of plastic particles into water bodies. Plastic pellets, also known as nurdles, are the primary material used in the manufacturing of plastic items. Accidental spills and inadequate containment during transportation lead to the release of these pellets into rivers and oceans.

4. Stormwater Runoff:

Urban areas with impermeable surfaces contribute to plastic pollution through stormwater runoff. Rainwater washes plastics

from streets, sidewalks, and other surfaces into storm drains, ultimately reaching rivers and oceans. This source could be more problematic in densely populated coastal regions.



Plastic debris in the surface waters of Andaman and Nicobar Island

Microplastic Sources:

1. Fragmentation of Larger Plastics:

Mechanical and environmental forces, such as sunlight and wave action, break down larger plastic items into smaller fragments. These microplastics can be less than five millimeters in size and are often invisible to the naked eye. The process of degradation can take years, if not decades, depending on the type of plastic.

2. Synthetic Fibers:

The washing of synthetic textiles, such as polyester and nylon, releases microplastic fibers into wastewater. These fibers enter water bodies through sewage systems and ultimately contribute to the microplastic burden in oceans. The ubiquity of synthetic fibers in clothing exacerbates this issue.

3. Cosmetics and Personal Care Products:

Microbeads, minute plastic particles used in cosmetics and beauty-related products, pose a direct threat to marine life. When these products are washed off, the microbeads enter water systems and, eventually, the oceans. Many countries have implemented bans on the use of microbeads in makeup to address this issue.

4. Plastic Pellet Spills:

Accidental spills of plastic pellets during transportation and manufacturing contribute to the presence of microplastics in the sea. These small, pre-production pellets can absorb

pollutants from the surrounding environment and harm marine organisms upon ingestion.

Impact of plastic pollution in marine life:

Plastic impacts the ocean and its inhabitants both directly and indirectly. Direct effects are due to ingestion or entanglement in litter and fishing gear. Indirect effects include the evading of invasive species and pathogens with floating plastics, impacts on biodiversity, and loss of ecosystem services (GESAMP 2015).

Impact on Marine Life:

To date, nearly 700 marine species have been observed interacting with marine debris (Gall & Thompson 2015), with ingestion and entanglement being the two primary forms of interaction. The consequences of plastic pollution on marine life are profound and multifaceted. Ingestion of plastic is a pervasive issue, as marine species mistake plastic particles for food.

1. Ingestion:

This ingestion can lead to internal injuries, blockages, malnutrition, and, ultimately, death. This has detrimental effects on their health, disrupting ecosystems and jeopardizing biodiversity (Savoca et al., 2017).

2. Entanglement:

Abandoned fishing gear lead to a significant entanglement risk to sea life. Whales, dolphins, sea turtles, and seabirds can become ensnared in nets and lines, causing injuries, hindering movement, and often leading to death (Tschernij and Larsson, 2003).

3. Chemical contaminations:

Plastics can absorb and concentrate harmful chemicals from the surrounding environment. The toxic chemicals present in plastic materials can also contaminate the tissues of marine organisms, introducing harmful substances into the food web. When ingested, these chemicals may disrupt endocrine systems, impair reproductive health, and accumulate through the food chain, ultimately impacting human health (Hermabessiere et al. 2017).

Microplastics Impacts:

Microplastics particles permeate the marine environments, from surface waters to ocean

sediments. These microplastics are ingested by a variety of marine organisms, including plankton, filter-feeders, and bottom-dwelling species. This ingestion not only poses direct physical harm but also introduces plastic-associated toxins into the organisms, with potential implications for human health through the seafood chain (Ristetal.2018).

Ecosystem-Level Consequences

The impact of plastic and microplastic pollution extends beyond individual species to entire ecosystems. Coastal habitats, such as coral reefs and mangroves, are particularly vulnerable to plastic contamination. Microplastics can alter the physical and chemical properties of marine sediments, affecting nutrient cycling and the health of benthic communities (Zettler, Mincer, and Amaral-Zettler2013). Additionally, the presence of plastic debris may facilitate the transport of invasive species, further disrupting ecosystem dynamics. Marine plastic pollution deteriorates the aesthetic appeal of the environment and hinders fishing and tourism activities (Adam 2021). It also damages the disruption of cultural ties to natural resources' accessibility and viable recreational activities.

Economic Implications:

Removing plastic waste from the environment poses a financial burden to society, costing millions of dollars annually (Onyena et al., 2022).The economic consequences of marine plastic pollution are significant. Fishing and tourism industries, which are vital for many coastal communities, suffer as plastic pollution harms fish populations, degrades habitats, and affects the overall aesthetic appeal of coastal areas (Constanza et al., 2014).

Mitigation Measures:

Plastic pollution has emerged as a global environmental crisis, affecting ecosystems, marine life, and human health. In India, the problem is particularly acute due to the country's large population and rapid economic development. Mitigating plastic pollution requires a comprehensive and multifaceted approach that addresses both the production and consumption of plastic. Controlling plastic and microplastic pollution in the sea requires a combination of preventive measures, effective waste management, and global cooperation. The following strategies outline a holistic framework to address and control plastic and microplastic pollution:

1. Reduce Plastic Production and Consumption:

Advocate for policies restricting the making and use of single-use plastics.Encourage the development and utilization of alternative materials that are biodegradable or easily recyclable. Promote responsible consumer behaviour through awareness campaigns highlighting the environmental impact of plastic consumption.

2. Improve Waste Management:

Invest in and enhance waste collection and disposal systems, particularly in coastal areas and regions with high plastic pollution. Enforce strict regulations for proper plastic waste disposal and impose penalties for illegal dumping. Develop and expand recycling infrastructure to make it more accessible and efficient. Encouraging the segregation, reuse and recycling of waste at the household level or point of generation is a better option. Recycling of materials like paper, plastics, organic matter, metals and glassinto usable products can also be advocated. (Ampofo, 2013).

3. Educate and Raise Awareness:

Conduct public awareness campaigns to educate communities, businesses, and individuals about the consequences of plastic and microplastic pollution. Foster responsible behaviour, including proper waste disposal and recycling, through educational programs and outreach efforts. The plastics used for transporting goods, plastic components in goods such as vehicles, and electronic equipment have the potential for re-use or re-manufacture (Hopewell et al. 2009).

4. Innovate and Develop Sustainable Alternatives:

Invest in research and development of alternative materials that are biodegradable, compostable, and less harmful to the environment. Support and incentivize industries to adopt sustainable practices and materials, reducing their reliance on traditional plastics. Materials derived from renewable natural resources with similar functionalities to that of oil-based products need to be supported and has to be utilized in packaging applications (Wabnitz,C&Nichols,W.J.,2010).

5. Regulate Microplastics in Consumer Products:

Enact regulations to restrict or ban the use of microplastics in consumer products, such as personal care items and cleaning agents.Many

countries have taken measures to regulate the inclusion of microbeads in cosmetic products. Some other countries encourage the industry's product choice (Drohmann, et al., 2018). The replacement of microplastics in the manufacturing process, such as Chitin microbeads in place of non-degradable skin exfoliators, is gaining momentum (Ju et al., 2021).

6. Address Plastic Pellet (Nurdle) Spills:

Nurdle spillages due to maritime accidents have been frequently reported worldwide (Sewwandi et al., 2023). Implement measures to prevent spills of plastic pellets during transportation and manufacturing. Establish protocols for the clean-up and containment of pellet spills to prevent their entry into water bodies.

7. Enhance International Cooperation:

Given the trans boundary nature of marine pollution, international collaboration is crucial. India should actively participate in global efforts to address plastic pollution, sharing knowledge, best practices, and technologies with other nations. Develop and implement international agreements and treaties to collectively tackle plastic pollution (Thushari and Senevirathna, 2020).

8. Support Beach Clean-up Initiatives:

Periodic beach and ocean clean-up can raise awareness and subsequent research on shoreline litter status and trends. Engaging local communities, non-governmental organizations (NGOs), and volunteers in clean-up efforts to remove existing plastic debris from shorelines can raise awareness and promote a sense of responsibility (Wabnitz, C. & Nichols, W.J., 2010).

9. Research and Monitoring:

Support scientific research to better understand the sources, distribution, and impacts of plastic and microplastic pollution. Monitor and assess the effectiveness of implemented measures to control plastic pollution and adjust strategies accordingly. Research should be promoted on the pathways and mechanism of adsorbing the chemicals that leach from microplastics into the tissues of aquatic organisms. Similarly, rather than laboratory studies on single species, the ecosystem-level impacts of microplastic pollution

using multiple species and trophic levels are required. Bio-magnification of chemical pollutants from ingested microplastics and the impact on higher trophic levels organisms are required. Long-term monitoring is essential to specify microplastics and their interactions with persistent organic pollutants. The process of the fragmentation of microplastics into nanoplastics is also has to be studied. Continued re-assessment of community and government strategies for plastic waste reduction is required (Onyena et al., 2022).

10. Encourage Circular Economy Practices:

Promote a circular economy by encouraging the recycling and reuse of plastics rather than their disposal. Encourage businesses to adopt sustainable and eco-friendly packaging practices (Wabnitz, C. & Nichols, W.J., 2010).

11. Clean-up Technologies:

Invest in technologies designed to remove plastic debris and microplastics from water bodies. This includes the development of innovative clean-up devices and systems. Many new technologies have been considered in this line, which represent the cardinal efforts in the fight against plastic pollution (Schmaltz et al., 2020).

12. Engage Businesses and Industries:

Many countries have adopted extended producer responsibility (EPR), which provides the producers with the responsibility to manage their products until the post-consumer stage. This system has been successfully implemented for electronic waste in most developing countries. Due to the rising concern about the marine plastic issue, several developing countries, including those in Asia, have also started to implement this system for packaging and container waste (Johannes et al., 2021). Encourage businesses to take responsibility for their plastic footprint through initiatives like extended producer responsibility (EPR).

13. Legislative Measures:

The creation of more legislative bodies, such as the international protocol to prevent and reduce pollution from ships, has more impact. The protocol, which has been approved by several countries, helps to regulate the release of garbage from ships and prohibits the disposal of plastics into the sea. This agreement ensures the maintenance of Garbage record books, by which

the estimated amounts of garbage that is incinerated or discharged are regularly monitored.

Conclusion:

Plastic and microplastic pollution significantly threaten the well-being of marine ecosystems and its inhabitants. The consequences extend from individual organisms to entire ecosystems, impacting biodiversity, ecosystem services, and human well-being. Urgent and collective action is needed to curb the proliferation of plastic pollution, safeguarding the seas for current and future generations. Mitigating plastic pollution is a complex and on-going process that requires a combination of regulatory measures, public awareness campaigns, technological innovation, and collaborative efforts. The commitment of the government, active participation of communities, and the engagement of various stakeholders are crucial in achieving a significant reduction in plastic pollution. By adopting a holistic approach and continuing to explore sustainable alternatives, we can pave the way for a cleaner and more environmentally friendly future.

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Understanding and Addressing Abandoned, Lost, or Otherwise Discarded Fishing Gear (ALDFG)

20

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In the vast expanses of the world's oceans, a growing and formidable menace is adversely affecting the delicate balance of marine ecosystems—Abandoned, Lost, or Otherwise Discarded Fishing Gear (ALDFG). This threat, encompassing nets, lines, traps, and other synthetic equipment left unintentionally or intentionally in the ocean, has emerged as a silent crisis echoing the unintended consequences of industrialized fishing practices and the proliferation of non-biodegradable materials.

As we stand at the crossroads of environmental awareness and the urgent need for sustainable practices, ALDFG stands out as a pervasive and overlooked crisis, compromising the health and sustainability of our oceans. Against the backdrop of perceived boundlessness and resilience, the persistent and escalating presence of ALDFG signals a critical environmental challenge, challenging the once-held perception of oceans as remote and inexhaustible.

This chapter embarks on a journey to unravel the complexities surrounding ALDFG, offering insights into its multifaceted dimensions and highlighting the pressing need for comprehensive solutions. As we delve into the terminologies and background of ALDFG, we aim to shed light on its historical context, ecological consequences, and the imperative for collaborative, international efforts to safeguard the health and resilience of marine ecosystems.

Defining ALDFG: Unraveling the Terminology

ALDFG encompasses discarded, lost, or deliberately abandoned fishing gear in the marine environment, including nets, lines, traps, and associated equipment. The distinction lies in its abandonment, irrespective of intent, contributing to a global challenge that demands immediate attention.

Background: A Silent Crisis Unfolding in the Depths

Marine ecosystems, celebrated for their biodiversity and intricate ecological interdependencies, face a growing peril from abandoned nets, lost traps, and discarded lines. The origins of ALDFG trace back to the evolution of fishing practices, which was marked by the transition from traditional, biodegradable materials to the prevalent use of synthetic and enduring materials in gear construction. This shift, driven by technological advancements, has inadvertently given rise to a crisis that extends beyond the visible entanglement of marine life.

The implications of ALDFG transcend its immediate impact on marine fauna, encompassing broader environmental degradation, compromised ecosystem services, and economic ramifications for coastal communities dependent on thriving fisheries. As we embark on this exploration, a comprehensive understanding of ALDFG's origins, its far-reaching impacts, and the imperative for collaborative, international efforts becomes paramount.

ALDFG – What Is It?

This section delves into the significant components of ALDFG, its impact on ecosystems and wildlife, and the various causes contributing to its prevalence. The absence of reliable global estimates underscores the urgency of addressing this issue comprehensively. Before seeking to understand how the law can be applied to address ALDFG, it is essential to dissect the term itself and explore the reasons behind the abandonment, loss, or discarding of valuable fishing gear.

Ghost Nets and Ecological Impact: A Menace Unraveled

Perpetuating a Dangerous Cycle

Within the realm of Abandoned, Lost, or Otherwise Discarded Fishing Gear (ALDFG), an ominous entity, often referred to as "Ghost nets," ensnares marine life, prolonging a hazardous cycle of fishing, trapping, and entanglement. These ghost nets act as silent

assassins, becoming magnets for other debris, thus degrading habitats and diminishing the functional values of crucial ecosystem services. The increasing reliance on synthetic materials in fishing gear production, coupled with the expansive reach of fishing activities, has led to the proliferation of these ghost nets, both haunting oceanic depths and encroaching upon coastal ecosystems.

Habitat Degradation: A Gathering Menace

Ghost nets, aptly named for their phantom-like ability to continue fishing, trapping, or entangling other fauna, act as insidious collectors of debris, further degrading habitats and reducing the functional values of ecosystem services. In regions like India, ghost nets occasionally wash ashore, emphasizing the urgent need for awareness among fishermen, navigators, and other users of marine ecosystems, including divers and tourists, about the detrimental effects of these ghost nets on marine fauna.

Environmental Impact of ALDFG

ALDFG, particularly in the form of ghost nets, accounts for approximately 10% of marine debris volume. This poses a substantial threat to habitats, endangers marine species, and has far-reaching implications for biodiversity. The phenomenon of ghost fishing, where abandoned gear continues its fishing activities, results in substantial unaccounted catch losses, affecting both target and non-target organisms.

Diverse Impacts on Marine Ecosystems: A Multifaceted Threat

1. The ecological impact of ALDFG, especially ghost nets, spans a range of environmental consequences:
2. Continued Catch of Target and Non-target Species: The transformation of gear from initial loss of control to eventual demise determines its catching efficiency, affecting both target and non-target species.
3. Interactions with Threatened/Endangered Species: Ghost nets pose a threat to marine life, particularly species already vulnerable, leading to unintended interactions and potential harm.
4. Physical Impacts on the Benthos: ALDFG, especially fishing nets, can exert physical impacts on the benthic environment through smothering, abrasion, plucking of organisms, and translocation of sea-bed features during retrieval, potentially harming fragile organisms like sponges and corals.
5. Role as a Vector for Invasive Species: Ghost nets, acting as drifting entities, can

carry invasive species to new areas, disrupting local ecosystems.

6. Introduction of Synthetic Material into the Marine Food Web: The persistence of synthetic materials in ghost nets introduces them into the marine food web, posing potential threats to marine life at various trophic levels.

Impact on Marine Users: Beyond Environmental Consequences

ALDFG, particularly in the form of marine litter and ghost nets, extends its repercussions to marine users:

1. Navigational Hazards: Abandoned, lost, or discarded fishing gear becomes a significant navigational hazard, posing risks to vessels and endangering the safety of maritime activities.
2. Loss of Amenity and Disruption to Coastal Areas: The presence of ghost nets and marine litter disrupts the enjoyment of beaches and coastal areas, impacting tourism and local amenities.
3. Safety Concerns: Beyond environmental and ecological concerns, the safety of navigation takes precedence, given instances of injury and loss of human life caused by ALDFG.
4. Additional Costs: Marine litter and ghost nets result in additional costs for vessel owners and operators due to fouling of vessels and other gear.

The Specifics of Ghost Fishing: Gear Type, Conditions, and Environmental Factors

The capacity of ALDFG, particularly ghost nets, for ghost fishing is highly specific, dependent on gear type, conditions under which it was abandoned, lost, or discarded, and the nature of the local environment. Gears like gillnets and traps/pots exhibit the ability to continue fishing even after abandonment, with the duration of this cycle varying widely based on local environmental conditions. Understanding these specifics is crucial for devising targeted strategies to mitigate the impact of ghost nets on marine ecosystems.

In the unravelling narrative of ghost nets and their ecological impact, it becomes evident that this multifaceted threat demands comprehensive solutions and heightened awareness to preserve the health and resilience of our oceans.

Legal Framework and International Recognition

The menace of Abandoned, Lost, or Otherwise Discarded Fishing Gear (ALDFG) and plastic-based marine debris stands as a critical challenge for marine environments, casting shadows on long-term sustainability and biodiversity conservation. International efforts, articulated through instruments such as MARPOL Annex V and the FAO Code of Conduct for Responsible Fisheries, underscore the need to address these issues comprehensively. However, the absence of reliable global estimates of ALDFG poses a significant obstacle to formulating targeted solutions.

Marine Debris: A Global Predicament

Marine debris, often referred to as marine litter, has emerged as one of the most pressing problems of the 21st century. The United Nations Environment Programme (UNEP) defines marine debris as any persistent, manufactured, or processed solid material disposed of or abandoned in the marine and coastal environment. The "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972," commonly known as the "London Convention," serves as one of the pioneering global conventions addressing marine pollution. With 89 countries as parties to the Convention, it prohibits all dumping except for possibly acceptable wastes, aligning with the principle that the polluter pays for environmental harm.

Polluter Pays Principle and Plastic Problem in the Indian Ocean

The polluter pays principle, a foundational tenet of environmental policy, asserts that individuals responsible for environmental harm must bear the costs associated with rectifying and mitigating that harm. Applying this principle involves imposing severe penalties on violations and implementing pay-as-you-throw schemes to discourage littering and illegal dumping. The plastic problem, particularly pronounced in the Indian Ocean nations, prompts a comprehensive response. Asia's leading contribution to mismanaged plastic waste underscores the urgency for effective regulations.

India, with a trajectory spanning three decades, has instituted various regulations to manage solid waste. Since 2018, India has been an active participant in the UNEP Clean Seas campaign, aiming for a pristine coastline. In July 2022, India's environment ministry took a significant step by banning several single-use plastic items. Despite central and state-level legislation for plastic waste management, challenges persist due to poor implementation and inadequate infrastructure for land-based plastics.

International Instruments Recognizing the Need to Address ALDFG and Mark Fishing Gear

Several international instruments recognize the need to address ALDFG and emphasize the importance of marking fishing gear. Key instruments include:

1. MARPOL Annex V (73/78): Focused on preventing the disposal of garbage from ships.
2. FAO Code of Conduct for Responsible Fisheries (1995): Advocates the marking of fishing gear to address ALDFG.
3. International Guidelines on Bycatch Management and Reduction of Discards (FAO 2011): Aims at reducing the impact of lost fishing gear.
4. Agreement of Port State Measures to Prevent, Deter, and Eliminate Illegal, Unreported and Unregulated Fishing (2009).
5. UNGA Resolution A/RES/70/1 on Sustainable Development Goals (2015): SDG 14.1 targets the prevention and reduction of marine pollution, including ALDFG.

