2 Biodiversity of the Blue Zone

...Come along, come with us
Take a dive into the deep blue mass
Amazing are the creatures
With their unique adaptive features....
The Authors

2.1 Producer Community

The producer community consists of organisms that are capable of synthesizing their own food through photo- or chemosynthesis. Most of the primary production in the marine and estuarine ecosystems is carried out by phytoplankton. Apart from phytoplankton that manufacture their organic food through photosynthesis (in the photic zone), there are several strains of bacteria that can prepare their food through the process of chemosynthesis. Chemosynthetic bacteria (also known as chemoautotrophs) can produce their own food from inorganic compounds without sunlight, a process called chemosynthesis. They use energy derived from chemical reactions that involve substances such as ammonia (NH_3), sulphides (S^{2-}), nitrates (NO_3^-) and sulphates (SO_4^{2-}). This energy is then used to manufacture organic food molecules. Chemosynthetic bacteria are found in areas where there is little or no sunlight and where the inorganic substances that they require are in abundance. The bacteria that live around deep-sea hydrothermal vents are examples of chemosynthetic bacteria. These bacteria use sulphide ions that spew from the vents. They oxidize the sulphide to sulphur and sulphates and use the energy released by this process to produce food. Like other autotrophs, they form the base of a productive food chain that consists of a diverse assembly of organisms, including worms, clams, and crabs, that constitute the hydrothermal vent community.

Several groups of bacteria, including the purple bacteria, the green bacteria and cyanobacteria, are able to photosynthesize. Purple bacteria and green bacteria are usually strict anaerobes (organisms that live in environments that lack oxygen) and are found in areas of the marine environment such as mud flats that provide light, anaerobic conditions and sulphur-containing compounds. These organisms cannot use water in their photosynthetic process, and therefore, they do not produce any oxygen (Fig. 2.1). Instead, they often use hydrogen sulphide (H_2S) and produce elemental sulphur or sulphate (Fig. 2.2). Purple bacteria and green bacteria are an important source of food for some zooplankton and filter feeders.

The seaweeds, seagrasses, salt marsh grasses and mangroves are also among the producer list of the marine and estuarine ecosystems (Figs. 2.3, 2.4 and 2.5)

2.1.1 Phytoplankton

Phytoplankton are free-floating tiny floral components that are widely distributed in the marine and estuarine environments. Like land plants, these tiny producers require sunlight, nutrients or fertilizers, carbon dioxide gas, and water for growth. The cells of these organisms contain the pigment chlorophyll that traps the solar energy for use in photosynthesis. The photosynthetic process uses the solar radiation to convert carbon dioxide and water into sugars or high-energy organic

A. Mitra and S. Zaman, *Blue Carbon Reservoir of the Blue Planet*,
DOI 10.1007/978-81-322-2107-4_2, © Springer India 2015

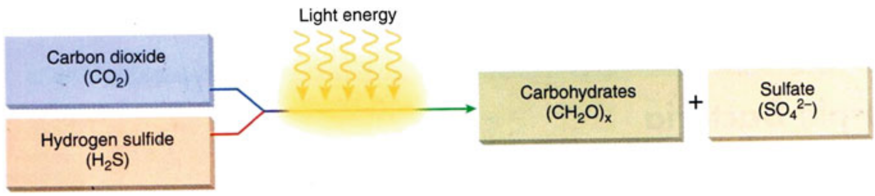

Fig. 2.1 Free oxygen is not generated during food preparation by purple and green bacteria

