Chapter 2

The Environment - Bay of Bengal

2.1. General features of the Bay of Bengal

The Bay of Bengal, extends between latitudes 0° and 23°N and longitudes 80° and 100°E occupying an area of 4.087 x 10^6 km^2. It is surrounded on three sides by landmasses and is a region of positive water balance. The average annual excess of precipitation over evaporation is of the order of 70 cm (Venkateswaran, 1956). The total annual river runoff in the Bay of Bengal has been estimated to be 2000 km^3 (Sen Gupta *et al.*, 1977 and Naqvi & Naik, 1983). All the major rivers of India, Bangladesh and Myanmar drain into the Bay of Bengal. It is a unique ocean with interrelated oceanographic, biological and sedimentary processes driven by the monsoon winds. The semi enclosed nature of the Bay and its proximity to the equator make it different from other ocean. Associated with monsoon is the large volume of freshwater supply and sediment input by Ganges, Brahmaputra and other rivers (Figure 2.1). Thus the prevalent low salinity plays a major role in various exchange processes between the atmosphere, surface and deep waters that affect the biological and biochemical processes.

2.2. Physical aspects

Understanding of the physical oceanography of the Bay of Bengal is largely based on the evaluation of the climatological features of the area and its neighborhood. The hinterland of the Bay of Bengal is defined as the extensive land area that contains the tributaries and distributaries of the major rivers, which flow into the Bay. The hinterland acquires special importance because of the extensive river runoff into the Bay and its effect on water properties. Thus the catchment areas, the plains and the deltas of the big rivers- Brahmaputra, Cauvery, Damodar, Ganges, Godavari, Irrawady, Krishna, Mahanadi, Mahaveli, Pennar and Salween-fall in to the hinterland (Varkey *et al.*, 1996).

The Bay and its hinterland cover a wide range of climatic features. Since the climate of the study area is primarily influenced by the monsoons, a climatic classification based on amounts of precipitation, particularly about the length of dry and wet seasons, is relevant and such a classification for this area is presented by Landsberg *et al.*, (1966). The hinterland of the Ganges, Brahmaputra, Damodar, Mahanadi and Mahaveli experiences tropical rainy climates and tropical humid summer climates with humid winters. The rivers that flow into the bay across the southeast coast of India are associated with landmasses of tropical semi-deserts of dry climates with humid winters.

Rain over the Bay of Bengal shows strong seasonality. The southeast coast of India has a winter rainfall maximum and the rest of the east coast of India, Bangladesh and Myanmar have a summer rainfall maximum (Ramage, 1984). Over the Bay of Bengal storms and depressions are observed mostly from June to November (Rao, 1981). Tropical cyclones in the Bay of Bengal during the post monsoon transition period are associated with very heavy rain and stormy winds especially in the coastal areas (Rao, 1981). The existing literature presents the following hydrographical setting in the Bay of Bengal during different seasons.

During the winter monsoon, surface salinities in the Bay of Bengal ranges between 27.0 and 33.0 practical salinity unit (psu). The 33.0 psu isohaline runs almost parallel to the coast. Lowest salinity (27.0 psu) is observed in the region around 20°N and is a result of river runoff from the Ganges - Brahmaputra system. At 100 m, over most of the shelf, salinity varies between 34.6 psu and 34.9 psu except near the river mouths where the effect of freshwater discharge is still noticeable (Suryanarayana, 1988, Suryanarayana *et al.*, 1991). At 200m, salinity is more uniform with insignificant mixing with top diluted water (<34.5 psu). During this season along 14°N surface salinities vary from 32.0 to 34.4 psu from about 100 to 300 km offshore compared with 27.0 to 32.5 psu along 20°N from 50 - 300 km offshore. At about 17°N, surface salinities vary between 27 psu (near the shore) and 33.5 psu (about 200 km). Less salinity extends up to 200 km and vertically occupies about 60 m of the water column. During the season in the 20°N, surface salinities vary from 27 psu near the shore to 32.5 psu towards offshore (300m). The low saline water (>34.5 psu) extends up to over 300 km from the shore and up to 50m of depth.