Potential International Actions: The Role of IMO and MARPOL Annex V

International Maritime Organization (IMO): While MARPOL has effectively addressed various aspects of marine pollution, additional measures are needed to specifically tackle marine debris and ALDFG. Recommendations for the IMO include:

- Expanding action plans on adequacy of port reception facilities.
- Investigating and reporting on the adequacy of port reception facilities for fisheries waste, including ALD gear.

MARPOL Annex V: Acknowledged as a key mechanism in addressing marine pollution from shipping, MARPOL Annex V can play a crucial role in addressing ALDFG. Recommendations for MARPOL Annex V include:

- Reducing the 400 GT minimum tonnage for vessels under Annex V.
- Developing an addendum with detailed guidance on measures to address ALDFG.
- Providing qualitative and quantitative standards for port reception facilities.

These recommendations underscore the need for concerted international efforts to amend and enhance existing frameworks, ensuring effective measures to combat the escalating threat of ALDFG on a global scale.

Strategies for Mitigation:

Addressing the persistent risk of Abandoned, Lost, or Otherwise Discarded Fishing Gear (ALDFG) necessitates a comprehensive, multi-pronged approach that involves research, awareness, removal, and recycling. This chapter explores both preventive and curative measures to combat the intricate challenges posed by ALDFG.

1. Preventive Measures: Marking of Fishing Gear

Gear marking plays a pivotal role in preventing ALDFG and promoting responsible fisheries. The Code of Conduct for Responsible Fisheries (FAO 1995) advocates for the marking of fishing gear, emphasizing the importance of identifying gear owners. Internationally recognizable gear marking systems should be incorporated into marking requirements.

The potential benefits of marking fishing gear include:

- Assisting in preventing gear loss and ghost fishing, leading to less marine litter.
- Reducing the time spent trying to recover lost gear.
- Facilitating the recovery of lost gear.
- Enhancing the ability to apply fisheries regulatory measures, including those for controlling fishing capacity and preventing Illegal, Unreported, and Unregulated (IUU) fishing.

The life cycle of fishing gear, from manufacture to disposal, must be addressed comprehensively. This includes considerations for gear material manufacture, design, fabrication, storage, use, recycling, and disposal. Recognizing ALDFG within the context of the Sustainable Development Goals (SDGs), particularly in relation to sustainable fisheries, biodiversity, and food security, is crucial. The forthcoming FAO Guidelines on the Marking of Fishing Gear should be widely promoted by Regional Seas Programs, Regional Fisheries Management Organizations (RFMOs), and Regional Fisheries Bodies (RFBs).

2. Onshore Collection/Reception and/or Payment for Old/Retrieved Gear

The provision of onshore collection facilities, along with incentives such as payment for old or retrieved gear, serves as a preventative measure. This reduces the likelihood of fishers discarding unwanted gear at sea and encourages responsible disposal practices.

3. Reduced Fishing Effort

Implementing measures to reduce overall fishing effort, such as limiting fishing time or the amount of gear per vessel, is a fisheries management strategy that can impact ALDFG rates. By controlling the intensity of fishing activities, the potential for gear loss and abandonment can be curtailed.

4. Better Reporting of Gear Loss

Improved reporting mechanisms for gear loss, originating from fishers or other operators encountering ALDFG, are essential. While direct reporting from gear operators provides accurate location and identification information, such reporting is currently rare and needs to be encouraged and facilitated.

5. Disposal and Recycling

Proper disposal and recycling of fishing gear are imperative for mitigating ALDFG. Encouraging responsible practices in the management of gear at the end of its life cycle contributes to reducing the environmental impact.

6. Awareness Rising

Raising awareness about the ALDFG problem is a cross-cutting measure that supports the development and implementation of mitigation strategies. Targeting fishers, port operators, marine users, and the general public through local, national, regional, or international campaigns is crucial. It is essential to strike a balance in using graphic images of entangled marine species to raise awareness without inadvertently discouraging fishers from reporting ALDFG incidents.

By integrating these preventive and curative strategies, a concerted effort can be made to mitigate the multifaceted challenges posed by ALDFG, fostering responsible and sustainable practices in the world's oceans.

Conclusion

This chapter provides an in-depth exploration of the complexities surrounding ALDFG, offering a comprehensive overview of its causes, consequences, and global efforts for mitigation. By weaving together scientific insights, legal considerations, and practical solutions, it serves as a valuable resource for specialists, researchers, and graduate students seeking a thorough understanding of the challenges posed by abandoned fishing gear in marine environments.

Underwater Sampling, Monitoring and Assessment Methods of Marine Biodiversity

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Marine biodiversity represents a layered complexity of living organisms, ranging from diversity within species to entire ecosystems. It is integral to all dimensions of sustainable development—economic, social, and environmental—supporting the Earth's well-being and providing essential services for humanity's health, happiness, and prosperity. Regrettably, human-induced pressures such as overfishing, climate change, invasive species, and pollution have led to a steep decline in marine biodiversity worldwide. Therefore, it is crucial to monitor and evaluate biodiversity across different marine habitats. This evaluation can assist in identifying species, habitats, and communities that are significant due to their rarity, those that serve as biological indicators, or those crucial to local human societies. Such assessments help pinpoint species and areas in need of conservation or restoration efforts.

Monitoring of ecosystem

Monitoring is the systematic acquisition of data and information pertaining to a designated 'ecosystem under consideration' within a scientific framework. This process also involves the comprehensive examination of resource utilization by both direct and indirect stakeholders associated with the ecosystem. To ensure the robustness of the monitoring endeavor, it is imperative to conduct periodic assessments, ideally spanning an extended temporal scope.

Initiating the monitoring protocol entails the execution of a baseline survey, a foundational undertaking designed to gauge parameters that may undergo temporal fluctuations. The fundamental data procured during the baseline survey encompass

1. Cartographic representation of the ecosystem's geographical extent, delineating spatial details.

2. Comprehensive inventory of local and migratory organisms, obtained through primary and secondary data collection, inclusive of their ecological status.
3. Identification and characterization of the various direct and indirect stakeholders, elucidating their interactions with the ecosystem and targeted resources.
4. Examination of existing regulatory frameworks governing the ecosystem, encompassing the extent of surveillance and adherence.
5. Analysis of decision-making processes and governance structures within local communities, providing insights into factors influencing ecosystem conservation.
6. The overarching objective of monitoring is to furnish data that substantiates the formulation of effective management strategies for the designated ecosystem. By employing a scientifically rigorous approach, monitoring contributes essential insights that underpin informed decision-making and facilitate the sustainable conservation of the ecosystem in question.

In this chapter, we aim to understand the monitoring of coastal and marine ecosystem. Hence, the various underwater sampling methods with are commonly follow is detailed along with the sample collection tools, along with cleaning and preservation methods.

Underwater Sampling Methodologies: A Scientific Exploration

The exploration and understanding of underwater ecosystems demand sophisticated methodologies that can unravel the complexities of marine environments. From the broad-scale insights offered by the Manta Tow and Timed Swim techniques to the nuanced observations facilitated by Transects, Quadrats, and Underwater Videography, this scientific exploration navigates the methodologies essential for comprehending the intricate dynamics of life beneath the waves. Every technique brings its own distinct value to the scientific arsenal, facilitating the exploration of underwater ecosystems and the enhancement of

our understanding of the intricate equilibrium supporting marine life.

1. **Manta Tow Technique:** The Manta Tow method is a preeminent approach employed for acquiring a comprehensive, broad-scale depiction of an aquatic site. This technique involves towing a diver behind a watercraft, circumnavigating the designated site. The objective is to obtain a general overview of the ecological characteristics prevalent in the underwater environment.
2. **Timed Swim Technique:** The Timed Swim technique entails a diver swimming for a predetermined duration or distance, offering a holistic assessment of the overall site. This method provides valuable insights into the spatial distribution and ecological features of the surveyed area.
3. **Transect Methodology:** Transects serve as an intermediary approach, furnishing information of moderate scale. These involve the placement of lines on the reef floor, beneath which corals and other objects are systematically tallied. Various survey methods include:
 - a. **Line Transects:** Encompassing line intercept transects (for horizontal plane) and chain transects (for three-dimensional surveys, with the chain conforming to the contour).
 - b. **Point Intercept Transects:** Involving measurements at specific intervals beneath or beside the transect tape.
 - c. **Belt Transects:** Measuring entities within a belt adjacent to the transect, facilitated by structures like PVC poles or T-bars.

To demarcate transects, materials such as waterproof fiberglass tape on a spool with a winding handle, marked rope with coloured indicators or knots denoting distance, or plastic chains with links of known length are commonly utilized.

4. **Quadrat Sampling:** Quadrats, defined as square or rectangular sampling units, are instrumental in enumerating or measuring organisms within a specified area. The appropriate size of a quadrat depends on the organism's size and spatial abundance. Commonly, quadrats of 0.5-1m² or larger are employed for assessing species diversity, while smaller 25 cm by 25 cm quadrats are

suitable for fine-scale investigations of sessile benthic juvenile recruits and other diminutive organisms. Permanent quadrats serve the purpose of longitudinally observing specific coral colonies.

5. **Underwater Videography:** Utilizing video footage to capture the general reef area offers qualitative insights. For quantitative studies, videos are particularly advantageous for large-scale ecological monitoring using techniques such as belt transects. The width of the belt in video transects is determined by the distance the camera is held from the coral reef benthos. Replicating the exact path, speed, and distance from the substrate for repeated video sampling poses challenges but is essential for maintaining consistency in data collection.

Sampling and Data collection

Data collection emerges as an indispensable component in scientific endeavours aimed at unravelling the mysteries of underwater life. They give quantitative as well as qualitative insights of the ecosystem. By systematically collecting data from various locations within the ecosystem, scientists can extrapolate population densities, assess species richness, and discern patterns of spatial distribution. This quantitative information is fundamental for formulating accurate ecological models, understanding population dynamics, and gauging the health of marine communities. Qualitative data derived from sample analysis contribute to the identification of species, assessment of biodiversity, and discernment of ecological niches within the marine habitat.

Sample collection plays a crucial role in data collection. Scientific research, aimed at unravelling the mysteries of marine life, relies heavily on accurate and representative data obtained through sample collection. Sample collection is, therefore, a foundational step in the scientific process that empowers researchers to contribute meaningfully to marine conservation and ecosystem preservation. Based on the type of research activity envisioned, commonly used sampling devices and methods employed for collecting organisms are given in Table 1.

Table 1. General Sampling Techniques for collecting/ monitoring of Marine Organisms

Sampling Device/ methods	Targeted Organisms
Nets: Sieve, gillnets, trammel nets, trawl, dipnet	Marine organisms especially from minute microscopic planktons to larger nektons.
Traps	Fishes, crabs, octopus, lobsters
Visual observation	Larger megafauna visible on the water surface (large pelagic fish shoals, Jellyfish blooms etc.)
Visual observation by underwater video, Scuba assisted dives	All marine organisms especially sessile epifauna, invertebrates up to large Nektons
Aerial survey	Larger megafauna visible on the water surface
Acoustic (echo-sound)	Fish/ marine mammals' species
Dredges, sledges	Benthic organisms and Epifauna (both sessile and motile)
Remotely Operated Vehicle (ROV)	Coastal area not accessible by Scuba dives, Deep water species (generally >200m depth)
Light Traps	Organisms attracted by light (Photosensitive organisms in plankton, mobile benthos, nektons)
Hand held shovels and rake	Intertidal organisms
Tagging and marking	Nektons (mammals/whales/ fishes), Sessile benthic fauna (large corals)

While employing these sampling techniques, we tend to collect samples for analysis in laboratory. Good quality preservation methods are essential for maintaining the quality of biological samples, thereby enabling researchers to conduct thorough analyses and make informed conclusions. The direct preservation of various organisms in fixatives or preservatives is not

universally suitable due to the diverse physiological responses exhibited across taxonomic groups. The employment of a relaxant serves the purpose of inducing a state of anaesthesia in specimens, rendering them unresponsive and incapable of contraction upon immersion in fixative solutions. Commonly used relaxant with their dosage is given in Table 2.

Table 2. Relaxant with dosage and target organism

Sl No:	Relaxant	Targeted Organism	Dosage
1.	Magnesium Chloride (MgCl ₂)	Most marine organisms	Prepared with freshwater at a concentration of 7.5% by weight, matching the osmotic pressure of seawater. A blend of isotonic MgCl ₂ solution and seawater in a 50:50 ratio is recommended as a suitable general mixture. It is advisable to add the solution gradually when dealing with delicate organisms.
2.	Menthol	cnidarians and ascidians	Sprinkling crushed menthol crystals or adding

				drops of concentrated menthol solution, which is prepared in ethanol.
3.	Chloretone/ chlorobutanol	echinoderms, including large holothurians	Few drops of saturated solution of Chloretone in ethanol	
4.	Clove (eugenol)	oil crustaceans	25% solution of clove oil in ethanol	
5.	Cooling/freezing	Crustaceans, like crabs, and shelled molluscs.	Fast freezing is advised, as slow freezing can negatively impact anatomy and histology. It is not advisable for soft-bodied organisms.	
6.	Propylene phenoxitol	Bivalves	1 to 2 drops	

Type of preservatives used depends on the type of analysis intended. In case of genetic analysis, Ethanol, a prominent choice for preservation. A small quantity of the fresh specimen is preserved in higher ethanol concentrations, ranging from 95-100%.

For general preservation, Formalin, typically employed at concentrations ranging from 5-10%, constitutes a solution derived from the industrial "formalin" mixture, containing 38%

formaldehyde dissolved in water. To ensure iso-osmotic conditions for marine animal specimens, it is recommended to blend formalin with seawater. Specifically, for taxa characterized by calcareous components (a prudent practice for all taxa), formalin necessitates buffering with laundry borax (sodium borate), or alternatively, by the addition of calcium carbonate powder/sand. For enhanced histological and anatomical fixation, utilizing buffer recipes or specialized fixatives such as Bouin's is advisable. Common fixatives and preferred concentration for various taxa are detailed in Table 3.

Table 3. Common fixatives and preferred concentration for various taxa

Sl no	Group	Relaxant	Cleaning agent (if any)	Fixative
1.	Porifera	Nil	Nil	70-95% Ethanol
2.	Hard corals	Nil	Bleached with a solution of sodium hypochlorite	Dried for preservation. For DNA based studies colony to be preserved in 95% Ethanol
3.	Soft Coral	Nil	Nil	Preserved in alcohol or buffered formalin solution. Storage: Alcohol For DNA based studies colony to be preserved in 95% Ethanol
4.	Sea fans	Nil	Nil	Preserved in alcohol or buffered formalin solution then quickly dried.

				For DNA based studies colony to be preserved in 95% Ethanol
5.	Black corals	Nil	Nil	Preserved in alcohol or buffered formalin solution. Expanded polyps are necessary for taxonomy. For DNA based studies colony to be preserved in 95% Ethanol
6.	Anemones	menthol	Nil	Ideally, specimens are preserved in formalin while fully expanded and then stored in alcohol.
7.	Flatworms	Nil	Nil	Let the animal crawl and expand on a moistened paper, then gently transfer both the paper and the animal onto frozen formalin for preservation; thereafter, preserve in ethanol. A small piece of live tissue extracted from the worm using a razor serves as the subsample for DNA and can be preserved in 95% ethanol.
8.	Nemertean worms	MgCl ₂	Nil	Fix the worm straight in formalin, preserve in ethanol. Tissues in 95% ethanol for DNA work
9.	Crustaceans	clove oil, freezing	Nil	Fixation and preservation in alcohol is ideal. Tissues in 95% ethanol for DNA work
10.	Molluscs	MgCl ₂ and propylene phenoxitol	Shells can be cleaned in Aluminium thioglycolate or solution of sodium hypochlorite	Fixation can be in alcohol or formalin
11.	Bryozoans	Nil	Nil	Preservation is by Air drying.
12.	Ophiuroids, asteroids, echinoids	MgCl ₂		Preserved in either ethanol or formalin. Ethanol fixation is preferable when specimens are intended to be kept moist,

					whereas formalin offers a better fixative for specimens that will be dried.
13	Crinoids	Nil			Fixed and preserve in 70-95% EtOH
14.	Holothuroids	MgCl ₂ or chlorethane			Fixed and preserve in 70-95% EtOH
15.	Urochordates	menthol			Preserved and kept in formalin for storage. Tissues stored in 95% ethanol for DNA analysis
16.	Fishes	Nil	With water	running	Preserved and kept in formalin for storage. Tissues stored in 95% ethanol for DNA analysis
17.	Planktons	Nil	-		Fixed and stored in 5% formalin

Biodiversity Assessment

Quantifying biodiversity at the species or population level aims to establish an index reflecting the number of species present and their relative abundance within a specific ecosystem. These assessments are crucial for identifying key conservation areas and establishing priorities. Areas are ranked based on various criteria such as rarity, diversity, habitat condition, fragmentation, resilience, threats, and ecosystem processes, offering a comprehensive view of the ecosystem. Optimal levels of biodiversity enhance ecosystem resilience against stressors like climate change and invasive species. Monitoring biodiversity over time is vital for detecting changes and informing sustainable development strategies.

Numerous biodiversity indices have been developed to mathematically evaluate biodiversity. There are various methods for measuring biodiversity, with richness and evenness being the primary considerations.

Species richness

Species richness refers to the number of different species present in a particular area or habitat. It is a measure of biodiversity that quantifies the diversity of species within a given community or ecosystem. Species richness considers only the number of species and does not take into account the relative abundance of each species. Higher species richness indicates a greater

variety of organisms coexisting within an ecosystem, while lower species richness suggests a more limited diversity of species. It is one of the fundamental metrics used to assess and compare biodiversity across different environments.

Species evenness

Species evenness is a measure of how evenly or uniformly the individuals of different species are distributed within a community or ecosystem. It considers not only the number of species (species richness) but also the relative abundance of each species. In a community where species evenness is high, all species are represented in relatively equal proportions, meaning that no single species dominates the community. Conversely, in a community with low species evenness, one or a few species may be significantly more abundant than others, resulting in an uneven distribution of individuals across species.

Species evenness complements species richness in providing a more comprehensive understanding of biodiversity within an ecosystem. It helps to assess the balance and stability of a community by indicating the degree to which resources are shared among different species. Communities with high species evenness are often considered more stable and resilient to environmental changes compared to those with low evenness.

Diversity indices

A diversity index is a mathematical measure used to quantify the diversity of species within a community or ecosystem. These indices provide a way to summarize various aspects of biodiversity, including species richness (the number of different species present) and species evenness (the distribution of individuals among those species). They encompass aspects such as rarity, commonness, and the composition of the community.

1. Simpson's Index(D)

The Simpson Diversity Index, also known as the Simpson Index is a measure of biodiversity that quantifies the diversity within a community by considering both species richness and species evenness. It provides a single numerical value that reflects the probability that two randomly selected individuals from the community belong to different species.

Simpson's Index is calculated as follows:

$$D = 1 - \sum_{i=1}^S \left(\frac{n_i}{N} \right)^2$$

Where S is the total number of species in the community, n_i is the number of individuals of the i -th species and N is the total number of individuals in the community.

Simpson's Diversity Index ranges from 0 to 1, where: $D=0$ indicates low diversity (or high dominance by one species). $D=1$ indicates high diversity (or perfect evenness, where all species are equally abundant).

Simpson's Dominance Index is the inverse of the Simpson's Index ($1/D$).

2. Shannon-Weiner Index (H)

Shannon-Weiner Diversity Index, originally proposed by Claude Shannon in 1948, is a measure of biodiversity that quantifies the diversity within a community. It takes into account both species richness (the number of different species present) and species evenness (the distribution of individuals among those species).

Shannon -Weiner Index (H) is calculated as follows

$$H = -\sum_{i=1}^S p_i \ln p_i$$

Where, S is the total number of species in the community, p_i is the proportion of individuals belonging to the i -th species relative to the total number of individuals in the community and $\ln$ denotes the natural logarithm.

The Shannon-Weiner Index provides a single numerical value that reflects the uncertainty associated with predicting the species identity of a randomly selected individual from the community. Higher values of the index indicate greater species diversity within the community.

3. Margalef's Diversity Index (IMg)

This index was developed by the Spanish ecologist Ramon Margalef in 1958. Margalef's Diversity Index, also known as the Margalef Index or IMg, is a measure of biodiversity that quantifies the richness of species within a community relative to the total number of individuals present.

