CHAPTER 25

BIOGEOGRAPHY OF NORTHERN INDIAN OCEAN

Monolisha S., Grinson George and Trevor Platt

Fishery Resources Assessment Division
ICAR-Central Marine Fisheries Research Institute

Biogeography is defined as the branch of science that deals with the large-scale distribution of flora and fauna in the context of environmental properties and topographic features. Studies on biogeography in Northern Indian Ocean have been relatively few. These lectures will survey the available literature, will mention as-yet unpublished work and will discuss possible future directions for biogeographical research in the Northern Indian Ocean.

General Characteristics of the Arabian Sea and Bay of Bengal

The Indian coastline is about 7517 km long, with 5423 km along the mainland and 2094 km in the Andaman and Nicobar, and Lakshadweep Islands (Table. 1). The Northern Indian Ocean includes the Arabian Sea to the west and the Bay of Bengal to the east of India. Arabian Sea is bounded by Pakistan and Iran in the north, Northeastern Somalia and the Arabian Peninsula in the west and by India in the east. Its total area is 3,862,000 sq.km and its maximum depth is 4,652 meters. Bay of Bengal is the largest one among the world bays. It forms the northeastern part of the Indian Ocean. It is bordered by India and Sri Lanka to the west, Bangladesh to the north and by Myanmar and the Andaman and Nicobar islands to the east. The Bay of Bengal occupies an area of 2,172,000 sq. km. A number of large rivers – the Ganges and its tributaries such as the Padma and Hooghly, the Brahmaputra and its tributaries such as the Jamuna and Meghna, and other rivers such as the Irrawaddy River, Godavari, Mahanadi, Krishna and Kaveri flow into the Bay of Bengal. Geographically, the Northern Indian Ocean is subdivided by several major islands – the Andaman and Nicobar Islands in the Bay of Bengal and the Lakshadweep in the Arabian Sea. The islands were formed as a result of various geological processes such as volcanism, seafloor spreading and continental drift. The Lakshadweep islands are a group of 36 low-lying coral islands, 10 of which are inhabited. The Andaman and Nicobar Archipelago in the Bay of Bengal, comprises 554 islands, some of which are merely large rocks. If these are excluded, the total number of islands is 294, of which 36 are inhabited.

The Arabian Sea covers the Gulf of Oman, the Persian Gulf and Red Sea, which is in total 1.8 times the area of the Bay of Bengal. The Carlsberg-Murray Ridge (Fig. 1) is one of the important features of the Arabian Sea. It plays a vital role in the process of upwelling (mixing up of nutrient rich dense cold water towards the ocean surface by wind driven motion). The continental shelf width is greater in the Arabian Sea compared with the Bay of Bengal (Table 1). Seven large rivers and several smaller ones discharge into the Bay of Bengal.

Riverine discharge is comparatively lower in the Arabian Sea. The difference in freshwater input between the two regions has led to decrease in surface salinity in BOB and higher salinity levels in the AS. The higher salinity and surface temperature in AS are also influenced by the influx of rich saline waters from the Persian Gulf and Red Sea and the intense thermal stratification in the northern Arabian Sea. Higher surface temperatures are observed in the Arabian Sea than the regions of Bay of Bengal. The thermocline is usually below 50-55m in the Bay of Bengal but occasionally it may lie between 100-125m. In the AS, in the cold months the thermocline descends to about 100-125m, then it moves up reaching in 20-30 m under the influence of wind. Surface currents show many differences between the regions. During the south-west monsoon, the surface currents in the equatorial regions of the north Indian Ocean are driven by the southwest monsoon winds and are therefore easterlies. Somalia current flows parallel to the coast of Somalia in the north-east direction, with a weak surface counter current on its right. The meridional components of the currents in the western half of the Arabian Sea are northerly while in the eastern half they are southerly. The surface currents in the BOB are easterly during the southwest monsoon period but they are very weak compared with the currents in the Arabian Sea. During the northeast monsoon,