During summer monsoon, the surface salinities range between 22.0 psu and 34.0 psu over the coastal area. The 33.0 psu isohaline forms a boundary across central east coast (at about 16°N) between the southern high salinity belts. The low salinity front in the north is formed as a result of heavy run off from the Mahanadi - Ganges-Brahmaputra system. Off Madras, the diluted water extends up to about 50 m with more or less uniform thickness, whereas in winter the pattern shows wavy structures. Off Visakhapatnam (around 17°N) the diluted water extends up to around 70 - 90 m with a wavy pattern across the shelf. In the northern regions (near 20°N), the diluted water extends up to >110 m with almost uniform thickness (Shetye *et al.*, 1991). Further northwards salinity decreases to 21.0 psu. Gopalakrishna & Sastry (1985) reported a low salinity of 20.0 psu around 20°N.

During the intermonsoon season, sea surface temperature (SST) increases from 27.5°C in the north to 30.5°C in the central Bay. The SST distribution indicates the warming of the surface waters between winter and summer. The lower SSTs in the northwestern Bay show the after effects of strong surface cooling during winter. The higher SSTs in the central Bay represent the seasonal peak during intermonsoon. During the summer monsoon, warm waters (>29.5°N) are noticed in the northwestern Bay. From this region, SST decreases gradually to 28°C toward southwest along Indian coast. In general it can be seen that the surface waters south of 14°N are cooler (<29°C) compared with those north of 14°N. During winter monsoon, the lowest SST is 25.5°C observed in the northern Bay and SSTs around 26°C are seen in the central east coast of India. In the southern and central Bay, Rao & Jayaraman, (1968) reported variations of SST between 26°C and 28.6°C during February-March 1963 and the highest SSTs (>27.5°C) were attributed to the diurnal sea surface temperature maximum. The temperature difference from the head of the Bay to the Southern Bay is 3.0°C (Balaramamurthy, 1958 and Wyrtki, 1971). The southward increase of temperature is partly accounted for by the latitudinal variation of insolation. In the northwestern Bay, cold (<26.0°C) surface waters and a temperature inversion of 1°C at 50m at the distance of 360km from the Gopalpur coast was reported during 1965 (Sankaranarayana & Reddy, 1968). Rao & Sastry, (1981) reported temperature inversions of 1.5°C at depths of 5 - 50 m in the northern Bay during January 1963. Suryanarayana *et al.*, (1993) and Pankajakshan *et al.*, (2002) have also reported low (<26.5°C) temperature at near surface depths and a temperature inversion of 2°C at subsurface layers in the northwestern Bay during winter period.

Murty & Varadachari (1968) reported strong upwelling of the Waltair coast and weak upwelling along off Madras during summer monsoon of 1964. The difference in the intensity of upwelling during this period was attributed to the relatively strong winds along the coast of Waltair. Naqvi *et al.*, (1979) reported moderate level of upwelling along east coast of India during summer monsoon, even though the runoff from the rivers may partially compensate for the offshore movement of the surface waters (Sen Gupta *et al.*, 1977). Hydrographic data collected (Shetye *et al.*, 1991) during the summer monsoon of 1989 along the east coast of India showed (a) an upwelling band (about 40 km wide) along most of the coastline and (b) a southward moving freshwater plume over the northwestern Bay of Bengal.

The turbidity of the waters of the east coast of India varies greatly from season to season depending on runoff and associated suspended load. Suspended sediment enters the Bay of Bengal through the many rivers mainly during the summer monsoon. The Bay receives about 16×10^8 tonnes of silt yearly (Suryanarayana, 1988) along with abundant runoff. The suspended load settles down or gets transported away from the river mouths depending upon currents. La Fond & Sastry, (1957) used a hydrophotometer to study the transparency of the coastal waters along the east coast of India. They found that in the summer season, turbid water tends to remain near shore and flows down the coast. As the rainy season recedes the water becomes clearer in near shore areas, remaining, however, more turbid than over the shelf. Sundara Raman & Sreerama Murty, (1968) found that during the month of March (intermonsoon) the transparency was 100% at >8 km off the Karaikal coast.