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

Where S = total number of species N = total number of individuals in the sample $\ln$ = natural logarithm.

Margalef's Diversity Index measures the species richness of a community by taking into account the logarithmically transformed number of individuals. Higher values of the index indicate greater species richness within the community. It provides insight into the complexity and diversity of ecological communities.

4. Menhinick's Diversity Index (DMn)

Menhinick's Diversity Index is a measure of biodiversity that focuses on the species richness of a community in relation to the total number of individuals sampled. It is particularly useful for assessing biodiversity in ecological studies, especially when comparing the diversity of different communities or sites.

$$DMn = S/\sqrt{N}$$

Where S = the total number of species in a community and N = total number of individuals sampled.

Menhinick's Diversity Index provides a measure of species richness that accounts for the size of the sample. It gives more weight to communities with a higher number of species relative to the size of the sample, thus providing a more accurate representation of biodiversity. Higher

values of the index indicate greater species richness within the community.

5. Evenness Index (J)

The Evenness Index (J), also known as Pielou's Evenness Index, is a measure of how evenly individuals are distributed among different species within a community. It complements measures of species richness by considering the relative abundance of each species. The evenness of a community can be represented by Pielou's evenness index (Pielou 1966):

$$J = H / \ln S$$

where H = Shannon – Wiener diversity index
S = total number of species in the sample
ln = natural logarithm

The Evenness Index (J) ranges from 0 to 1, where:

J=0 indicates low evenness, meaning that one or a few species dominate the community.

J=1 indicates perfect evenness, where all species are equally abundant.

The Evenness Index provides a measure of how equitably individuals are distributed among different species, allowing for comparisons of community structure and diversity across different habitats or ecosystems. J and D can be used as measures of species dominance (the opposite of diversity) in a community. Low J indicates that 1 or few species dominate the community.

6. Community Similarity Index

The Community Similarity Index, also known as the Bray-Curtis Similarity Index, is a measure used to quantify the similarity between two or more communities based on their species composition and relative abundances. It is widely used in ecology and biodiversity studies to compare the similarity of species assemblages across different sites or habitats.

The Bray-Curtis Similarity Index is calculated using the following formula:

$$BC = \frac{2C}{S1 + S2}$$

Where:

BC is the Bray-Curtis Similarity Index.

C is the total abundance of species shared between the two communities.

S1 and S2 are the total abundances of species in the first and second communities, respectively.

The index ranges from 0 to 1, where:

BC=0 indicates no similarity between the communities.

BC=1 indicates complete similarity, meaning that the species composition and relative abundances are identical between the communities.

The Bray-Curtis Similarity Index provides a quantitative measure of community similarity that accounts for differences in species abundance, making it particularly useful for comparing communities with varying levels of species richness and evenness.

Biodiversity at different scales

Alpha Diversity: Alpha diversity refers to the diversity of species within a particular habitat or ecosystem. It focuses on the variety of species present within a defined area or sample, without considering the differences between habitats or ecosystems. In other words, alpha diversity measures the richness (number of different species) and evenness (relative abundance of each species) within a single community or location. It provides insight into the local biodiversity and is often used to assess the health and ecological complexity of specific habitats.

Beta Diversity: Beta diversity is a measure of biodiversity that quantifies the differences in species composition between different habitats or ecosystems within a larger geographical area. It reflects the turnover of species from one habitat to another and provides insight into the heterogeneity or similarity of species composition among different sites. In other words, beta diversity compares the diversity of species between different locations or habitats, highlighting the degree of variation in species composition across spatial gradients. It helps ecologists understand patterns of biodiversity distribution and assess the degree of habitat heterogeneity within a region.

Gamma Diversity: Gamma diversity refers to the overall diversity of species across a large geographical area or region, encompassing multiple habitats or ecosystems. It represents the total number of species present within the entire geographic extent, regardless of the individual habitats or ecosystems within that area. In

essence, gamma diversity reflects the combined alpha and beta diversities across all habitats or ecosystems within a region. It provides a comprehensive understanding of biodiversity at a broader scale, considering the variety of species present across different habitats and landscapes within a given geographic range.

$$\text{Gamma Diversity} = \text{Alpha diversity} + \text{Beta diversity}$$

Conclusion

In conclusion, the intricate marine biodiversity, ranging from intra-species diversity to entire ecosystems, plays a pivotal role in sustaining the planet's health and supporting economic, social, and environmental pillars of sustainable development. Despite its significance, a precipitous decline in global marine biodiversity is evident due to various anthropogenic threats. Recognizing the urgency, this chapter emphasizes the importance of monitoring and assessing various ecosystems. Through systematic baseline surveys and sophisticated underwater sampling methodologies, scientists can unravel the complexities of marine life. Ultimately, the integration of robust monitoring, advanced sampling methodologies, and comprehensive biodiversity assessments is fundamental to the sustainable conservation of marine ecosystems.

Suggested Reading

English, S., Wilkinson, C. and Baker, V. (1994) Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science, Townsville, 34-49.

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Templado, J., Paulay, G., Gittenberger, A., Meyer, C. (2010) Sampling the marine realm. In:

Eymann J, Degreef J, Häuser C, Monje JC, Samyn Y, VandenSpiegel D (Eds) Manual on field recording techniques and protocols for all taxa biodiversity inventories. ABC Taxa, 273–302.

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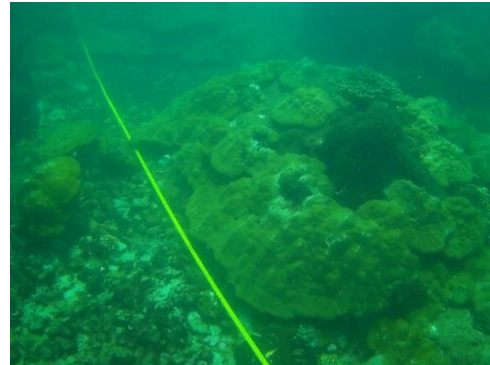


Fig. 1. Line transects for studying corals



Fig. 2. Common quadrats (50cm x 50cm)

Mapping the Spatial Distribution of Marine Resources

Dr. Shelton Padua

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Geographic information system (GIS) is a tool for making maps. GIS helps us in using spatial information and it is mainly concerned with the location of the features as well as properties/attributes of those features. It helps us gather, analyse and visualize spatial data for different purposes. A GIS quantifies the locations of features by recording their coordinates which are the numbers that describe the position of these features on Earth. The uniqueness of GIS is its ability to do spatial analysis. GIS helps us analyse the spatial relationships and interactions. Sometimes, GIS proves to be the only way to solve spatially-related problems and it is one of the most important tools that aid in decision making process. GIS basically helps to answer three questions; How much of what is where? What is the shape and extent of it? Has it changed over time?

Globally, on an average, GIS tools save billions of dollars annually in the delivery of goods and services through proper route planning. GIS regularly help in the day-to-day management of many natural and man-made resources, including sewer, water, power, and transportation networks. GIS help us identify and address environmental problems by providing crucial information on where problems occur and who are affected by them. It also helps us identify the source, location and extent of adverse environmental impacts. GIS enable us to devise practical plans for monitoring, managing, and mitigating environmental damage. Human impacts on the environment, conflicts in resource use, concerns about pollution, and precautions to protect public health have spurred a strong societal push for the adoption of GIS.

GIS is composed of hardware, software, data, humans and a set of organizational protocols. The selection and purchase of

hardware and software is often the easiest and quickest step in the development of a GIS. Data

collection and organization, personnel development and the establishment of protocols for GIS use are often more difficult and time consuming endeavours. A fast computer, large data storage capacities and a high quality, large display form the hardware foundation of most GIS. GIS software provides the tools to manage, analyse, and effectively display and disseminate spatial information. GIS as a technology is based on geographic information science and is supported by disciplines like geography, surveying, engineering, space science, computer science, cartography, statistics etc.

In GIS, we handle the spatial and attribute data sets. Spatial data describes the absolute and relative location of geographic features while attribute data describes characteristics of the spatial features. These characteristics can be quantitative and/or qualitative in nature. Attribute data is also referred to as tabular data. Vector and raster are two different ways of representing spatial data. Raster data is made up of pixels (or cells), and each pixel has an associated value. A digital photograph is a simple example of a raster dataset where each pixel value corresponds to a particular colour. In GIS, the pixel values may represent elevation above/below sea level, or chemical concentrations, or rainfall etc. The key point is that all of this data is represented as a grid of (usually square) cells. Vector data consists of points, lines, and polygons. The individual points are stored as pairs of (x, y) co-ordinates. The points may be joined in a particular order to create lines, or joined into closed rings to create polygons, but all vector data fundamentally consists of lists of co-ordinates that define vertices, together with rules to determine whether and how those vertices are joined.

As with many other systems, GIS basically works on the principle of 'GIGO' that is garbage in garbage out. Hence the quality of data that you feed into GIS is very important and it determines the quality of the end products. But, when used wisely, GIS can help us live healthier, wealthier, and safer lives.

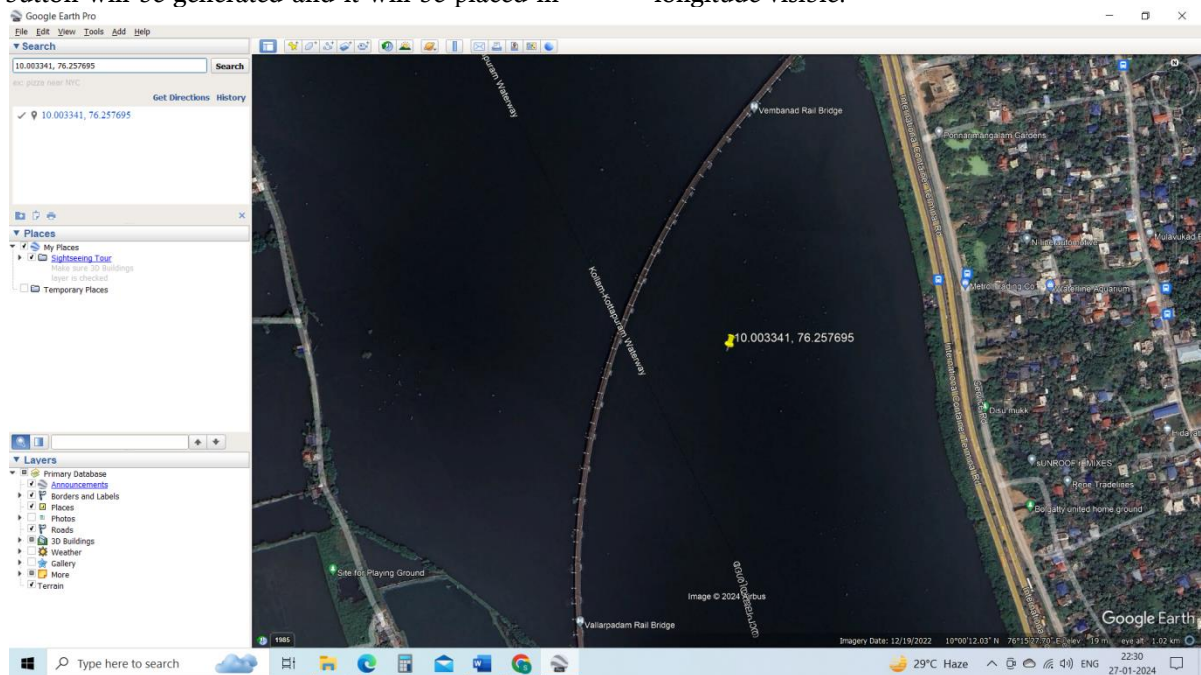
We will try to use two commonly available software (Google Earth and QGIS) for simple mapping.

Using Google Earth for Location Mapping

If you know the latitude and longitude of the location, type those coordinates in the search

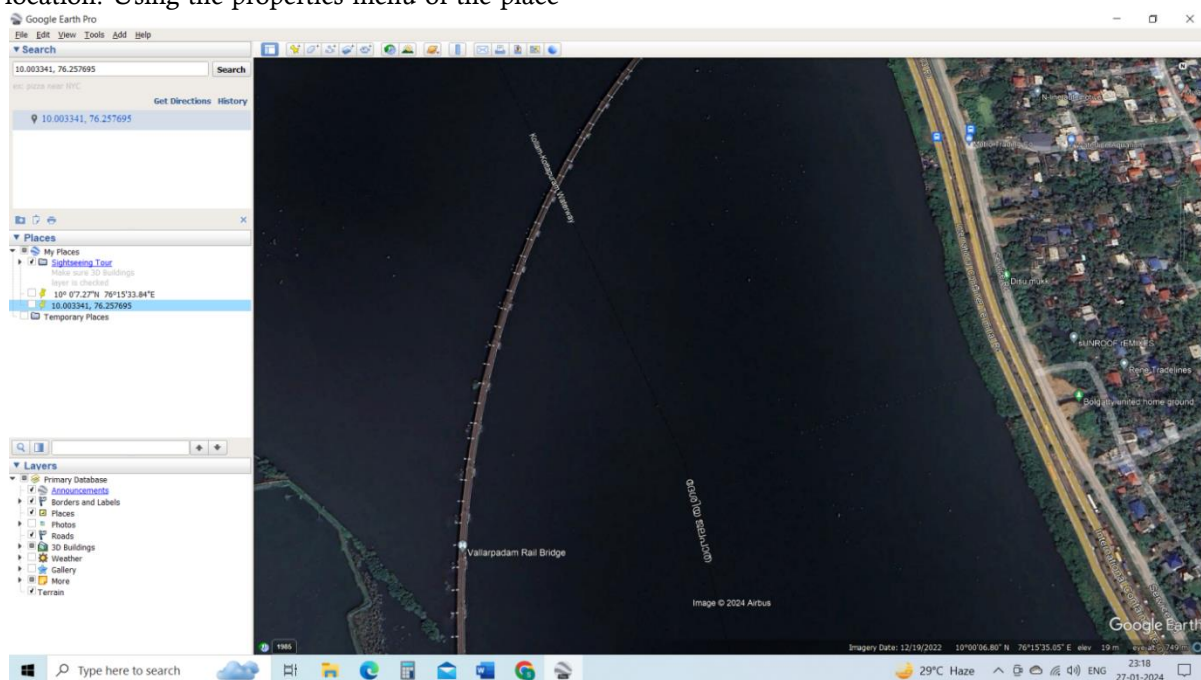
window and press the search button, a push button will be generated and it will be placed in

the exact coordinates with the latitude and longitude visible.



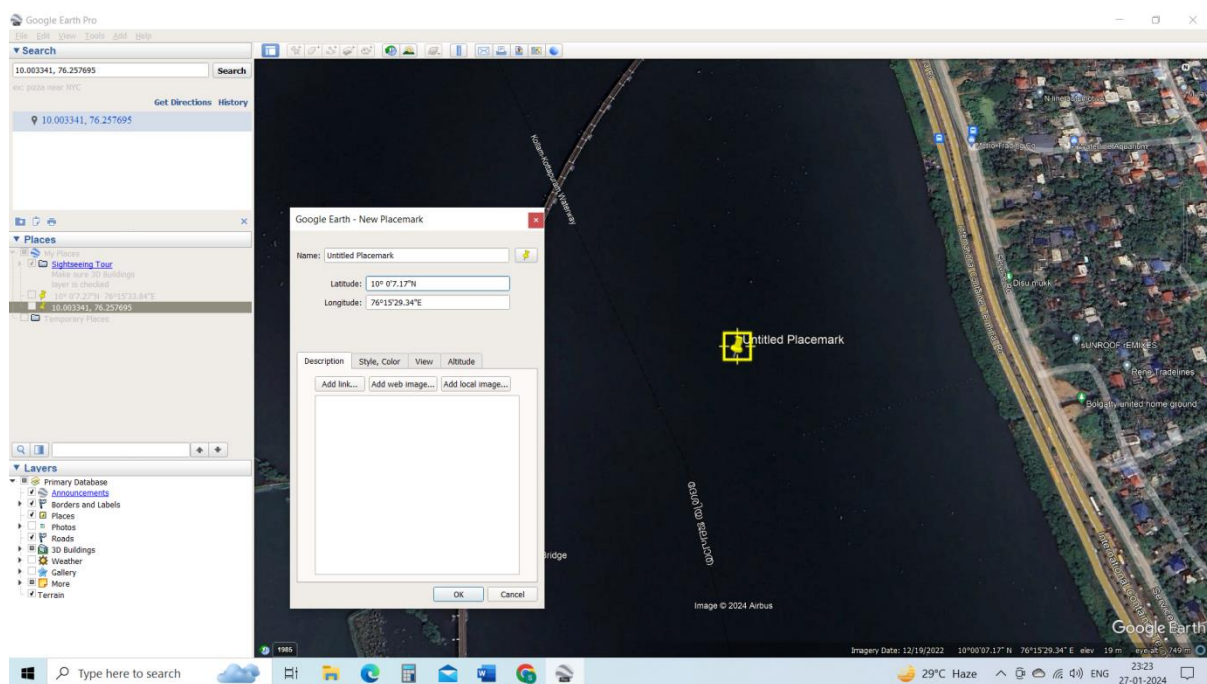
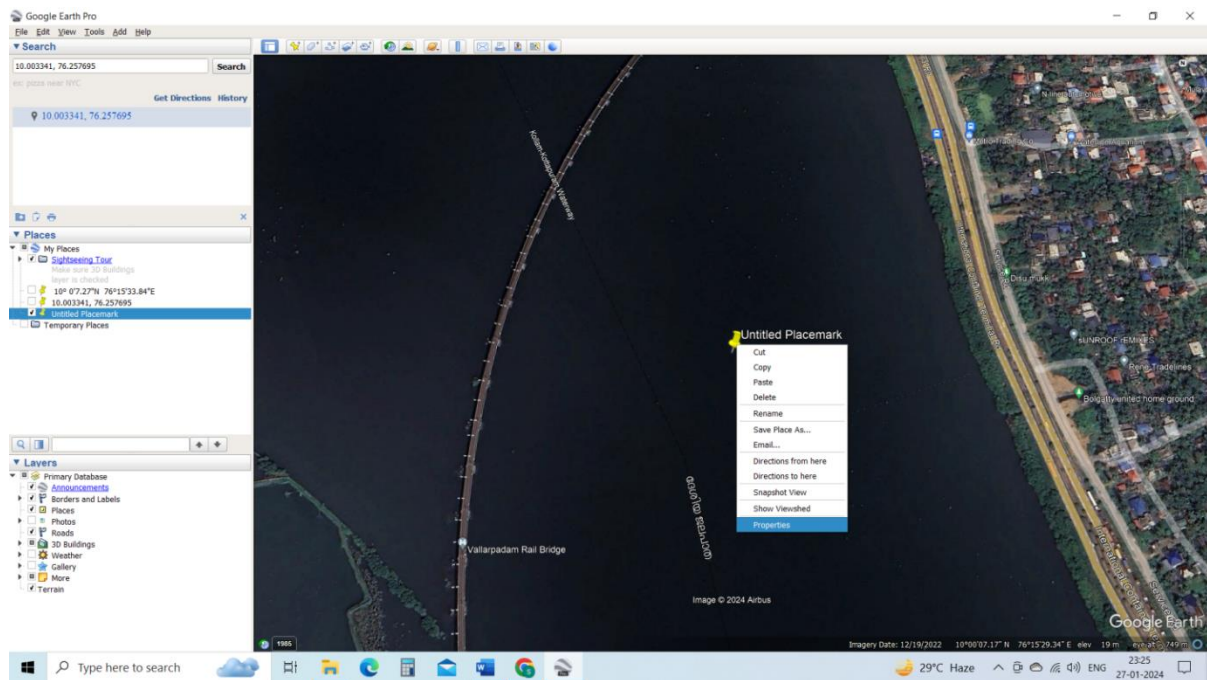
If you do not know the coordinates, but know the spot on the imagery, you can use the push button icon to add a place mark over the location. Using the properties menu of the place

mark, one can do the required modifications like changing the place mark title, icon style etc.