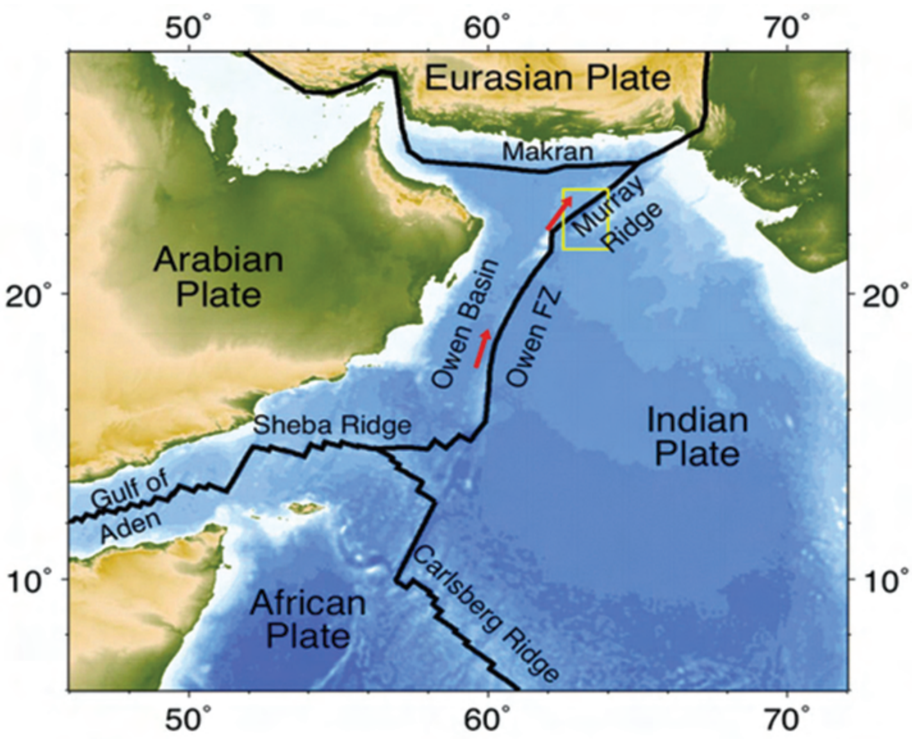

Fig. 1. Carlsberg - Murray Ridge in the west coast of India

the complete reversal of the surface currents takes place and the currents are westerlies in both Arabian Sea and the BOB. The seasonally reversing monsoon current is one of the important characteristic features of the Northern Indian Ocean.

Table 1. Coastal Resources of the Indian Ocean

Maritime states	Total length of coastline (sq. km)	Length of coast affected by erosion (km)	Continental shelf width ('000 km)
Gujarat	1214.7	36.4	184
Maharashtra	652.6	263	112
Goa	151	10.5	10
Karnataka	280	249.6	27
Kerala	569.7	480	40
Tamil Nadu	906.9	36.2	41
Andhra Pradesh	973.7	9.2	33
Orissa	476.6	107.6	26
West Bengal	157.5	49	17
Daman and Diu	9.5	0	-
Pondicherry	30.6	6.4	1
Total Mainland	5422.6	1247.9	-
Lakshadweep	132	132	4
Andaman and Nicobar	1962	0	35

(*Sanil Kumar *et al.*, 2006 obtained from Naval Hydrographic chart)

Biogeographic partitioning of an ocean or a region means finding the borders between biogeographical area based on the distribution of floral and faunal species (Golikov *et al.*, 1990). The Indian coast has important geological features and biologically productive areas such as sandy beaches, estuaries, sandy beaches, bays and creeks, lagoons, rocky shores, coral reefs, mangroves, marshes and mudflats. The East and west coast of India provide a wide range of habitats to plants and animals. The distributional patterns of floral and faunal species can be homogenous or heterogeneous, depending on both abiotic and biotic factors such as physical-chemical conditions and trophic structures. These factors shape the distribution of organisms, such that the biological communities are in harmony with their environment in space and time.

Phytoplankton

Phytoplanktons are a diverse group of unicellular microalgae metabolically and physiologically similar to higher plants. Phytoplankton play a major role in indicating the ecology of the region and it highly contributes as primary producer in the food web and are key partners in cycling of carbon and nutrients in the ocean. Diatoms, cyanobacteria, dinoflagellates and coccolithophores are the most dominant phytoplankton taxa in the Indian coastline. These groups are named as "phytoplankton functional types" because they play vital role in biogeochemical cycles of the marine ecosystem. Phytoplankton community structures vary from one place to another depending upon various environmental factors resulting in heterogeneous biogeographical patterns. The major factors that influence the biogeographical patterns of phytoplankton are (1) environmental conditions (e.g. temperature and nutrient concentrations), (2) interspecific relationships (*i.e.,* predation and competition), and (3) dispersal (Follows *et al.*, 2007). The distribution and species composition of phytoplankton determines the structure and functioning of the marine food web (Finkel *et al.*, 2007). Therefore, detailed investigations of the mechanisms that lead to certain phytoplankton biogeographical patterns can help us to understand better the processes involved in pelagic ecosystems and their response to a changing environment.