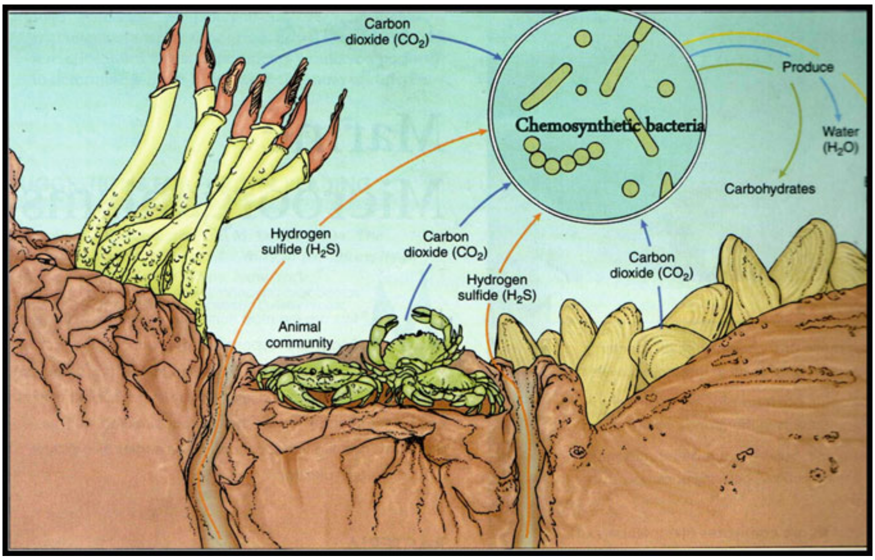

Fig. 2.2 Chemosynthetic bacteria survive in the deep-sea vent zones and are capable of synthesizing food from carbon dioxide and hydrogen sulphide using the energy derived from chemical reactions

Fig. 2.3 Thallus structure of seaweeds in the intertidal zone

Fig. 2.4 Salt marsh grasses contribute to primary production in the coastal and estuarine system

Fig. 2.5 Mangrove floral community constitutes the primary producer tier in the coastal and estuarine system

compounds from which the cell forms new materials. The synthesis of organic material by photosynthesis is termed primary production. Since phytoplankton are the dominant producers in the ocean, their role in the marine food chain is of paramount importance. Approximately 4,000 species of marine phytoplankton have been described and new species are continually being added to this total (Lalli and Parsons 1997). Phytoplankton exhibit remarkable adaptations to remain in floating condition in the sea water. In fact, all marine phytoplankton tend to stay in the photic zone to utilize the solar radiation for performing the process of photosynthesis. In order to retard the process of sinking, this group of organisms adopts various mechanisms. These include their small size and general morphology, as the ratio of cell surface area to volume determines frictional drag in the water. Colony or chain formation also increases surface area and slows the rate of sinking. Most species carry out ionic regulation, in which the internal concentration of ions is reduced relative to their concentration in sea water. Diatoms also produce and store oil, and this metabolic by-product further reduces cell density. In experimental conditions, living cells tend to sink at rates ranging from 0 to 30 m day^{-1}, but dead cells may sink more than twice as fast. In nature, turbulence of surface waters is also an important factor in maintaining phytoplankton near the surface where they receive abundant sunlight. Excessive phytoplankton population imparts greenish colour to the brackish water bodies that are often witnessed in aquaculture farms (Fig. 2.6).

Phytoplankton present in the marine and estuarine environments use carbon dioxide for photosynthesis and hence play an important role in maintaining the carbon dioxide budget of the atmosphere. The larger the world's phytoplankton population, the more carbon dioxide gets pulled from the atmosphere. This lowers the average temperature of the atmosphere due to lower volumes of this greenhouse gas. Scientists have found that a given population of phytoplankton can double its numbers in the order of once per day. In other words, phytoplankton respond very rapidly to changes in their environment.

Phytoplankton sometimes may cause adverse impact on the marine and estuarine environment. During excessive bloom of phytoplankton, the light energy is intercepted, which could otherwise reach fixed plants such as eelgrass (*Zostera* sp.) and kelp. Furthermore, when the phytoplankton eventually die back and break down, an excessive amount of oxygen is required to fuel this process, and hence, areas may become deprived of oxygen. Excessive nutrients, and/or changes in their relative concentrations, may be one factor in a chain of events leading to changes in the species composition of the phytoplankton communities. Increased occurrence of toxic algal blooms may accelerate toxin production. Toxic phytoplankton, when consumed by shellfish or other species, can affect the marine food chain, including poisoning of seabirds, mammals and even humans.

It has been established that phytoplankton naturally contains DMS (dimethyl sulphide), which is released from dead phytoplankton into the atmosphere. This compound can transform into sulphuric acid, which eventually may contribute to acid rain (http://oceanlink.island.net/ask/pollution.html).