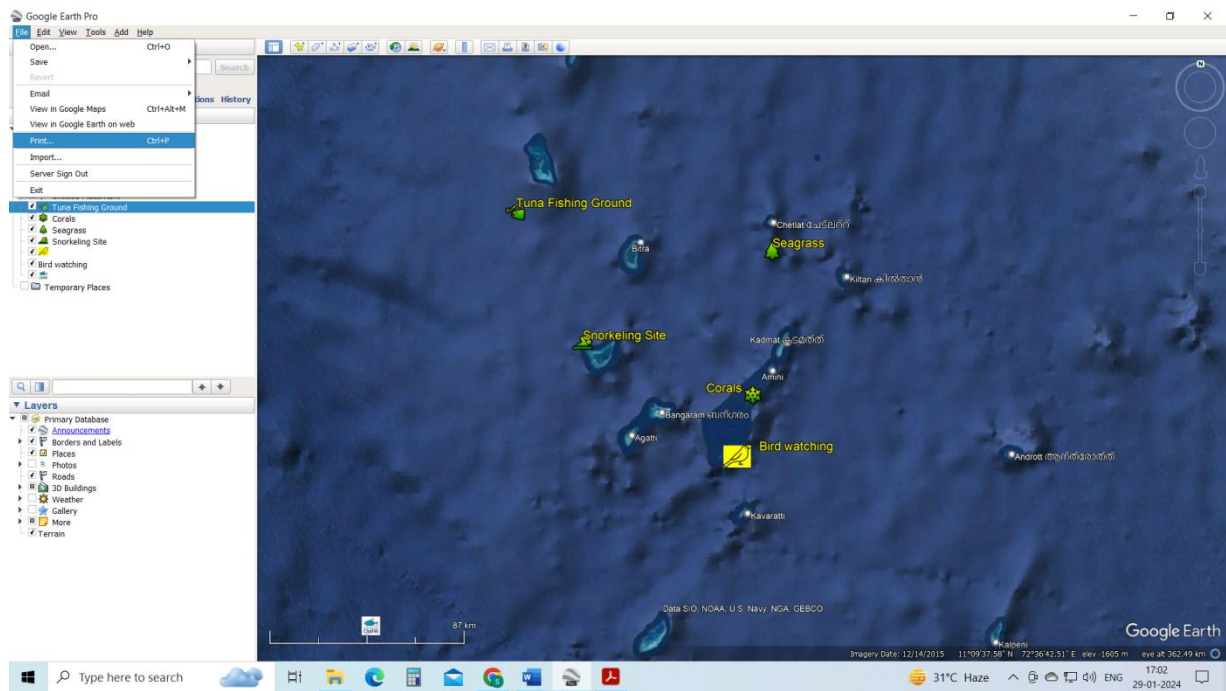


Right-clicking the placemark icon will open drop-down menu showing the properties button using which you can change the

placemark icon properties and do the editing.

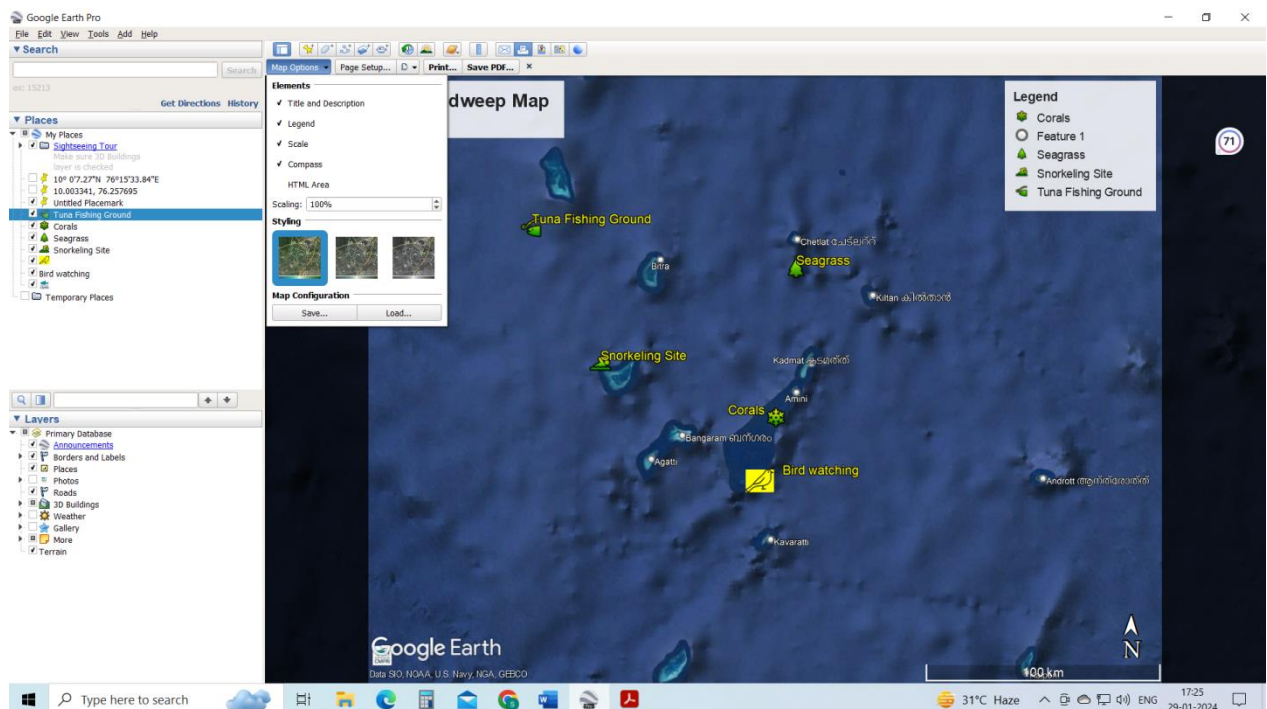


Once you are finished adding the placemarks, you can make the map composition from the print option of the File menu.

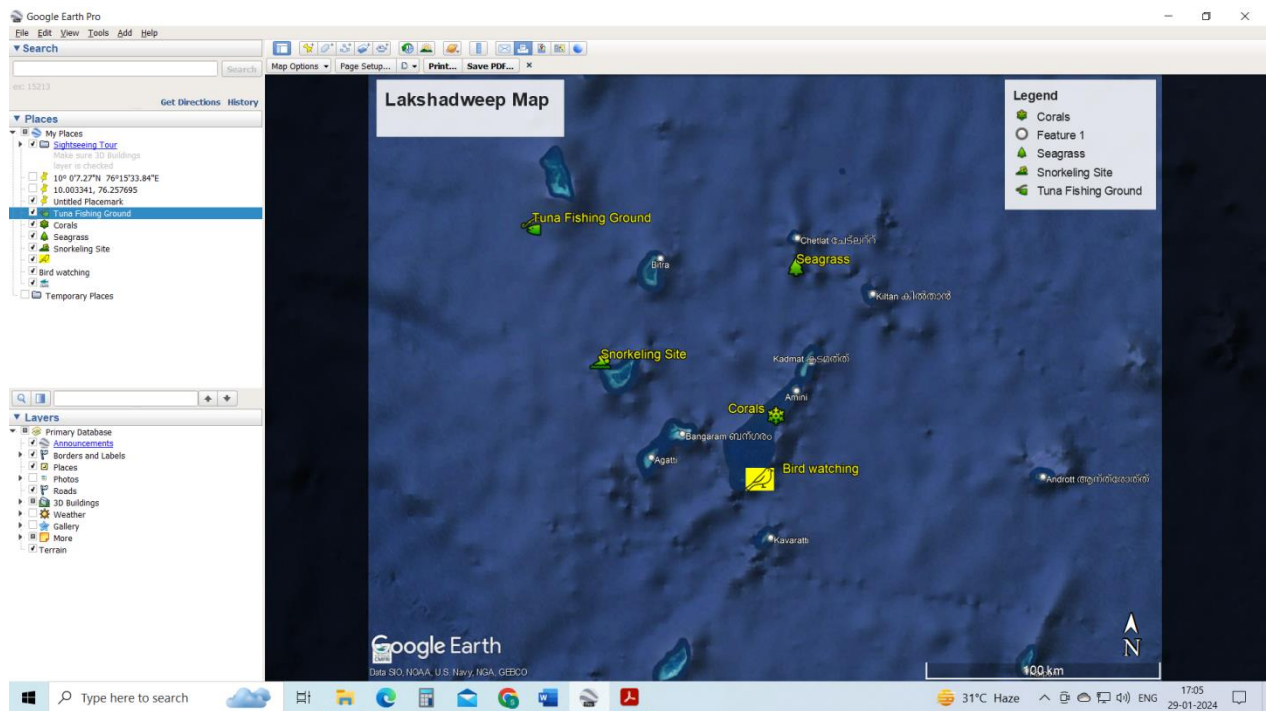


It will open up the print composition window using which you can add the map elements like

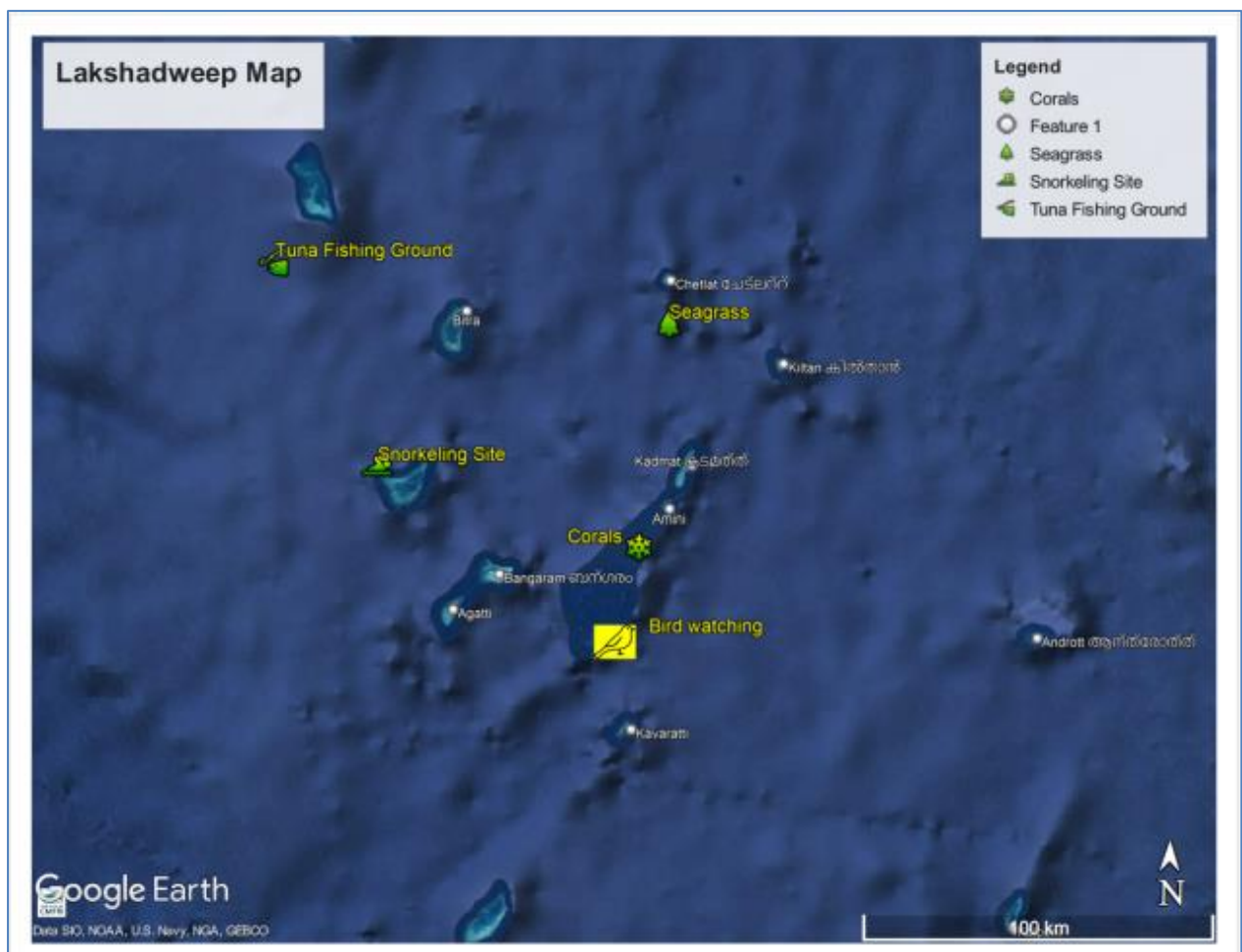
Title, north arrow, legend and scale from the 'Map options' menu.



Make necessary editing in the map elements and save the map/print the map.



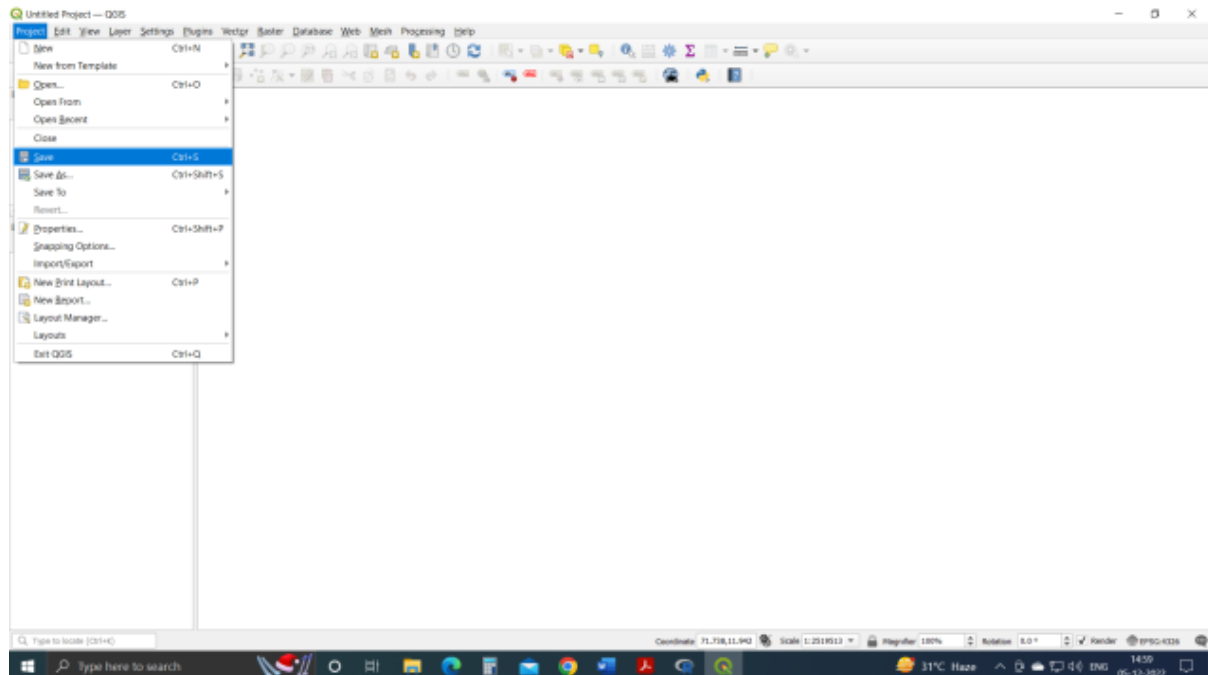
The saved map will look like as shown below.



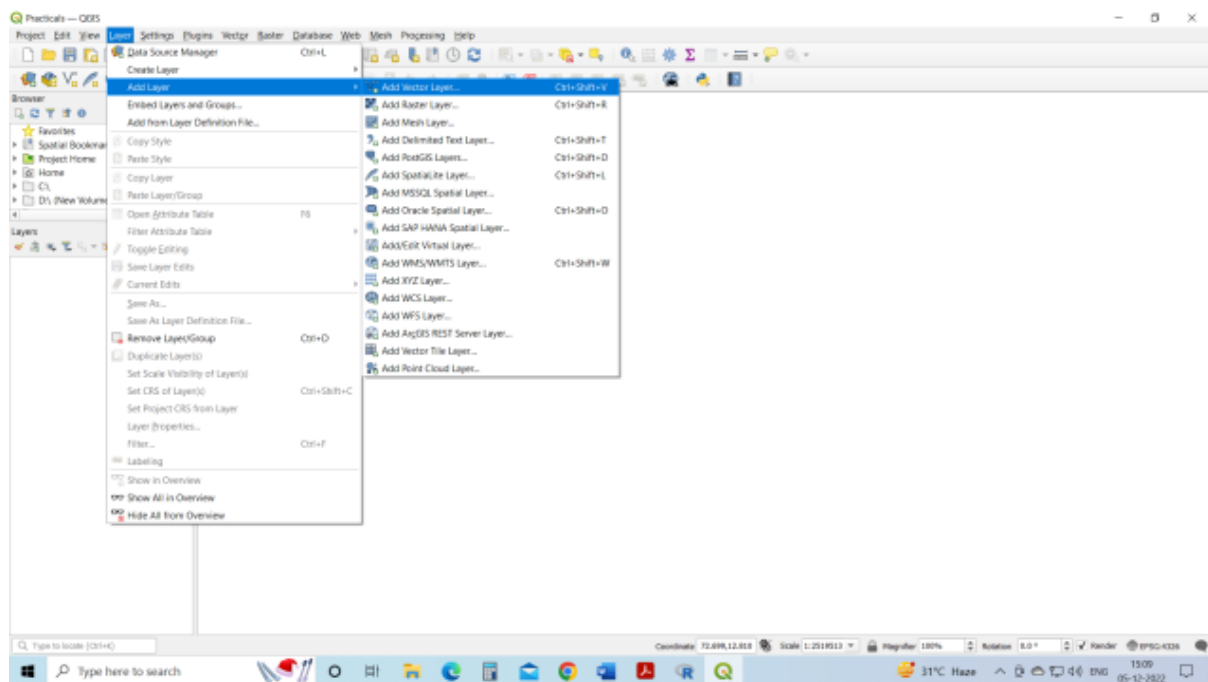
Making a Simple Location Map Using QGIS

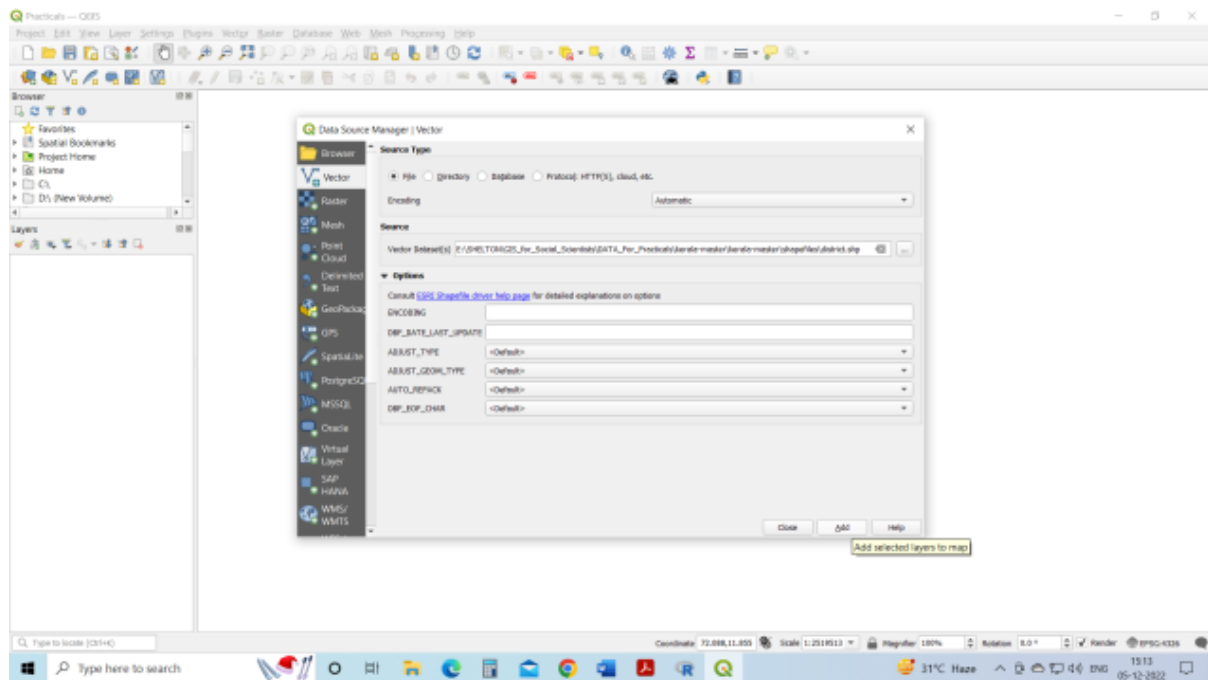
Here we learn to make a simple location map.