Early research in the phytoplankton of the Indian Ocean was conducted during the International Indian Ocean Expedition (1963). From the surveyed literature, approximately 600 species represent the phytoplankton community structure in the Northern Indian Ocean. Chrysophytes, cryptophytes, haptophytes, chlorophytes and prasinophytes are the diverse phytoplankton communities representing the Indian coastal waters. Dominant species reported in the Bay of Bengal region are *Proboscia alata, Climacodium frauenfeldianum* and *Thalassionema nitzchioides*. Associated species reported includes *Pseudo-nitzschia Pseudo delicatissima, Chaetoceros messanensis*, *Chaetoceros compressus, Thalassionema frauenfeldii, Thalassiothrix longissima, Leptocylinfrus minimus, Lauderia annulata, Guinardia striata, Thalassionema nitzchoides* and cyanobacterium *Trichodesmium* (D'Silva *et al.*, 2012; Paul *et al.*, 2007; Subrahmanyan *et al.*, 1971). Diatoms are the dominant groups found in the east and west coast of India. Proliferation of diatoms in these regions has been reported with sharp pycnocline, thermal stratification and deficiency of nutrients in the upper mixed layer (Sukhanova *et al.*, 2006; Tomas, 1997). There are reports of replacement of diatom dominance by the presence of *Trichodesmium* during the onset of monsoon in the Chennai, Port-Blair and Kolkata regions of the southeast coast and southwest coast of India (Mohanty *et al.*, 2010; Sahu *et al.*, 2014). *Noctiluca scintillans* and *Trichodesmium erythraeum* are the two common causative species of phytoplankton blooms in the Indian coast. Some species of diatoms and cyanobacteria (presence of cyanobionts) are capable of utilizing nitrogen and ammonium as a urea source. This indicates the symbiosis of nitrogen fixation by phytoplankton's in the nitrogen depleted environment of Bay of Bengal. Species such as *Chaetoceros coarctatum*, *Nitzschia sp*, *Dactyliosolen fragilissimus*, *Leptocylindrus danicus* and *Pseudo-nitzschia heimii*, *Oxytoxum nanum, Scrippsiella* sp. are the major dominant species occurred along the southwest coast and Gulf of Kutch and Khambhat (Ahmed *et al.*, 2016). Picoplankton such as *Synechococcus* and *Prochlorococcus* are reported from the tropical waters with influx of higher nutrients, representing the systems of regenerated production; which states that the north and southern eastern Arabian sea is one of the major region with higher nutrients reported during the upwelling in the summer monsoon season (Bhattathiri *et al.*, 1996; Madhupratap *et al.*, 1996; Ramaiah *et al.*, 1996; Roy *et al.*, 2006). There are two peaks of plankton distribution observed during March-April and October-November off the Mumbai (North West) coast of India. This peak coincides with the season of peak abundance of the commercial pelagic fishes *Bregmaceros mcclellandi* and *Harpodon neherus* in the North west coast of India (Gulf of Kutch and Khambhat) (Raghuprasad, 1968). These water masses are found throughout the stronger upwelling region, Somalia and Gulf of Aden with similar phytoplankton community structure.

Going by the literature, phytoplankton species in classified water masses undergo continuous changes over time in their dominance and diversity, a process that may be compared to terrestrial succession.

Zooplankton

Zooplankton plays an important role in the pelagic community structure as consumers of primary production. Literature on the plankton biomass and diversity of the Northern Indian Ocean covering all the seasons and regions is limited. The International Indian Ocean Expedition (IIOE) of 1960-1965 was the first attempt to describe the biogeography of zooplankton in the Arabian Sea based on quantitative data such as biomass and density (Currie, 1963). Based on the literature of Zooplankton diversity and distribution of the Northern Indian Ocean, approximately 7100 species of zooplankton were recorded from the Indian seas (Venkataraman and Wafar, 2005). The most common distribution of zooplankton includes copepods (Gajbhiye *et al.*, 1991; Haq *et al.*, 1973; Madhupratap *et al.*, 1990), ostracods (George and Nair, 1980; Stephen, 1996), euphausiid species (Mathew, 2000), amphipods (Nair and Jayalakshmi, 1992), total hydromedusae (Santhakumari, 1976, 1978, 1997), and chaetognatha (Nair *et al.*, 2002; Wishner *et al.*, 2001). The zooplankton biomass was reported to be highest in the northern and western Arabian Sea, the coasts of Somalia and Arabia (Somalia and Gulf of Aden and Persian Gulf), and also on the southwest coast of India (Southwest coast). Crustaceans followed by copepoda, rotifera, cirripede larvae, polycheates and cladocerans are the dominant groups found in these regions. Species reported are *Acartia* sp., *Acartia pacifica, Acartiella faoensis, Arctodiaptomus salinus, Oithona* sp., *Oncae* sp., *Alona affinis, Moina brachiate,* Mysid larvae and Zoea larvae of crabs (Ajeel, 2012). The southwest monsoon experiences two offshore current jets, one associated with the parting of the Somali Current from the coast. This jet brings up the upwelling of cooler rich water developing the blooms of diatoms *Nitzschia delicatissima* (Smith and Codispoti, 1980). Adult females and copepodites of *Calanoides carinatus* and *Eucalanus* spp., which can readily ingest the diatoms, were markedly more abundant only within upwelling areas along the Somalia coast during the southwest monsoon and not found elsewhere in the northern Arabian Sea.