Nearly all marine plants, whether unicellular or multicellular, even those attached to substrata (sessile) or free floating, pass some part of their life cycle in floating condition as phytoplankton. However, those organisms which always remain

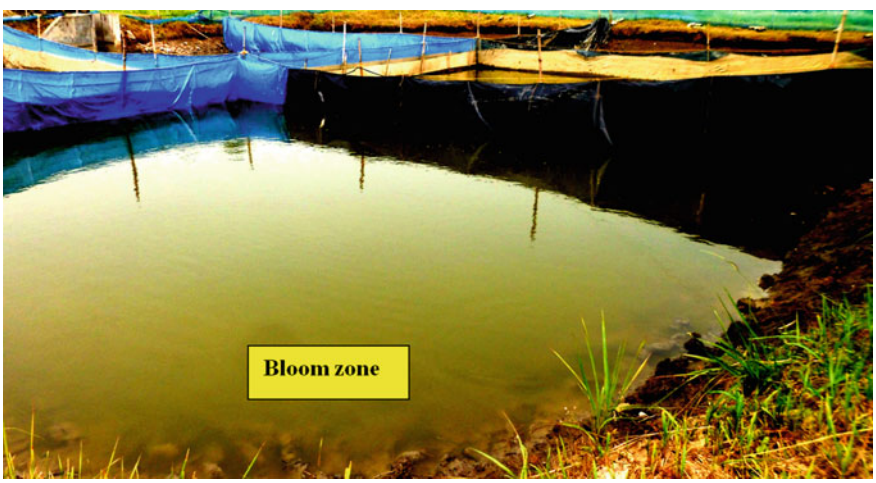

Fig. 2.6 Brackishwater with a greenish tinge due to phytoplankton bloom

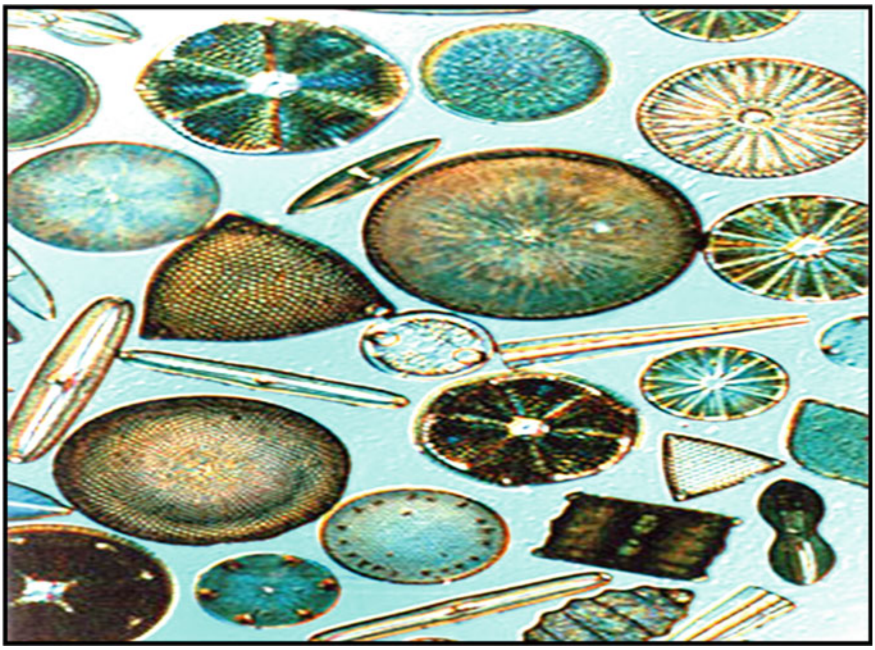

Fig. 2.7 Common brackishwater phytoplankton with unique shape and configuration

planktonic through out the life cycle are as follows: (1) diatoms, (2) dinoflagellates, (3) coccolithophores, (4) selective species of blue-green algae and (5) some species of green algae. The members of phytoplankton community have unique size, shape and morphological features (Fig. 2.7).

Diatoms

These floating plants are all microscopic in size and are characterized by the presence of shell or frustule. The shell or frustule is composed of translucent silica. The cell wall of diatom has two parts resembling a pillbox bottom and lid. The lid is called the **Epitheca** and the bottom is known as **hypotheca**. These shells have great importance from the geological point of view and constitute the diatomaceous crust. The diatoms exhibit remarkable varieties and forms and many species possess beautifully sculptured shells. Examples of diatoms are *Skeletonema costatum* and *Coscinodiscus eccentricus*.

Depending on the nature of valves and pattern of ornamentation in the valve surface, the diatoms are grouped into **centric** and **pennate** diatoms. The major differences between these two groups are given in Table 2.1.

Dinoflagellates

These are important producers of the marine environment and rank second in importance in the economy of the sea. Typically, these are unicellular; some are naked, while others are armoured with plates of cellulose. The dinoflagellates possess two flagella for locomotion. Several of them are luminescent and produce light. *Prorocentrum* sp. and *Ceratium trichoceros* are two common dinoflagellates of marine and estuarine waters.