Open the QGIS software and give a name to the project. (Open QGIS>Project Menu>Save>give file name (Practicals.qgz))

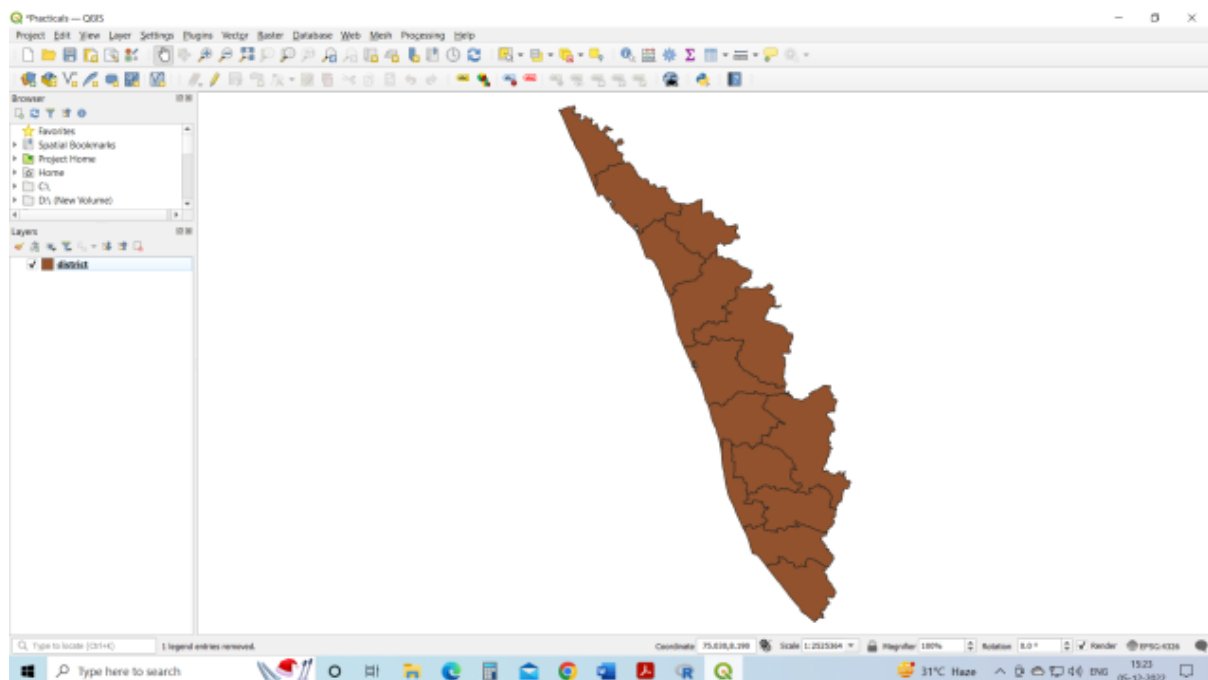


Now, load the shape file (District.shp). Layer Menu > Add Layer> Add Vector Layer> select the file name (District.shp)>Add.



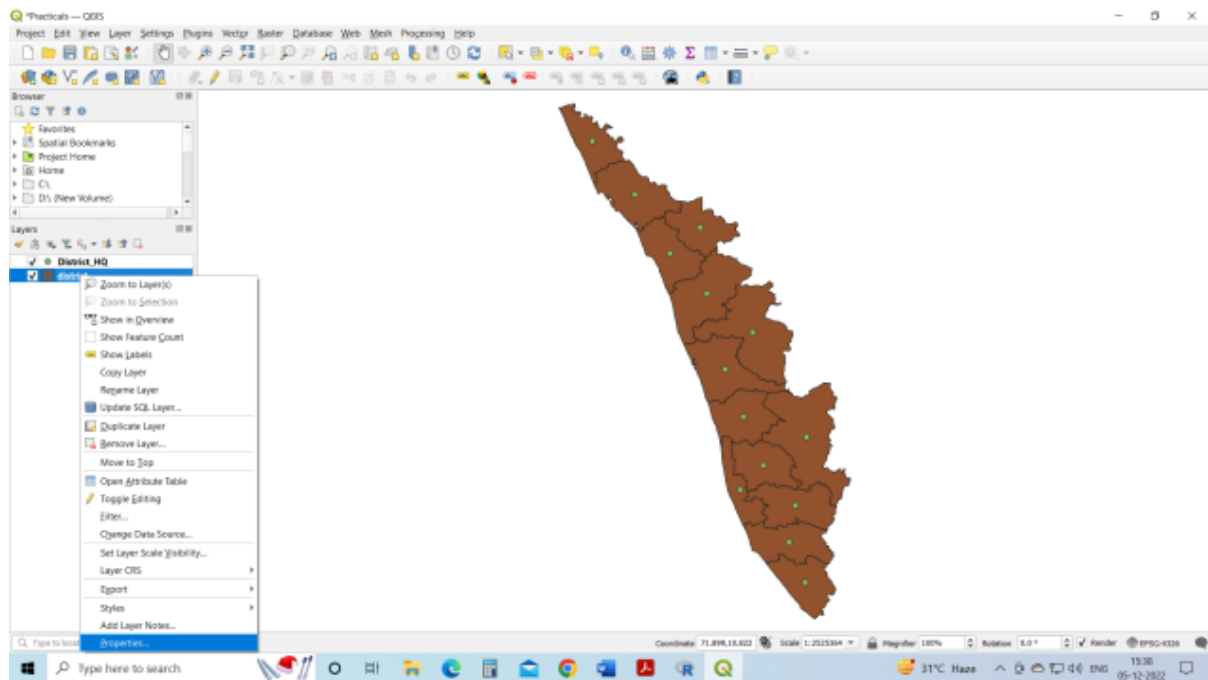


Now the Districts will appear in the map window and we can modify the appearance of the districts using the Layer panel.



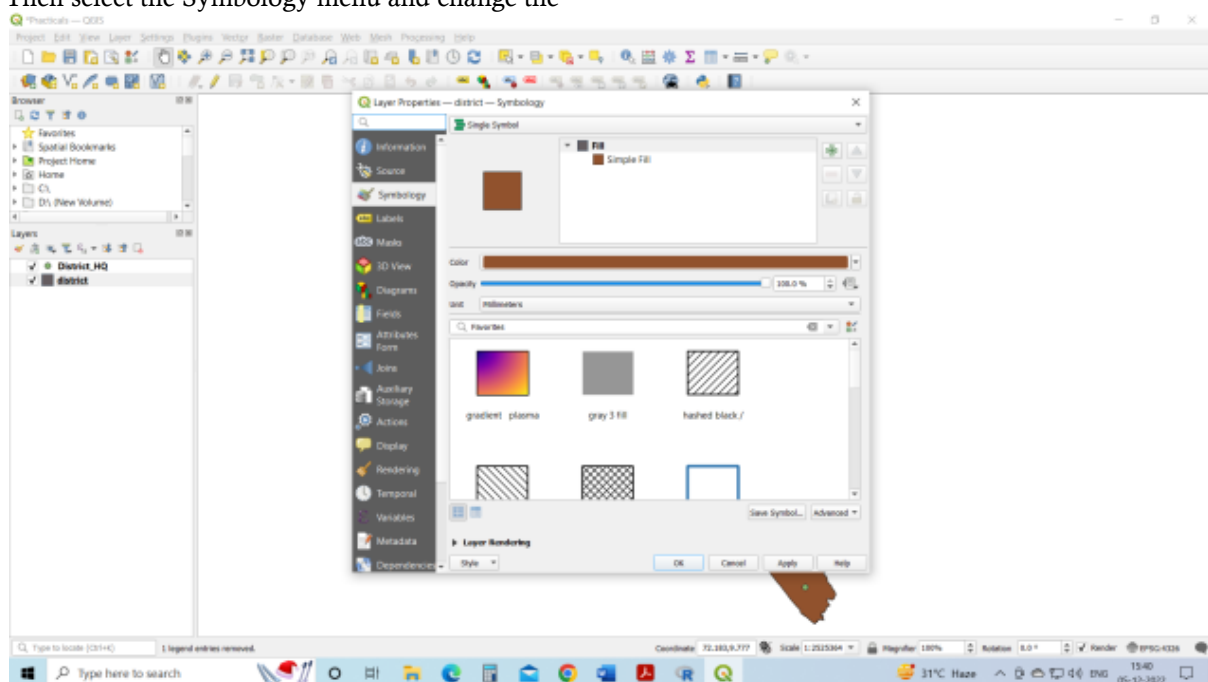
Likewise, add the file District_HQ.shp (Layer Menu > Add Layer> Add Vector Layer> select the file name (District_HQ.shp)>Add).

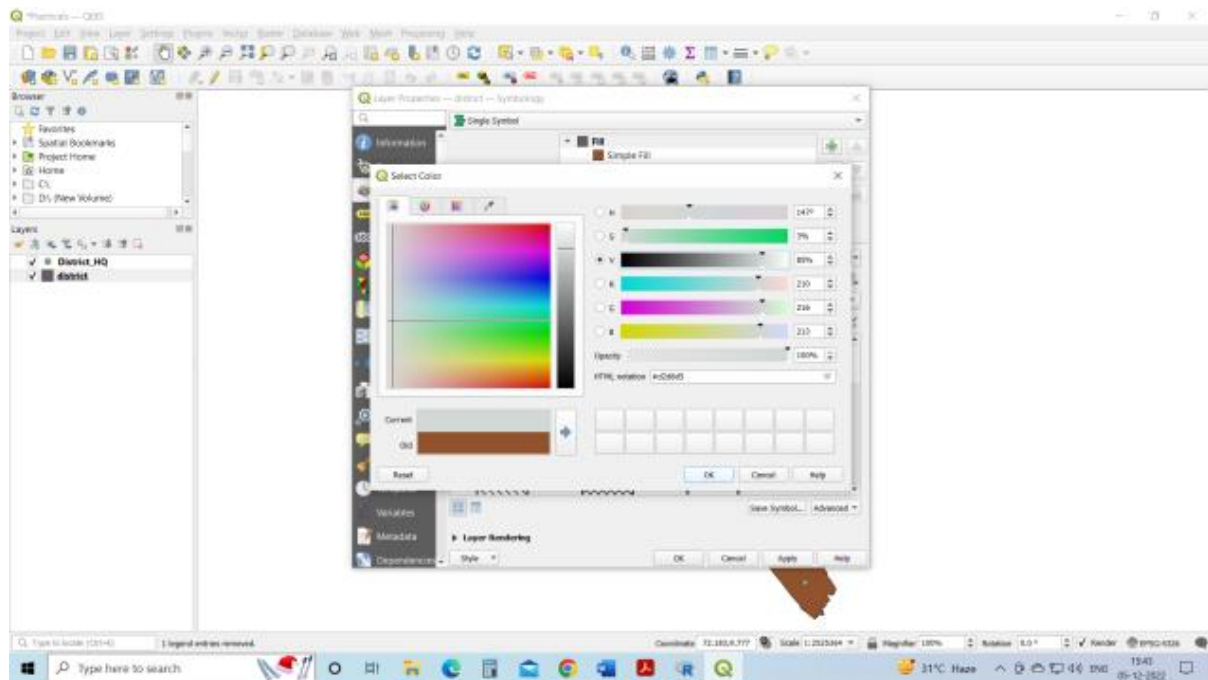
Now, we will change the appearance of the above vector files. Right-click the District.shp file in the layers menu to open its properties.



colour of the polygon by clicking the colour bar in the window.

Then the Layer Properties window will appear. Then select the Symbology menu and change the

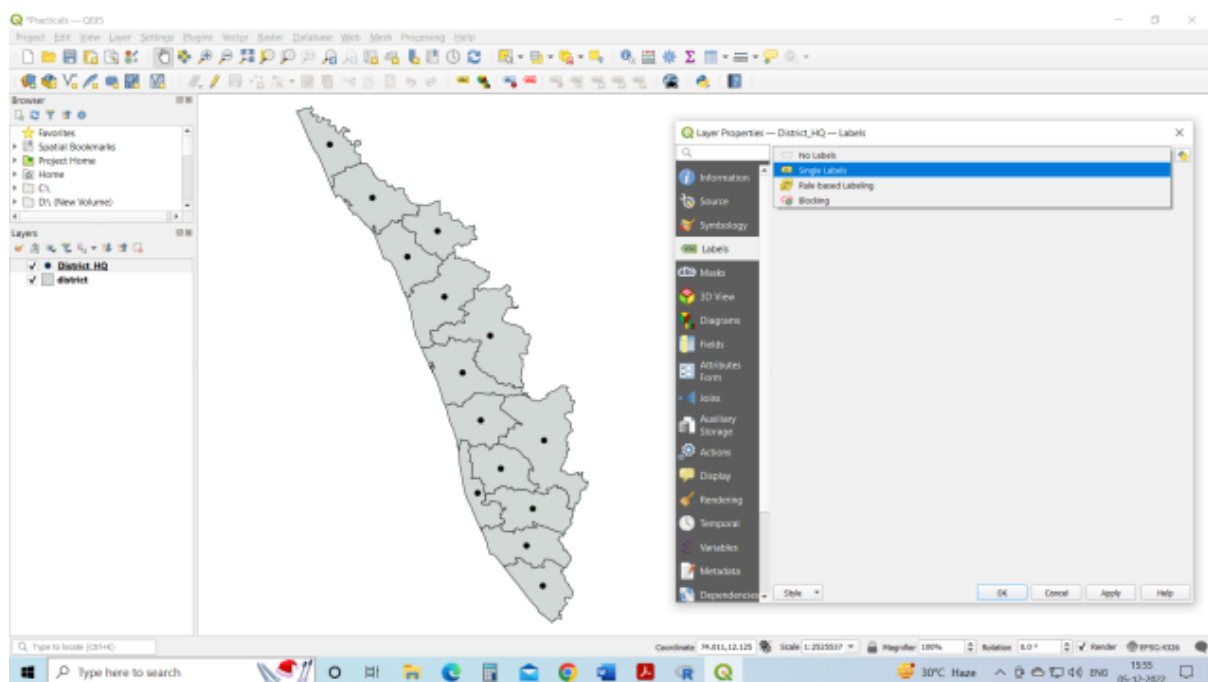




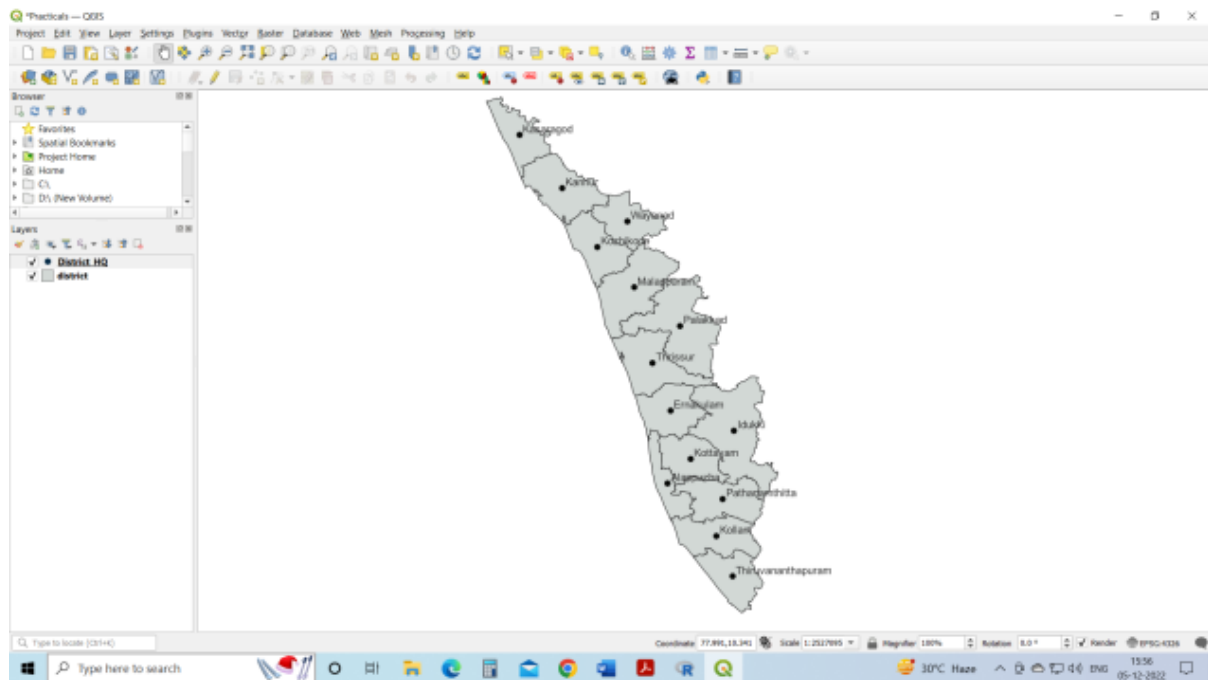
Likewise, change the colour of the District_HQ.shp file.

Now, we will add names to the points (District_HQ.shp). Right-click the District.shp

file in the layers menu to open its properties. *Layer Properties* window will appear. Then select the Labels menu and change the selection from *No Labels* to *Single Labels*.



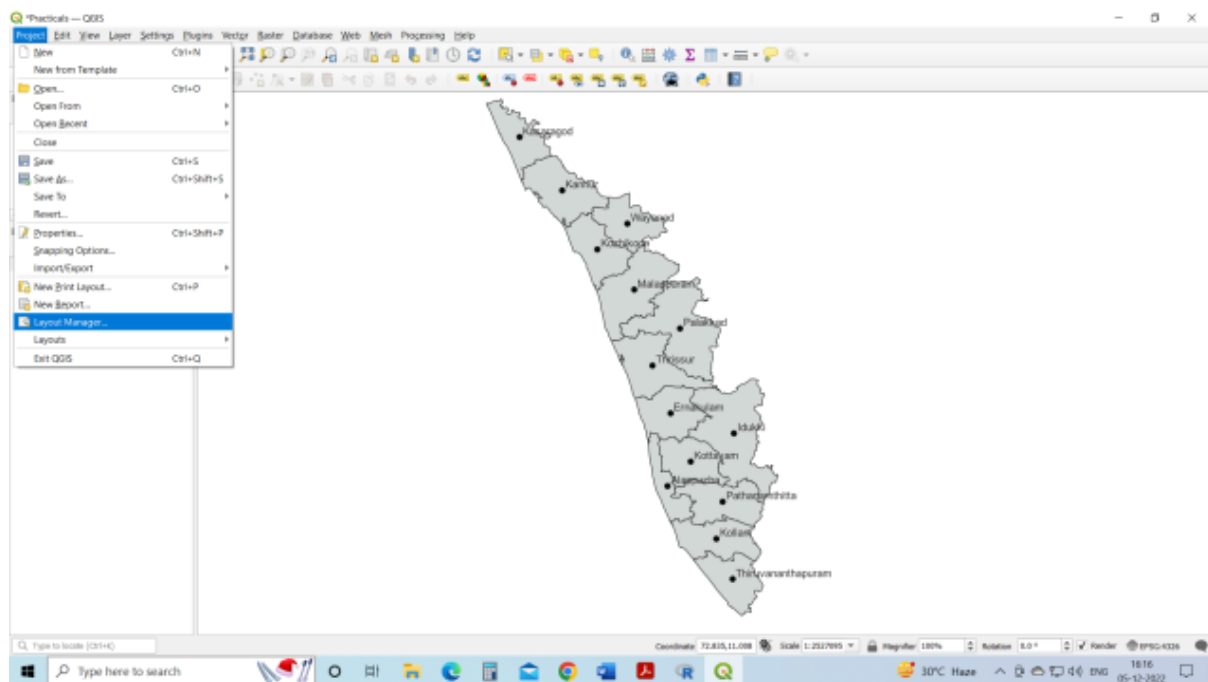
And click *Apply Button*. Now the District_HQ names will appear on the Map Window.