The northwestern Arabian Sea *i.e.*, the Gulf of Kutch and Khambhat represents the higher density of Copepods. Some copepod species reported are *Gaussia princeps*, *Euchaeta* spp., *Haloptilus* spp., *Pontella* spp., and *Candacia* spp. Of the large calanoid copepods the family Eucalanidae dominates the Arabian Sea. During the summer monsoon, the peak and high densities of copepod abundances occur in the upwelling regions off Somalia and Gulf of Aden and far offshore regions of the Arabian Sea (Southwest and Gulf of Kutch and Khambhat). Copepods are the major dominant species reported in dominant during the southwest monsoon which is replaced by *Oithona* sp (Madhupratap *et al.*, 1990; Piontkovski *et al.*, 2013). The other dominant copepods, *Paracalanus*, *Clausocalanus*, *Acartia negligens*, and *Acrocalanus* sp., present in both the northeast and southwest monsoons are equally abundant within and outside the areas of upwelling. During the summer coastal upwelling, *Calanoides carinatus*, is an indicator species for upwelling in the tropical Indian and Atlantic Oceans. In offshore, non-upwelled waters, *Eucalanus attenuatus*, *Pleuromamma indica*, and *Pleuromamma abdominalis* were dominant (Smith, 1982, 1984, 1995). Some endemic species of the Arabain Sea and Bay of Bengal are copepod *Gaussia sewelli*, *hydromedusae Aglaura hemistoma* and *Solmundella bitentaculata*. Mysids belonging to the genera Paralophogaster are confined to the Red Sea and Arabian Sea, while the species *Siriella ionesi* is limited to the Arabian Sea. The Arabian Sea is stratified for several variables, with particular importance to zooplankton and fish associated to the intense oxygen minimum layer from about 150 to 1500 m, particularly on the east side.

The southeast coast of India was recorded with dominance of Ostracods, Salps, Chaetognaths and Decapods (Santhakumari and Saraswathy, 1981). Other taxa include Foraminifera, Calanoida, Cheatognatha, Appendicularia, Polychaeta, Hydrozoa and Echinodermata. Fish eggs and larvae occurrence was noted throughout the year and had peak abundance in summer (Soundarapandian and Varadharajan, 2013). The characterization of the zooplankton community structure is essential in detail to understand the life cycles, recruitment of the dominant species (zooplankton and fishes) of the physical domains of the coastal waters of the NIO.

Plankton Diversity and Pelagic fisheries

Plankton diversity is said to be an index of fertility not only in the water column but also at the sea bottom. Earlier attempts on studying the relationship between the plankton diversity and fisheries along the coasts of India were restricted mostly to specific areas either on the east or west coast of India. Studying the production of phytoplankton and zooplankton should give insight into the fishery potential of the study regions.

Indian Ocean is with rich plankton biomass, highly concentrated to the upwelling regions. There are several investigations on plankton biomass and relationship to potential fishery rich regions. From the surveyed literatures, it is seen that the seasonal rhythm in the organic production is well reflected in the fishery trends, *i.e.,* the peak of organic production corresponds with the low fishery periods and vice versa, suggesting an inverse relationship. Higher fishery yields were found after the peak organic production allowing some time for the conversion of the organic matter synthesized to form fish protein. Applying this concept, analyzing the trends of annual fish production in the recent years, the seasonal abundance of the pelagic fishes including Clupeidae, Scrombidae, Carangidae and Engraulidae are observed during October in the west coast of India. In the east coast, the seasonal abundance of pelagic resources is found during June-September. This abundance pattern in the west coast of India coincides with the post southwest monsoon with enrichment of nutrients by upwelling and plankton production. April to September remains calm and is favorable for fishing activities on the east coast.

Zooplankton distribution was 3.5 times higher in the southerly half of the west coast and 2.5 times more productive than the east coast. This is well reflected in the fish landings also, since the landings along the west coast are about three times those of the east coast. It is very evident that the zooplankton biomass is higher in the Arabian Sea than in the Bay of Bengal. If the abundance of zooplankton is an indication of the potential fishery resources of an area, there is possibility of substantial increase in the rate of exploitation particularly in areas such as the south-eastern coast of India, west Pakistan and Iran in the Arabian Sea region, Burma coasts, East Pakistan, West Bengal, Orissa and Sri Lankan coast, Andaman Sea in the Bay of Bengal. There are several reports on exploratory and commercial fishing activities in these areas of high plankton production and potentially rich fishing grounds. A good understanding of the biogeography of the region will support possible expansion of sustainable fisheries in Northern Indian Ocean.

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