2.3. Chemical aspects

The immense river runoff into the Bay of Bengal is expected to influence the biogeochemical cycles to a great extent. In addition to supplying large amounts of dissolved and suspended matter, the runoff may also affect the chemistry through controls on circulation and mixing. The rivers from these regions are known to make excessively large contributions to the global transport of suspended load by rivers to the ocean (Milliman & Maede, 1983) and the lithogenic substances may strongly influence the sedimentation of biogenic matter (Ittekkot *et al.*, 1992). This is expected to significantly alter the water-column regeneration processes, the extent of which remains unknown.

In the Bay of Bengal, dissolved oxygen concentration in the mixed layer is close to the saturation values. As depth increases, the oxygen concentration decreases and like other parts of the northern Indian Ocean, the Bay also experiences depletion of dissolved oxygen at intermediate depths (Wyrtki, 1971). However unlike the Arabian Sea, the redox conditions within the oxygen minimum layer in the Bay of Bengal are just above those required to support denitrification (Rao *et al.*, 1994). The oxygen concentrations at comparable depths below the thermocline are generally lower in the Arabian Sea than in the Bay of Bengal (Wyrtki, 1971). This may be attributed to a high rate of supply and oxidation of organic matter in the former region due to a higher rate of organic production at the surface.

However the sediment trap deployments have shown that organic carbon fluxes to the deep Bay of Bengal are higher than those in the Arabian Sea (Ittekkot *et al.*, 1991). Ittekkot *et al.*, (1991) postulated that a large riverine input of nutrients might support the large export of production in the Bay of Bengal. But the available data on nutrients are not compatible with this interpretation. The chemical data available show that the rivers flowing into the Bay might not contribute much to the inorganic nutrient pool (Sen Gupta & Naqvi, 1984; Prasanna Kumar *et al.*, 2002).

Rao *et al.,* 1994), has given two possible explanations for the observed higher sinking fluxes with the inferred lower respiration rates in the Bay. The first possibility, the export production in the Bay of Bengal may be lower than that in the Arabian Sea, but the extend of water column regeneration from the soft tissue may also be lower as a consequence of incorporation of organic carbon in the fast settling matter due to the large terrigenous inputs. There are other evidences to believe that the organic matter reaches the deep sea floor in relatively undecomposed state in the Bay of Bengal (Broecker *et al.*, 1980). The second possibility is, as a consequence of a reduced advection and strong stratification, the supply of fresh and labile DOC to the subsurface layers of the Bay may also be less. This difference assumes significance in view of the reported insufficiency of the vertical sinking fluxes in fuelling subsurface respiration in the Arabian Sea (Ducklow, 1993 and Naqvi & Shailaja, 1993).

Sankaranarayanan & Reddy, (1968) studied the distribution of nutrients in the northern Bay of Bengal and observed marked regional variations. The maximal values of phosphate and nitrate occurred shallower than in the Arabian Sea, at 600 - 800m and 300-800m respectively. No increase in silicate concentrations is observed in the surface waters of the northern Bay, in spite of massive river runoff, which occurs in the region.

The most recent publication mentioning the nutrient distribution in the Bay of Bengal during summer monsoon (Prasanna Kumar *et al.*, 2002) reports that, in the Bay the upper 30m of the water column has depleted levels of nitrate. They further observed that the nitracline (in general) is situated between 50 and 100m depths. Silicate distribution in the Bay showed similarity to that of nitrate, except for a high concentration of more than 2μM in the upper waters of the north. The higher silicate indicated that it must have originated from the source in the north.