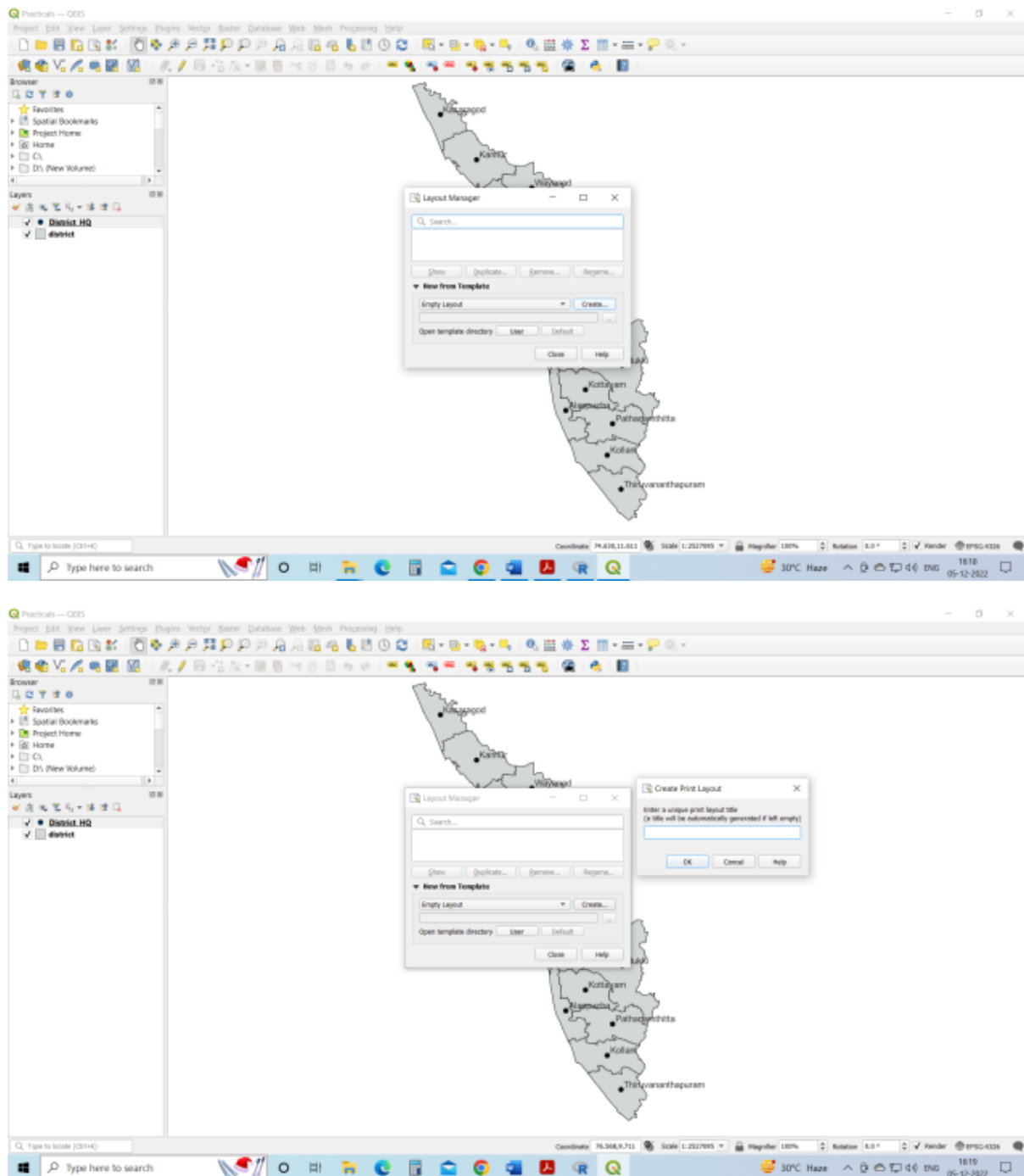


Now we will make a map layout from this data.

Go to the Layout Manager in the Project Menu (Project Menu>Layout Manager) and create an

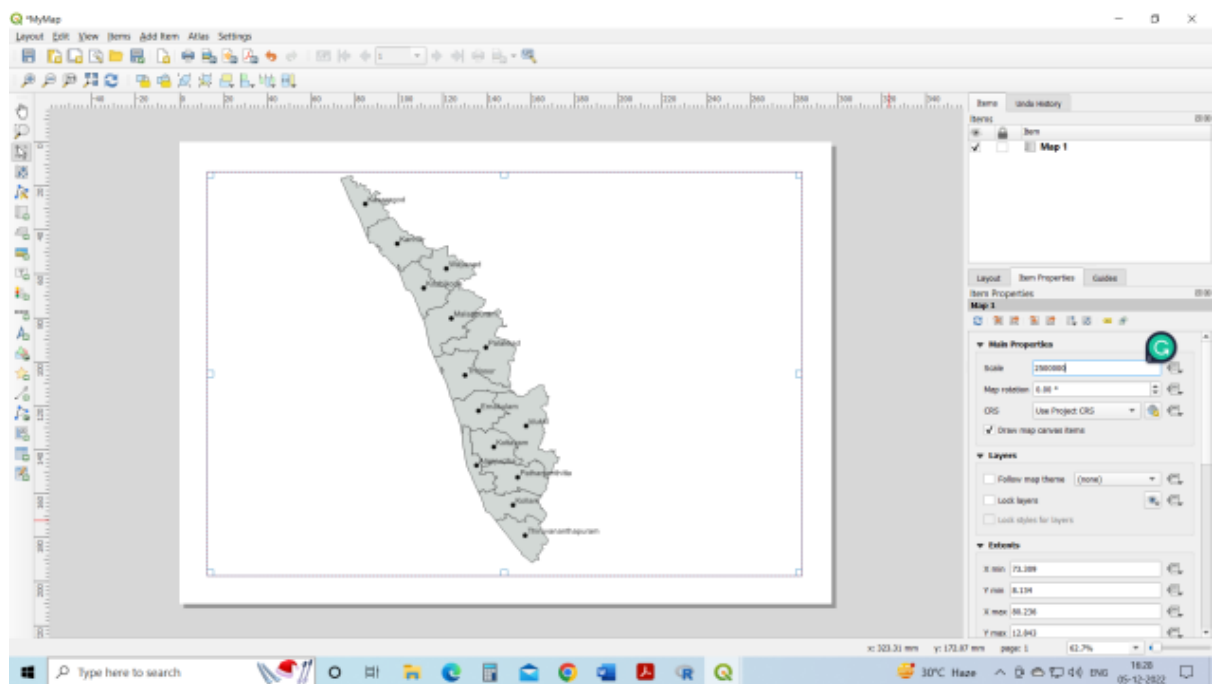
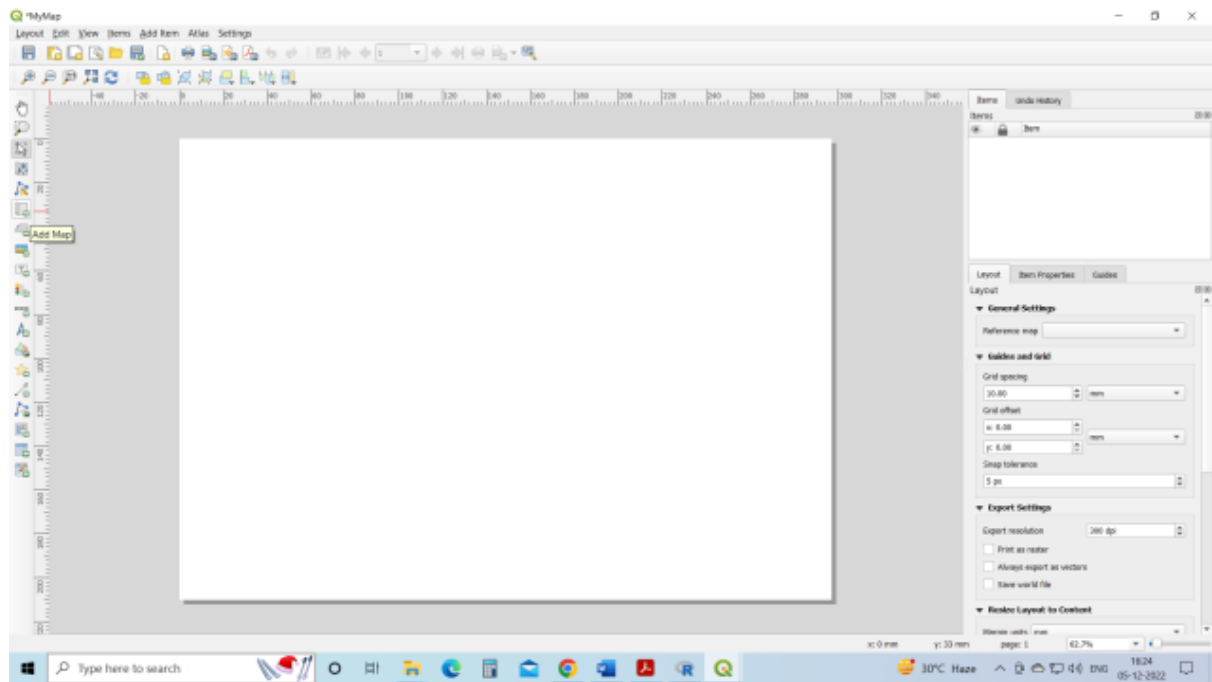
Empty Layout by clicking the create button in the Layer Manager, give a name for the Layout (*MyMap*) and press OK.



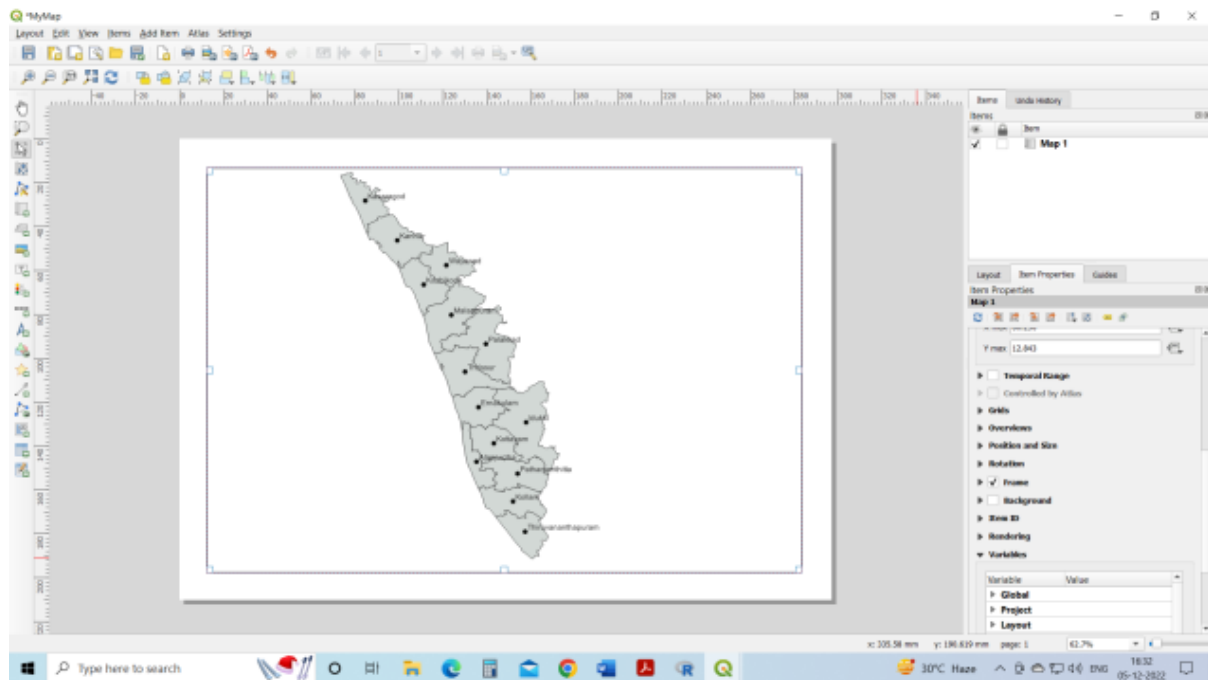


Now the MyMap layout will open up and one can make the necessary manipulations in it to make the map.

At first, we have to add the map to the *MyMap* layout by clicking the *Add Map* icon in the left panel of the map layout window and by clicking and dragging in the canvas.

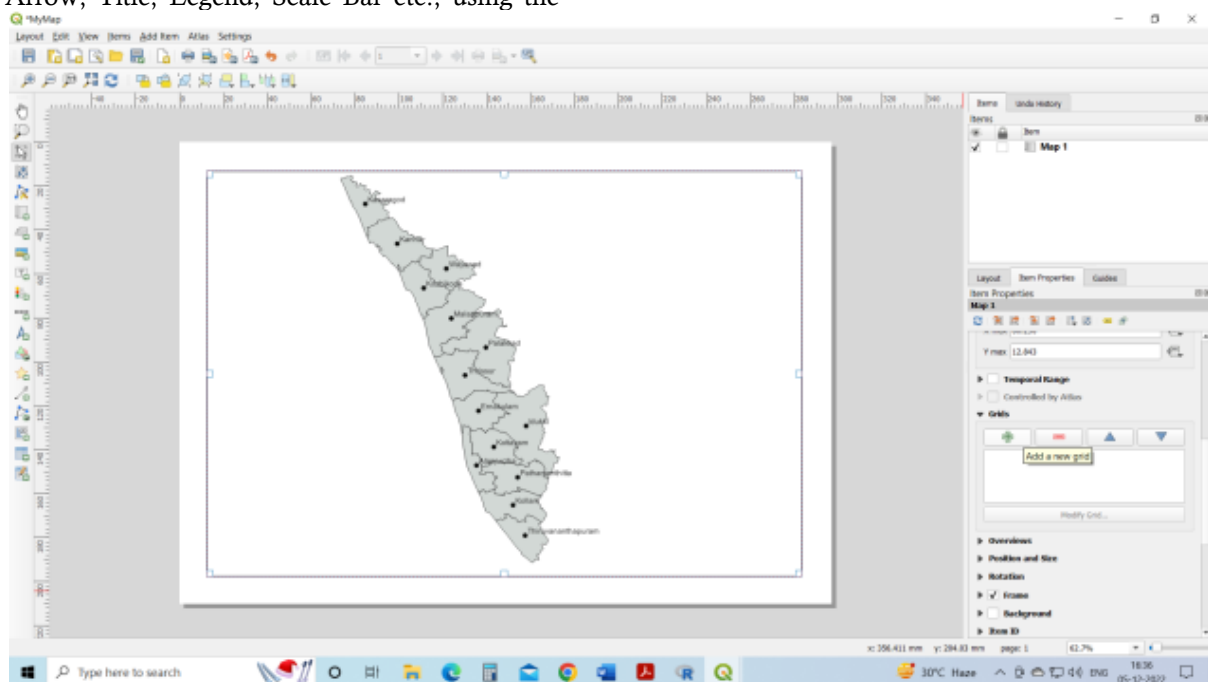


You can give a frame to the map by ticking the *Frame* option in the *Item Properties Menu* in the panel on the right side.



Now, we can add the lat-long grids to the map by adding a new grid to the map layout and changing its properties to suit the requirements. We can also add other map elements like North Arrow, Title, Legend, Scale Bar etc., using the

icons in the left side of the Map Layout Window. Once the map is ready, it can be exported as an image using the Export As Image icon at the top of the Map Layout Window.



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Marine Environmental Quality Assessments and Monitoring

23

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The marine environment refers to an environment where the water bodies such as oceans, seas, bays, estuaries and others interface and intermingle, both way with the atmosphere and lithosphere, and also towards the sea from the mean high-tide mark and vice versa. The marine environment is resultant of the physical, chemical, geological, biological and genetic factors contributing towards it. It also includes the various stages of associations, and features that interrelate and decide the productivity, status, and value of the marine ecosystem, the natural balance of the great bio-network.

Evaluating the environmental quality, by scrutinizing the disturbances in the ecosystems, plus the reciprocations of its manifold constituents to different stresses and forces, is the means as well as the challenging need for the preparation and execution of appropriate managing strategies, restoration protocols, and conservation measures and practices. Hence, environmental monitoring becomes an integral part of the environmental quality assessment.

The significance of water, sediment, and biota of the marine environment needs preservation in order that the environmental values are safeguarded. Environmental values point towards the beneficial uses or the strength of an ecosystem. Beneficial uses are the usefulness of the environment being good for the community gains, security, wellbeing, or aesthetic satisfaction. Ecosystem wellbeing is the natural healthy state of the environment itself and is evaluated in terms of the ecological constitution, utility, or ecosystem processes. The ecological standards can be influenced by emissions/discharges and degeneration of the environment, or loss or damage of the natural habitats.

In this chapter, the focus is given to two of the important constituents of the marine environment *viz.* the coastal and marine waters and sediment. The expression 'environmental quality' pertains to the extent of contents in water, sediment, or biota or changes in the

physical/chemical characteristics of water and sediment compared to its natural state. The strength of comprehension of normal situations in the locality of a development / responsible activity proposal, and the sensitivity/adaptability of prevailing biota to the stresses exerted by the development, will powerfully impact the extent of assurance of success in the formulation of the environmental quality criteria and forecast of the environmental outcomes. This can be achieved by means of an environmental impact assessment (EIA) procedure.

The water and sediment quality of the marine environment is also naturally influenced by the biotic and abiotic factors of the ecological system. Various ecological variables can be used as key indices for the appraisal of water and sediment quality of the marine environment. The integrated monitoring and measurement of the selected indicators will bring light to the current status of the health of the concerned ecosystem. Continuous/periodical monitoring of the marine environment is essential for their quality assessment and maintenance.

In the traditional method of marine and coastal environmental monitoring, representative sampling sites are selected based on a statistical design to suit the data analysis. Water and sediment samples are collected from these sites using approved protocols. In addition, there are contemporary means that can examine and estimate the environmental quality, pinpointing on biotic or abiotic parts, or both. When biotic components are incorporated in the evaluation and observation to judge the environmental quality, the aids used can vary from the individuals to the ecosystem, amid the ecological levels. Typical biological sensitivity can also be gauged utilizing ecotoxicological methodology, observation of physiological and behavioural responses in this regard. Whatever is the method of monitoring the environment, field-level sampling forms the first step in the assessment of the quality of the environment by quantifying selected indicator variables.

Water quality with reference to marine fisheries and mariculture

Water sampling

There should be no contamination during sampling and all the samples are properly sub-sampled and preserved to avoid/minimize changes in the water quality during storage. Niskin bottle sampler is used for collecting water samples from specific depths.



Fig 1 Niskin bottle sampler

Before sampling, the sampler and sampling bottles should be acid washed with 1N HCl in the laboratory and washed twice with clean water. They should be rinsed with distilled water. Care should also be taken to avoid the sewage flush out from the boats/ships at the time of sampling. Proper sampling is of utmost importance. Take adequate number of samples to have representative sampling of the water body. Sampling should be contamination free to evade invalid results on analysis. Samples should be appropriately sub-sampled for the different types of analyses as per researchable issue.

To avoid/minimize changes in the water composition during storage, standard preservation methods are to be adopted. The collected samples are to be kept in ice box in the field and under refrigeration in the laboratory till analysis. Sample holding duration under preservation varies with analytical variables. The processing protocol should be meticulously followed for individual samples. For dissolved oxygen (DO), the samples must be fixed immediately using Winkler's reagent onboard vessel itself. Samples for analysis of dissolved gases, pH and alkalinity

must avoid atmospheric contamination during sampling and subsampling.

Factors affecting the water quality

Temperature:

Water temperature is vital for the growth, reproduction, and overall health of fish concerned. Atmospheric temperature affects water temperature and density. The water temperature fluctuations can cause strain and disease in fish, leading to augmented mortality and lesser growth rates. Tropical fishes have a preference of 25 - 32°C. On the other hand, temperate fishes favour 10 - 15°C. Extreme temperatures can cause mortality.