2.4. Biological aspects

The biological productivity of any oceanic region is largely based on the organic production (primary production) of that region. Measurements of primary production in the Bay of Bengal were made for the first time during Galathea

Expedition. Subsequently, during International Indian Ocean Expedition (IIOE) similar measurements were made from many parts of the Bay of Bengal (Kabanova, 1964,1968; Krey, 1973,1976). Later, Radhakrishna *et al.*, 1978a; Radhakrishna, 1978b; Devassy *et al.*, 1983; and Bhattathiri *et al.*, 1980) studied the primary productivity of Bay of Bengal. Most of the studies depict Bay of Bengal as an oligotrophic system. Although, many major world river systems, bring in large quantities of suspended and dissolved substances, the narrow shelf, heavy cloud cover, less light penetration have been attributed as reason for this (Qasim, 1977; Radhakrishna, 1978b, Gomes *et al.*, 2000). More recently, Prasanna Kumar *et al.*, (2002) and Madhupratap *et al.*, (2003) reported Bay as a low productive region. During their study (July - August 2001) surface chlorophyll *a* in the Bay weakly increased from 0.06 mg m^{-3} in the south to 0.28 mg m^{-3} in the north, which is 4 - 5 times less, compared to Arabian Sea (0.32 - 1.12 mg m^{-3}) during the same season. Integrated chlorophyll *a* (up to 120 m) apart from being low varied only nominally from 9 - 11 mg m^{-2} in the Bay of Bengal compared to Arabian Sea values (26 – 60 mg m^{-2}). Integrated primary productivity (up to 120 m) was also less in the Bay of Bengal and varied from 89 - 221 mg Cm^{-2} d^{-1} compared to Arabian Sea (770 – 1782 mgC m^{-2} d^{-1}).

Due to their sheer abundance and intermediary role between phytoplankton and fish, the zooplankton are mainly the index of utilization of aquatic biotope at the secondary trophic level. Zooplankton distribution usually shows patchiness and studies on mesozooplankton up to 1985 suggest an increasing trends in biomass towards the south in the Bay of Bengal. Maximum biomass (0.75 – 1 ml m^{-3}) was observed off the region between Madras and Visakhapatnam while the other regions had much lower biomass (See review by Desai & Kesava Das, 1988). Madhupratap & Parulekar, (1993) reviewed the earlier works in the Bay of Bengal and reported the lack of good coverage for zooplankton in the Bay of Bengal. Despite fairly high production along its western boundary during southwest monsoon, zooplankton standing stock appears to be of the modest ranges. IIOE data have averages ranging from 10 - 18 mg m^{-3} from the northern Bay. Other data available show 31- 54 mg m^{-3} during August - September between 10 - 13°N (Achuthankutty *et al.*, 1980) and 18 - 31 mg m^{-3} in June between13 - 17°N (Nair *et al.*, 1981). Both of these reports show much poorer values for the rest of the coastal areas (Nair *et al.*, 1977).

During night increase of biomass and abundance of zooplankton species including those of carnivores occur in the upper 200m layer as a result of upward migrations, including those of carnivores, from deeper waters. A large number of epipelagic species however does not migrate to mesopelagic depths probably because they cannot survive in the poorly oxygenated waters of the oxygen minimum layers (Madhupratap & Parulekar, 1993).

The preceding account on Bay of Bengal illustrates the peculiarities of this region as a tropical basin and the available information on hydrography and biological parameters. However, it is also evident that this region is one of the least explored areas in the Indian Ocean especially with regard to many biological aspects. Hence, the present investigation is relevant while it has generated seasonal data on many of the biological parameters (chlorophyll *a*, primary production and mesozooplankton biomass). In addition to this, a fresh data set has been generated for microzooplankton, an important component of the planktonic food web, which has hitherto not been studied in this region.

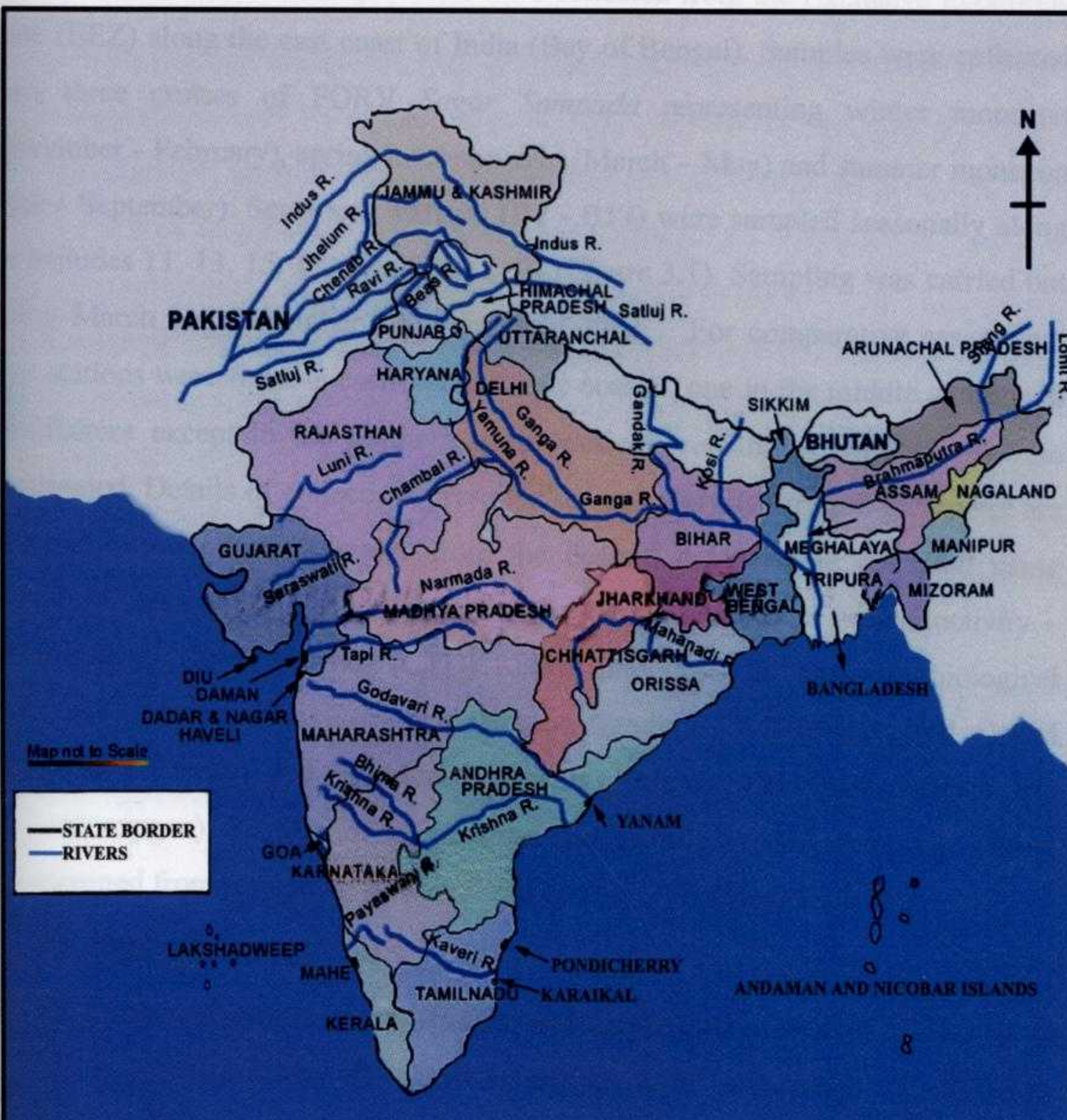

Figure 2.1. Major rivers of India