There is depth-wise variability in water temperature. Unless there is a mixing of pelagic and benthic region, by wind or any other means, there can be thermal stratification in the ocean, with depth-wise decrease in temperature, especially in summer. Ocean temperature is useful for determining the location and variability of ocean currents and eddies, areas of upwelling where nutrients and ocean productivity may be abundant, atmospheric convection, determining heat exchange between the ocean and atmosphere as well and as an indicator of long-term climate change.

pH:

Optimal pH levels in coastal and marine waters help in avoiding stress and disease in fish and for better production. Fish are responsive to changes in pH. Photosynthesis (removal of CO₂) increases the pH, whereas addition of CO₂ (by respiration or dissolution of atmospheric CO₂ in seawater) decreases the pH. The pH change can affect growth, reproduction, and overall health of fish and shell fish. The recommended pH range is 6.5 to 8.5. Variation from this range can cause stress and disease in fish.

Total alkalinity:

Total alkalinity quantifies the neutralization ability of water when there is an introduction of a strong acid into the water. The presence of salts of sodium, potassium, calcium and magnesium containing ions of carbonates, bicarbonates, as well as hydroxides in the water is usually the source of total alkalinity in a water body. Total alkalinity below 20 ppm is considered as critical for natural waters, the optimum range being 80-120 ppm.

The measurement of total alkalinity in an aquatic system is done by titration of its representative water samples with HCl or H₂SO₄ i.e., a strong acid. The titration is to be done in two consequent events in the same Erlenmeyer flask, keeping a white background underneath to

detect colour change easily. In the initial phase, use phenolphthalein indicator to pH 8.3. In the second phase, add methyl orange as indicator and titrate with further drops of acid to pH 4.2. The volume of acid used under each titration is quantified in terms of CaCO_3 equivalent value and the sum of the two together being the total alkalinity. The unit of total alkalinity is milligrams per liter of calcium carbonate ($\text{mg l}^{-1} \text{CaCO}_3$).

Salinity:

Salinity is the total concentration of all ions in a known quantity of water. Salinity is an important attribute of natural waters that decides what species of aquatic animals are present in that water body. The changes in salinity affect the growth and survival of the concerned species.

Dissolved oxygen:

The aquatic organisms require oxygen to respire, and dissolved oxygen (DO) is a very important water quality parameter in the marine environment. The ideal DO range for most fish species is 5 - 7 mg l^{-1} . Low DO can bring about stress, disease, and mortality in fish. Maintaining optimal DO levels is indispensable for the survival and growth of fish.

Dissolved carbon dioxide:

The concentration of carbon dioxide (CO_2) increases when respiration exceeds photosynthesis. Saturation of CO_2 occurs during early morning. When CO_2 enters fish blood it lowers the blood pH and reduces the ability of a fish's blood to transport oxygen. Favourable range of CO_2 concentration in water is < 5 mg l^{-1} .

Oxidation Reduction Potential or Eh:

Oxidation reduction potential (ORP) is a measure of the proportion of oxidized to reduced substances in water. It is measured with respect to Hydrogen electrode (Eh). Eh range of natural waters 0.45 – 0.52 V. Appearance of Fe^{++} ion at 0.2 V coincides with depletion of oxygen in water. Below 0.2V, the transformation of sulphate to sulphide occurs.

Nitrogenous compounds:

Nitrogenous compounds, such as ammonia-N, nitrate-N and nitrite-N cause major water quality problems in marine environment and aquaculture. Toxicity with total ammonia-N (TAN) is very significant, with toxic levels causing mortality and reduced growth rates in fish. High levels of Total ammonia-N, nitrite-N, and nitrate-N can be toxic to fish and other aquatic organisms. The concentrations greater than 0.1 mg l^{-1} for TAN, 0.5 mg l^{-1} for nitrite-N and 100 mg l^{-1} for nitrate-N are toxic.

Total Suspended Solids (TSS) and Turbidity:

High levels of total suspended solids and turbidity in the coastal and marine environment can reduce light penetration, affecting the growth of aquatic plants and algae (essential energy sources in the aquatic food chain). High levels of total suspended solids (> 100 mg l^{-1}) can cause a reduction in growth rates and a rise in fish mortality.

Marine Sediment

Marine sediment is any deposit of insoluble particle, mainly rock and soil constituents, carried over from land region to the ocean by wind, ice, and rivers, plus the remains of marine organisms, submarine volcanism products, chemical precipitates from seawater, and matter from outer space that accumulate on the seafloor. All areas of the seafloor hold some form of sediment. There are different types of sediments from diverse sources, and the quantity of accrued sediment varies from place to place.

Sediment sampling

Sediment can be sampled using a grab. Usually Van Veen grab is used for this purpose. Van Veen grab having a sampling area of 0.1 m^2 is a standard device for sediment sampling. This is a proficient soft sediment sampler which can be used for a variety of sediments occurring in the coastal near shore as well as the marine areas. It is consistent and easy to run and it has broad-spread relevance, so that data comparison of other regions is possible.



Fig 2. A Van Veen grab

Sample should be representative of the area sampled. Collect at least four replication samples from a station. Pool these replicate samples in a wide basin. The pooled sediment is mixed meticulously. Then quartering is done, taking away the opposite quarters as shown below.

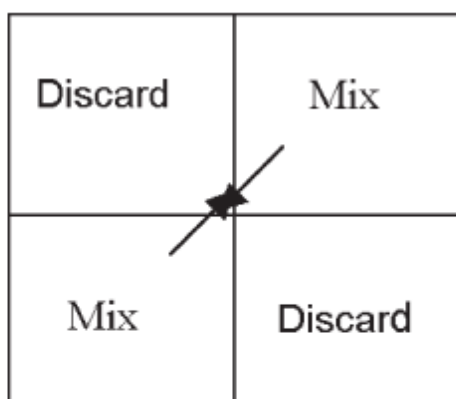


Fig 3 Quartering of sediment sample
Quartering is done till a substantial quantity i.e., around 500 g sediment is obtained. Collect in heavy duty plastic bags with self sealing facility.

Sediment processing

Do not store the sediment in wet condition for more than one day. Wet samples should be kept under refrigeration if storage is needed in the wet stage for more than one day. Then air-dry the sediment in shade in well-ventilated places. To reduce drying time, oven drying can be done at 50-60°C. (Temperature should not be increased above 60°C since it will cause loss of nutrients). Then pulverize the sediment gently by breaking clods using a pestle and mortar. (Do not over grind the sediment so as to break the sand particles, which will cause errors in textural analysis). Then sediment samples can be stored in well-labelled, capped plastic bottles or heavy-duty plastic bags. At this stage, the sample is ready for analysis. While storing, store in a dry place.

Sediment Quality

The physical and chemical characteristics of water are influenced by the characteristics of bottom sediments. The bottom sediments provide food and shelter for the benthic organisms and also act as a reservoir of nutrients for the growth of benthic algae which constitute food for aquatic organisms. The sediment also functions as a buffer and governs the storage and release of nutrients into the water. It serves as a biological filter through the adsorption of organic residues of food, excretory products and algal metabolites. The sediment holds high bacterial load which helps in decomposition and mineralization of organic deposits at the bottom. The nature and decomposition of sediment have important roles on the balance of coastal ecosystems and also in the inorganic and organic nutrients present in the coastal and marine water.

Factors affecting sediment quality

Sediment texture:

Sediment texture is the relative proportion of size of the mineral particles (sand, silt and clay). Sediment of sandy loam to silty clay texture is fairly good in productivity on aquaculture point of view.

Sediment pH:

Weak alkaline soil reaction (pH 7-8) had been found to be good for good fish productivity. Culture systems with acidic soils are generally less productive than with alkaline soils.

Organic Carbon:

Organic carbon is the most important factor determining the fertility status of soil/sediment. Organic carbon content originates in sediment due to the presence of organic matter. Organic matter contains 58% carbon. The soil organic matter binds soil particles which help the soil to maintain favourable conditions to facilitate aeration and permeability. It increases the water-holding capacity of soil and serves as a reservoir of the chemical elements that are essential for aquatic productivity. It helps in reducing soil alkalinity and acts as a buffer against rapid changes in pH. It serves as a source of energy for the growth of benthic microorganisms and helps in dissolving minerals to be absorbed by the growing plants. Biogeochemical processes undergoing in the bottom sediments tend to release nutrients into the water above by bacterial action on the sediments. Organic cycling in shallow brackish water systems is governed by the rate of conversion of living tissues into detritus and secondarily the rate of conversion of detritus into dissolved organic and inorganic forms of nutrients of which the former is faster. Secondary levels result in accumulation of organic detritus at the bottom.

Sediment colour:

Sediments exhibit a wide range of colour and when covered long enough with water they often develop darker shades of the original colours. A brown crust at the soil-water interface is a good sign, since it indicates that there is dissolved oxygen at the interface. A jet black colour at the sediment-water interface is undesirable since it reveals the absence of dissolved oxygen. When dissolved oxygen is depleted in the surface layer, compounds of ferrous iron form to produce black colour. In most pond bottoms, a jet black layer will occur a few centimetres below the sediment surface. Hydrogen sulphide is produced only in highly reduced black mud, but not all black mud is sufficiently reduced to produce H_2S . Sometimes reddish precipitates can be seen

on the bottom in shallow waters. This is more common in acidic systems with acid sulphate soils. Positive correlation is seen between fish production and organic carbon and it is found that 1.5% to 2.5% of organic carbon in sediment showed high fish production potential.

Conclusion

Good water quality is a key factor for sustaining fisheries healthy and productive in aquaculture operations. Factors such as temperature, pH, dissolved oxygen, nitrogenous compounds, total suspended solids etc. can affect water quality and fish health. Regular monitoring of these factors is necessary for the management of the environmental situations. The participatory approach in environmental management is very relevant in the present level culture systems. For 'environment management', we don't directly 'manage the environment'. It is human behaviour and actions that have an impact on the environment are to be altered with citizen co-operation to achieve environmental sustainability for economic productivity.

Based on thorough assessment of marine / coastal environmental quality, by way of continuous / periodical monitoring, water quality indices or ecosystem health indices can be derived from the generated dataset during the process, reflecting the current status of the environment. These indices can result in the formation of guidelines / policy suggestions to manage the environmental situation positively.

The Driver-Pressure-State-Impact-Response (DPSIR) method refers to a supple structure useful for decision-makers in relating human activities with the state of the environment (Fig 4). Drivers mean the growth in terms of population and socio-economic status in societies and the resultant altered lifestyles, patterns of consumption, and outlines of production. Drivers get reflected in anthropogenic actions which may knowingly or unknowingly force the environment to bear Pressures. Alterations in the State of the environment may be brought about by the pressures put forth by the community. The State is the situation of the biotic and abiotic constituents of the environment in a selected ecosystem expressed as the physical, chemical, and biological variables unique for that ecosystem. Changes in the features and performance of the environment will influence the services provided by the selected ecosystem and the wellbeing of the people dependent therein.

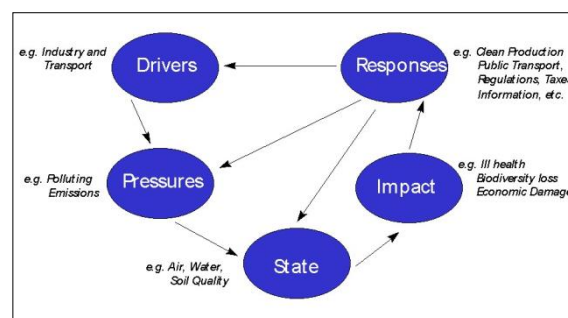


Fig 4 The DPSIR Framework

Ecosystem goods and/or services denote ecosystem functions/processes that openly or circuitously help people in their societal/fiscal drivers, or hold the future potential to do so. In Response to the consequences on the services provided by the selected ecosystem or their seeming values, decisions are taken by the environmental managers. These responses include sole or group action plans formulated by people and the government to avoid, recompense, restructure, or acclimatize to alterations in the status of the environment. Appropriate evaluation and observation plans for the environmental status at the ecosystem plan needs a deep understanding regarding the services delivered by the ecosystem selected for scrutiny, as well as a detection of its significance spanning the manifold dimensions (e.g., environmental, societal, cultural and fiscal).

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Planktonic microorganisms in the global oceans are crucial as the main sustenance for filter-feeding organisms. Hence, the normal proliferation of the plankton species is beneficial for fisheries and aquaculture. Nevertheless, under certain circumstances, algal blooms can result in adverse consequences, leading to significant economic losses in aquaculture, fisheries, and tourism operations. While not all algal blooms are harmful, some produce toxins or other harmful substances that can pose serious threats to various organisms.

Algal blooms causing a discoloration of seawater are commonly known as 'red tide.' Harmful Algal Blooms (HABs) refer to the rapid and excessive growth of certain types of algae in aquatic environments, such as freshwater and marine ecosystems, producing adverse or detrimental consequences on aquatic life and humans. HABs pose risks to human health if they contaminate drinking water or if people consume seafood that has been exposed to these toxins. The Key characteristics of HABs include algal overgrowth and toxin production. HABs involve an unusually high concentration of algae, often creating a visible discoloration of the water. The excessive growth is typically fueled by factors such as nutrient enrichment (e.g., nitrogen and phosphorus), warm temperatures, and sunlight. The most crucial factors contributing to the rise of harmful algal blooms are recognized to be low nitrogen/phosphorus ratios and elevated temperatures.

HABs have been on the rise globally in recent decades, exhibiting increased frequency, prolonged duration, expanded regional coverage, and greater economic repercussions. These trends are attributed to factors such as heightened coastal eutrophication and climate change, as well as the introduction of invasive species through ballast water exchange. It is a global phenomenon,

reported from over 30 countries including India (Padmakumar et al., 2012). In India, the instances of bloom occurrences reported before and after the 1950s show a notable increase in their numbers (D'Silva et al., 2012).

India, being a prominent maritime nation, featured a vast coastline. The country's marine environment encompasses various complex habitats, fostering a rich diversity of flora and fauna. Moreover, India's expansive marine environment serves as a crucial source of sustenance for a substantial population, providing livelihoods for over 3.5 million individuals and contributing significantly to the country's economy (Nayak, 2017). Nevertheless, the persistent occurrences of microalgal blooms, including HABs, pose a threat to these ecosystems and the associated economic, social, and ecological services they offer.

Coastal habitats, characterized by their shallow depths and proximity to land, are particularly sensitive to changes in environmental conditions. This susceptibility stems from factors such as variations in water temperature, salinity levels, nutrient inputs, and human activities like pollution and coastal development. The Indian fishing industry relies significantly on the coastal region for its marine resources, making it particularly vulnerable to limitations imposed by red tides and harmful microalgae (Padmakumar et al., 2012). Several investigations depicted that about 39 different species were accountable for causing blooms in Indian waters (D'Silva et al., 2012). *Noctiluca* (dinophyceae) and *Trichodesmium* (cyanophyceae) were identified as the dominant bloom-forming genera. Efforts to manage and mitigate Harmful Algal Blooms often involve monitoring water quality, studying environmental factors that contribute to bloom formation, and implementing measures to reduce nutrient inputs into water bodies. Rapid detection and response are crucial to minimizing the potential harm associated with HABs.

Different types of HABs

Algal blooms have the potential to generate various toxins. A variety of microalgal groups, including dinoflagellates and diatoms, can give rise to HAB, with many of them producing toxins that can adversely affect both aquatic life

and human health. Typically, bloom-forming species can be divided into three primary groups;

1.Species that are capable of producing water discolorations that are generally harmless. Under certain circumstances, especially within sheltered bays, these organisms can proliferate to such an extent that they result in widespread fatalities of fish and invertebrates. This adverse impact occurs due to oxygen depletion caused by the overwhelming proliferation of these algae under certain circumstances.

E.g. Dinoflagellates:*Noctiluca scintillans*,
Gonyaulaxpolygramma, *Trichodesmiumerythraeum*

2.Species that generate powerful toxins capable of infiltrating the food chain and inducing a range of gastrointestinal and neurological ailments in humans.

Dinoflagellates are often cited as the most toxic algae, but diatoms and cyanobacteria can also

produce harmful chemicals.The neurotoxic and hepatotoxic metabolites from cyanobacteria endanger both humans and animals, accumulating in fish livers and kidneys. (Sonak et al., 2018).Monitoring and understanding the prevalence of these toxins in aquatic environments are crucial for safeguarding the health of both aquatic ecosystems and human populations. The different toxin associated problems are detailed in Table 1.

3.Non-toxic to humans, yet harmful to fish and invertebrates by gill damage or blockage.These microalgal blooms are normally harmless to human. But the incidence of the blooms is detrimental in sheltered bays and in aquaculture systems. These blooms seriously affect the feeding responses and respiratory mechanisms.

E.g. *Gymnodinium Mikimoto*;
Chrysochromulinasp.,*Chaetocerossp.*, and
Prymnesiumsp.

Table 1: Types of toxins produced due to algal blooms and its related problem

Name	Causative species	Type of toxins	Toxin pathway	Remarks
PSP	<i>Gymnodiniumcatenatum</i> , <i>Alexandrium spp.</i> , <i>Pyrodiniumbahamense</i>	Saxitoxins, gonyautoxins, neosaxitoxin, C- Toxin	Consumption of contaminated shellfishes like mussels, clams and fishes like sardines, etc.	Incidence of PSP reported in east and west coasts of India
DSP	<i>Dinophysisspp.</i> , and <i>Procentrumspp.</i>	okadaic acid and its derivatives (lipophilic toxins)	Consumption of contaminated shellfishes	DSP in infected shellfishes were reported from Karnataka (Karunasagar et al., 1989). It is characterised by gastrointestinal symptoms
ASP	<i>Nitzschiaspp.</i>	Domoic acid	Consumption of contaminated shellfishes	Causes gastrointestinal and neurological disorders
CFP	<i>Prorocentrumsp.</i> , <i>Ostreopsisspp.</i> , <i>Amphidinium sp.</i> , <i>Thecadinium sp.</i>	Ciguatoxins / maitotoxin	Consumption of contaminated small algae-eating fish	Characterized by cardiovascular and neurological symptoms
NSP	<i>Kerenia brevis</i>	Brevetoxins	Consumption of contaminated shellfishes and seagrasses	Characterized by cardiovascular, respiratory and neurological symptoms. It affects both aquatic animals like dolphins, mantis, sea turtles, etc., and humans. Also, associated with massive fish kills

Need of Addressing HABs

1) **Ecological Impact:** HABs can disrupt the ecological balance of aquatic ecosystems. The rapid growth of algae can lead to hypoxic conditions in the water, negatively affecting fish and other aquatic organisms. This disruption can have cascading effects on the entire food web, impacting biodiversity and ecosystem health.

2) **Fisheries and Aquaculture:** HABs can have serious economic consequences for the coastal fishing industry due to substantial impacts on the wild fish populations. Algal blooms also lead to the closure of fishing grounds affecting the livelihoods of those dependent on fisheries and aquaculture. The global shellfish aquaculture is reported with the incidence of algal bloom related fish deaths due to damage of gill tissues (Hallegraeff, 1993).

3) **Public Health Concerns:** Monitoring and managing HABs are essential to ensuring the safety of seafood and protecting public health. To date, there have been four cases of Paralytic Shellfish Poisoning (PSP) reported in the coastal areas of Tamil Nadu (1 case), Mangalore (2 cases), and Kerala (1 case) (Table 2)(D'silva et al., 2012).

4) **Tourism Impact:** Coastal tourism is an essential part of India's economy. HABs can lead to the discoloration of water, foul odors, and the presence of harmful toxins, negatively impacting the aesthetics of coastal areas. This can deter tourists and have economic consequences for communities relying on tourism.

Table 2: Human health impact of HABs reported in India

State	Year	Incident	Plankton sp.	Remarks
Tamil Nadu (Valayar village)	1981	PSP like – death of 3-person, 35 hospitalisations	Not identified	Consumption of <i>Meretrix casta</i>
Kerala (Vizhinjam)	1997	PSP like – 7 death and 500 hospitalisations	Not identified	Consumption of <i>Perna indica</i>
Karnataka (Mangalore)	2015	CFP – 2 hospitalisations	<i>Gambardiscussp.</i> (suspected)	Consumption of snapper
Kerala (Trivandrum)	2016	CFP – 6 hospitalisations	<i>Gambardiscussp.</i> (suspected)	Consumption of snapper
Kerala (Malabar coast)	2005	Stench from sea – 200 children hospitalised	<i>Heladosphaera</i> <i>Karenia brevis</i>	sp., Neurotoxin

Causes of HABs

The causative factor of algal bloom varies with the environmental settings of different regions.

- Coastal pollution

Coastal pollution, stemming from diverse sources such as domestic and industrial effluents, stands out as a significant contributor to HABs due to cultural eutrophication (caused by increase in human population). The introduction of pollutants into coastal waters, including nutrients from sewage, surface runoff and industrial discharges, can lead to a phenomenon known as eutrophication. Eutrophication involves an excessive accumulation of nutrients, such as nitrogen and phosphorus, in aquatic

ecosystems. The native flora and fauna may be forced out as the environment becomes more nutrient-rich, with substances like nitrates and phosphates increasing. Changes in water temperature and fluctuating phosphorous-nitrogen ratio creates conditions conducive to the growth of cyanobacteria. The escalating eutrophication, driven by increased nitrogen and phosphorus inputs, results in a high nutrient-to-silicate ratio, favoring non-diatom species, including several harmful flagellates.

- Dust Storms and Metals

Cyanobacteria, like certain types of *Trichodesmium* sp., utilize iron (Fe) sourced from dust particles to convert atmospheric nitrogen

into a usable form in coastal waters. Hence, this creates a conducive environment for the proliferation of toxic algae and the occurrence of red tide. The deposition of dust can induce changes in water chemistry and temperature, leading to water column stratification that favors the growth of harmful algae, enabling them to outcompete less harmful species. Additionally, the blooming of *Lyngbya* species is promoted by a synergistic combination of iron and phosphorus, enhancing their photosynthetic activity.

Furthermore, heavy metals like cadmium (Cd) and lead (Pb) deposited in water bodies, often originating from untreated nutrient-rich effluents in aquacultural activities, can contribute to algal blooms. The presence of these metals from aquaculture practices can further disrupt the ecological balance, potentially leading to the proliferation of harmful algae.

- Climate change

Variations in temperature play a crucial role in shaping circulation patterns. The changing conditions leads to changes in the physical composition of the water column and extended stratification periods. These changes favor the occurrence of HABs. Climate change processes, such as shifts in precipitation patterns, can independently enhance nutrient loading rates, thereby accelerating algal blooms caused by eutrophication. Instances have been observed where HABs intensify as water temperatures approach levels conducive to maximal growth. Consequently, climate change may contribute to the increased frequency and intensity of HABs in certain coastal ecosystems (Gobler et al., 2020).

Several recent studies have highlighted a common occurrence of HABs alongside other stressors linked to climate change. These stressors may include factors such as changes in temperature, nutrient runoff, and altered oceanic currents. Furthermore, the impact of climate change on environmental conditions can potentially exacerbate the frequency and severity of HAB outbreaks. Given these findings, it is becoming more pertinent to recognize HABs not only as isolated events but also as co-stressors that interact with and compound the effects of climate change on aquatic ecosystems.

- Upwelling and monsoon pattern

The occurrence of micro-algal blooms along the coasts of India is influenced significantly by factors such as upwelling and monsoon patterns. The withdrawal of the monsoon and the onset of the post-monsoon season create favorable conditions for bloom formation. Pre-monsoon conditions, characterized by warm waters and

low nutrient concentrations, particularly favor *Trichodesmium* blooms in the West coast. On the west coast, the upwelling events contributing to blooms.

Weak spells of rain during the summer can cause abrupt changes in salinity and temperature, triggering micro-algal blooms. This phenomenon is observed in the west coast, especially in Kerala, where the blooms of *skeletonema* (preferring low salinity) and the raphidophyte *Chattonella marina* (preferring low temperature) are favored during the summer season. The break in the monsoon provides an opportunity for certain phytoplankton species like *Cochlodinium* sp. and *Gymnodinium* sp. to bloom. Despite favorable conditions, blooms are less common on the west coast during the monsoon season. Research indicates that with the beginning of the northeast monsoon, there is an influx of lower salinity waters from the Bay of Bengal into the coastal regions of southwest India. This may promote the growth of specific bloom-forming species.

The Bay of Bengal is characterized by lower biological productivity compared to the Arabian Sea, attributed to strong stratification preventing nutrient transport from deeper layers to the surface. In BOB, the blooms happen during the pre-monsoon season mostly dominated by diatom and cyanobacterial blooms. The dinoflagellate, *Noctiluca scintillans*, also happen more frequently during the summer (Hegde et al., 2008) and it might form bloom events during the cyclone-prone seasons.

- Ballast water

The bioinvasion from other world oceans, necessitating thorough research into the spread of species responsible for HABs. Ballast water is considered a major carrier for spreading HAB species in maritime nations such as India.

Monitoring and Early Detection

The rise in HAB occurrences has heightened public awareness, leading to an increased demand for monitoring efforts. Consequently, there is a growing emphasis on early detection methods for identifying bloom species, understanding the conditions that favours algal blooms, and identifying the harmful toxins associated with these blooms. The lack of readiness for substantial range expansions or the proliferation of HAB issues in inadequately monitored areas is anticipated to pose a major challenge for human society in the future (Hallegraeff, 2010).

Remote sensing acts as a versatile tool for globally detecting and monitoring HABs. A novel

bio-optical algorithm has been devised to precisely gauge chlorophyll-a (Chl-a) concentrations, facilitating the identification and mapping of algal blooms in the visually complex waters of the Arabian Sea (Shanmugam, 2011). Initially formulated with Sea-viewing Wide Field-of-view Sensor (SeaWiFS) bands, this algorithm has since been adjusted for compatibility with Moderate Resolution Imaging Spectroradiometer (MODIS)/Aqua data. The Indian National Centre for Ocean Information Services (INCOIS) has taken the initiative to modify and adapt the Red Tide Indices to create the Bloom Index (BI) specifically tailored for Indian waters. This adaptation enhances the capability to monitor and assess algal blooms in Indian marine environments.

Regular monitoring of the physical, chemical, and biological parameters along the Indian coast is a critical practice for developing forecasting and warning systems related to HABs and the subsequent impacts on fish mortality. By systematically collecting data on factors such as water temperature, nutrient levels, and algal species composition, scientists and environmental agencies can detect early signs of HAB development.

Conclusion

HABs represent a complex ecological phenomenon with far-reaching impacts on both marine ecosystems and human communities. The consequences of HABs include environmental disturbances, significant mortality among aquatic fauna, alterations in traditional fishing practices, and substantial risks to human health. Two notable examples of human health risks associated with HABs are PSP and CSP, both of which can lead to severe health issues and, in extreme cases, even death. Efficient management and decision-making regarding Harmful Algal Bloom (HAB) occurrences along the Indian coastline require a thorough understanding of the specific environmental conditions involved. Factors such as water temperature, nutrient levels, and oceanographic conditions contribute to the initiation and proliferation of these blooms. By gaining insight into these factors, authorities can develop comprehensive management plans to mitigate the impact of HABs on both aquatic ecosystems and human activities.

Surveillance programs play a crucial role in monitoring the levels of phycotoxins, harmful substances produced by certain algae during blooms, in the environment and local seafood. Regular testing and analysis help identify areas prone to toxin accumulation, enabling timely interventions to protect public health.

Additionally, implementing sustainable environmental practices is key to preventing and managing HABs. This may involve measures such as controlling nutrient runoff, managing aquaculture practices, and promoting ecosystem balance. It is essential to conduct studies focused on comprehending the primary environmental factor or factors that contribute to HABs, at regional levels. This knowledge is crucial for more effective environmental health management.

In summary, a multidimensional approach that combines knowledge of environmental factors, surveillance programs for toxin levels, and sustainable practices is vital for curbing the occurrences of HABs. By taking proactive measures, authorities can work towards preserving marine ecosystems, protecting aquatic life, and ensuring the safety of seafood consumption for local communities.

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Molecular Tools and Techniques in Marine Fish Identification

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The well-being and persistence of various organisms in a specific environment rely on the distinctive biological characteristics of each species. The intrinsic genetic diversity within species and populations serves as a crucial factor for thriving amidst dynamic environmental conditions. Recognizing the genetic and morphological variations is essential for ensuring the sustainability of ocean resources, discerning adaptive evolution patterns, and effectively managing these resources. The accurate identification of fish species is paramount for sustainable fisheries management, preserving biological complexity. Determining stock structure is vital for formulating targeted management strategies. Recent advancements in molecular tools have facilitated precise identification and delineation of stock structure, empowering conservationists to plan and implement effective management and conservation measures.

Molecular taxonomic tools

Over the past decade, significant progress has been made in molecular taxonomic research, thanks to the emergence of advanced sequencing methods. The capabilities and accuracy inherent in molecular taxonomic investigations have greatly enhanced our understanding across various realms of biological science.

Various molecular markers are currently employed to decipher patterns of diversity within and between marine populations, categorized as Type I and Type II. A marker falls into the Type I category when linked to genes of known function, and into the Type II category when associated with genes of unknown function

Type I markers

Allozyme markers are type I markers as they are associated with genes of known functions. DNA encodes allozymes and genetic variation at the level of enzymes can be detected using allozyme electrophoresis. Allozymes are protein variants which originate from allelic variants which differ in electric charge and these variations could be detected using electrophoresis. Allozymes are codominant markers expressed in heterozygous individuals in a Mendelian fashion. Information regarding single locus genetic variation can be gathered using allozyme analysis which can

answer many questions regarding intra- and inter specific diversity of fish populations. To detect

variations in allozyme pattern, allozymes have to be extracted from tissues following standard protocols and variations detected through electrophoresis in an acrylamide or cellulose acetate gel. A single band will be present if individuals are homozygous and double bands when individuals are heterozygous. Allozymes have been extensively studied and used for many investigations due to their simplicity and cost effectiveness as any kind of soluble protein can be used for allozyme analysis. Many numbers of loci can be screened at a time using allozyme markers. Major limitations with the use of allozyme analysis include requirement of large amount of tissue which impedes its use with smaller organisms like larval forms. The tissue sampling method is invasive and hence every time the fish has to be sacrificed and tissue stored cryogenically. Point mutations in nucleotide sequences could not be detected using protein electrophoresis as such mutations may not result in change in the amino acid composition. In spite of all these limitations, allozymes have been widely used for fishery biology investigations like fish systematic, population genetic structure, conservation genetics and forensic applications.

Mitochondrial DNA markers

Mitochondrial DNA resides within the cytoplasm of organelles called mitochondria, distinguishing it as non-nuclear DNA. Functioning as a haploid genome, it undergoes maternal inheritance, and transcription occurs as a single unit. Mitochondrial DNA remains free from recombination events, is selectively neutral, and exists in multiple copies within each cell. Its isolation from various tissues or blood samples is straightforward due to its physical separation from the cell's nuclear DNA. The use of mitochondrial DNA facilitates the detection of population bottlenecks and hybridizations, given its smaller effective population size resulting from maternal inheritance.

Molecular taxonomic methods employing mitochondrial DNA often utilize Restriction Fragment Length Polymorphism (RFLP) based on length polymorphisms or sequence variations

to reveal genetic diversity patterns. RFLP involves digesting mitochondrial DNA with restriction enzymes, visualizing resulting polymorphisms through electrophoresis, and has been widely applied in understanding species-specific patterns in marine fishes. Sequencing technologies have popularized the sequencing of mitochondrial DNA regions, with universal primers targeting conserved sequences for broad applicability. Comparisons between species can be conducted using slow-evolving gene regions, such as the universal barcode Cytochrome C Oxidase 1, while fast-evolving regions like the D-loop are employed for intra-specific or population comparisons. Other gene regions, including cytochrome b and ND-1 and ND-5/6, are also utilized for intra-specific comparisons. Mitochondrial DNA genes play a pivotal role in fish systematics and population genetics.

Nuclear DNA markers

Nuclear DNA markers can be categorized as arbitrary and specific depending on the gene regions to be amplified.

Arbitrary markers

Arbitrary markers, such as RAPD (Random Amplified Polymorphic DNA) and AFLP (Amplified Fragment Length Polymorphism), play a significant role in genetic analysis. RAPD utilizes an arbitrary marker to amplify genomic DNA regions, resulting in a high level of polymorphism. This approach is rapid, cost-effective, and efficient, requiring no prior knowledge of specific genes or the genome. However, RAPD markers exhibit limitations in terms of reproducibility and repeatability, generating multiple products simultaneously. These markers cannot distinguish between homozygous and heterozygous states, and slight variations in amplification conditions lead to changes in band patterns. AFLP markers combine Restriction Fragment Length Polymorphism (RFLP) and RAPD techniques. Genomic DNA is digested with two restriction enzymes, followed by the ligation of double-stranded nucleotide adapters to the DNA fragments' ends, serving as primer binding sites for PCR amplification. Selective agents, represented by primers complementary to the adapter and sequences at the restriction site with additional nucleotides at the 3' end, amplify a subset of ligated fragments. Polymorphisms and the presence or absence of DNA fragments are then detected on polyacrylamide gels.

Specific markers

Variable Number of Tandem Repeats (VNTRs) refers to segments of DNA that are repeated numerous times within the nuclear genome of

eukaryotes, occurring in tens, hundreds, or thousands of repetitions. These repeats are tandem and exhibit variation in number across different loci of the genome and among individuals. Repetitive DNA can be categorized into minisatellite and microsatellite DNA. Minisatellite DNA consists of repeats with lengths ranging from 9 to 65 base pairs (bp), while microsatellite DNA features repeats of 2 to 8 bp. Microsatellites, more abundant in the genome compared to minisatellites, are widely applied in population genetic analyses. Minisatellites come in two types: multilocus and single-locus. Multilocus minisatellites exhibit tandem repeats ranging from 9 to 65 bp with lengths varying from 0.1 to 7 kilobases (kb). While minisatellite loci are useful for parentage analyses, they are less practical for population genetic studies due to complex mutation patterns. Single-locus minisatellite probes, however, are successful in detecting population genetic variations and find applications in forensics, parentage analysis, understanding mating success, and confirming gynogenesis. Microsatellites, simple repeated sequences highly variable in the genome, serve as valuable markers found approximately every 10 kilobases. These loci are instrumental in genome mapping and population genetic investigations, evolving rapidly at a rate of 10^{-3} to 10^{-4} mutations per generation. Inherited in a Mendelian fashion, microsatellites are codominant markers, popular for their high polymorphism. Automated genotyping using labeled primers enhances the accuracy and speed of size polymorphism analysis in microsatellites. However, challenges such as null alleles and stutter bands limit their use. While null alleles decrease accuracy in parentage analysis, stutter bands result from slipped strand mispairing during PCR. Microsatellite markers find diverse applications in fisheries and aquaculture, aiding in population genetic structure determination, conservation of biodiversity, phylogenetic and phylogeographic studies, understanding the impact of stocking and hybridization, and forensic identification of individuals.

Single Nucleotide Polymorphisms (SNPs) arise in the genome due to single-point mutations, encompassing insertions/deletions, transitions, or transversions. These mutations result in divergent alleles with alternative bases at specific nucleotide positions, providing valuable insights into intra- and inter-specific diversity patterns. SNPs, regarded as the most prevalent polymorphism in the genome, can be identified through PCR, microarray chips, or fluorescence technology. In fisheries, SNPs are emerging as next-generation markers with widespread

applications in population genetics and genomics research.

DNA microarrays, whether small glass microscope slides, nylon membranes, or silicon chips, serve as platforms capable of holding numerous immobilized DNA fragments in a standardized pattern. Reporter probes with known sequences can be matched with DNA from target samples of unknown origin. Microarrays are versatile tools, facilitating the construction of species-specific DNA probes for subsequent identification purposes. Target sample DNA, labeled with fluorescent molecules, is then hybridized to the microarray DNA. Positive hybridization emits a fluorescent signal, detectable using appropriate fluorescence scanning or imaging equipment.

Expressed Sequence Tags (ESTs), generated through random cloning of cDNA, prove valuable in gene identification and expression analysis. ESTs enable rapid and reliable analysis of genes expressed in specific tissue types under distinct physiological or developmental stages. cDNA microarrays, utilizing ESTs, are effective in identifying differentially expressed genes. Furthermore, ESTs find utility in linkage mapping, enhancing their versatility in various molecular biology applications.

Molecular markers in fishery biology investigations

- **To understand inter and intra specific variations**

The baseline for distinguishing species at the DNA or gene level is determined by the degree of divergence, and decisions should take into account the variability in evolution among taxa. Molecular markers play a crucial role in identifying mixed catches, larval forms, illegally caught endangered and threatened animals, stranded cetaceans, and processed fish products up to the species level. In situations where morphological identification is not feasible, molecular markers provide a reliable alternative. Additionally, these markers can be effectively employed for fish stock characterization and the identification of sub-species.

- **Phylogenetic and Phylogeographical studies**

Phylogenetic studies center on historical processes that impact the relationships between species, while phylogeographic studies delve into processes influencing geographical distribution. Mitochondrial DNA markers prove highly

effective in both phylogenetic and phylogeographic investigations. Utilizing mitochondrial DNA data enables the reconstruction of the evolutionary history of fish groups, providing crucial insights into historical demography. Moreover, this information aids in deducing conservation units and ecological patterns. Mitochondrial DNA serves as a potent tool for inferring intraspecific phylogenetic patterns in numerous marine fish species.

- **Identification of genetic structure between and within populations**

The crucial aspect of fisheries management and conservation involves identifying the stock structure within fish populations. Stocks represent subpopulations within species, potentially marked by reproductive isolation and distinct physiological or behavioral patterns. Mitochondrial DNA and microsatellite markers are extensively employed to deduce the genetic stock structure of marine fish populations. To attain a comprehensive understanding of subpopulation structure, it is essential to integrate genetic information with morphological and meristic data. Molecular tools also facilitate the identification of subunits within mixed fisheries and determine the origin of stock components, enhancing our ability to manage and conserve fish populations effectively.

- **Genetic tagging/marking**

Marking individual fishes is a valuable practice for monitoring their movement, migration, and assessing population size, especially in mixed fisheries where distinct stocks contribute. Traditional physical tags, being non-heritable, have limitations for generational tracking. However, employing genetic tagging, such as monitoring a rare allele in individuals across generations, proves advantageous. This approach aids in comprehending the impact of hatchery programs on harvest and distinguishing migrants from various regions over an extended timeframe.

- **Forensic investigation**

Molecular markers prove highly efficient in the identification of deceased or stranded fish, as well as preserved or canned items, where morphological identification is impractical. Molecular forensic technologies enable the certification of fishery products and the detection of illicit trading in fish and fishery products. Additionally, molecular tools can be employed to monitor intentional or unintentional releases of fish or organisms into natural waters, enhancing our ability to track and manage such activities.

- **Studying the trophic relationships**

Understanding trophic relationships in an ecosystem is crucial for ecological studies, and acquiring data on diet composition is integral to this endeavor. Identifying diet components up to the species level based solely on morphological features poses challenges, as partial or complete digestion can erase key morphological characteristics. The extraction of DNA from partially digested samples offers a solution, enabling the study of diet components through the use of molecular markers.

- **Ancient DNA to deduce historical evolutionary relationships**

DNA sequence information can be extracted from preserved samples found in museums, fossil remains, archaeological discoveries, and other unconventional sources, employing various methods. Numerous studies using such approaches have enhanced our comprehension of the evolutionary relationships among different taxa.

- **Applications in aquaculture**

Molecular markers prove highly effective in various aspects of aquaculture, including selective breeding and genetic improvement, identifying quantitative trait loci, detecting inbreeding events, genetically characterizing hatchery stocks, assigning progeny, implementing marker-assisted selection, and comprehending the impacts of ploidy induction and gynogenesis. Moreover, molecular markers find extensive applications in disease diagnosis within aquaculture. PCR-based kits are readily available for the detection of numerous diseases such as white spot syndrome virus (WSSV), infectious pancreatic necrosis virus (IPNV), viral nervous necrosis virus (VNNV), channel catfish virus (CCV), infectious hematopoietic necrosis virus (IHNV), and viral hemorrhagic septicemia virus (VHSV).

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