Coccolithophores

These are among the smallest category of phytoplankton having a size range between 5 and 20 µm. Some coccolithophores have flagella, while others are devoid of them. Their soft bodies are shielded by tiny, calcified circular plates or shields of various designs. These are normally found in the open sea, but their profuse

Table 2.1 Differences between centric and pennate diatoms

Point	Centric diatom	Pennate diatom
Cell shape	Discoid, solenoid or cylindrical	Elongated and fusiform, oval, sigmoid or roughly circular
Ornamentation	Radial in nature, i.e., the arrangement of the markings is radiating from the centre	Bilateral in nature, i.e., the arrangement of the markings is on either side of the apical (main) axis

occurrence has been recorded in coastal waters. They form important diet components of filter-feeding animals. *Coccolithus* sp. and *Isochrysis galbana* are common coccolithophores of oceans, seas and estuaries.

Blue-Green Algae

These include both unicellular and multicellular organisms. The blue colour in them is due to the presence of a pigment known as phycocyanin. Of the various organisms belonging to this category, the most important is *Trichodesmium erythraeum* because in certain seasons of the year, its biomass increases greatly resulting in the formation of clumps.

Green Algae

Microscopic green algae present in the planktonic community largely occur in coastal waters. The green colour in them is due to the presence of chloroplasts. They are widely distributed in the warmer (tropical) seas, and only few species are found in the Arctic and Antarctic oceans. Some common species of microscopic green algae that are planktonic in nature are *Chlorella marina*, *Chlorella salina*, etc.

Classification of Phytoplankton

The phytoplankton community consists of a variety of organisms, namely diatoms, dinoflagellates, blue-green algae, silicoflagellates, and coccolithophores which ranges in terms of size from 0.001 to 0.2 mm.

Phytoplankton may be classified variously from different angles which are discussed here:

(a) On the basis of size, the phytoplankton may be grouped under five categories (Table 2.2).
(b) Phytoplankton can also be classified on the basis of the cell characteristics (Table 2.3).

2.1.2 Seaweeds

Seaweeds or benthic marine algae are the group of plants that live either in marine or brackish water environment. They are macroalgae and contain photosynthetic pigments. Like the terrestrial producer community, the seaweeds can prepare their own food with the help of sunlight and nutrient present in the sea water. Seaweeds are found in the coastal region between high tide to low tide and in the subtidal region up to a depth where 0.01 % photosynthetic light is available. They require hard substratum for their growth, which may be tree trunks (preferably mangroves) that get submerged during the high tide or even brick or boulders that are often laid to enter the island from the adjacent bays or estuaries (Fig. 2.8).

Plant pigments, light, exposure, depth, temperature, tides and the shore characteristic combine to create different environment that determines the distribution and variety among seaweeds. The important criteria used to distinguish the different algal groups based on the recent biochemical,

Table 2.2 Classification of phytoplankton on the basis of size

Plankton category	Maximum dimension (μm)
Ultraplankton	<2
Nanoplankton	2–20
Microplankton	20–200
Macroplankton	200–2,000
Megaplankton	>2,000

Table 2.3 Classification of phytoplankton on the basis of cell characteristics

Class	Common name	Area(s) of predominance	Common genera
Cyanophyceae (cyanobacteria)	Blue-green algae	Tropical	*Oscillatoria*, *Synechococcus*
Rhodophyceae	Red algae	Cold temperate	*Rhodella*
Cryptophyceae	Cyptomonads	Coastal	*Cryptomonas*
Chrysophyseae	Chrysomonads	Coastal	*Aureococcus*
	Silicoflagellates	Cold waters	*Dictyocha*
Bacillariophyceae (Diatomophyceae)	Diatoms	All waters, especially coastal	*Coscinodiscus* *Chaetoceros* *Rhizosolenia*
Raphidophyceae	Chloromonads	Brackish	*Heterosigma*
Xanthophyceae	Yellow-green algae	Brackish	Very rare
Eustigmatophyceae	Yellow-green algae	Estuarine	Very rare
Prymnesiophyceae	Coccolithophorids	Oceanic	*Emiliania*
	Prymnesiomonads	Coastal	*Isochrysis*
			Prymnesium
Euglenophyceae	Euglenoids	Coastal	*Eutreptiella*
Prasinophyceae	Prasinomonads	All waters	*Tetraselmis*
			Micromonas
Chlorophyceae	Green algae	Coastal	Rare
Pyrrophyceae (Dinophyceae)	Dinoflagellates	All waters, especially warm	*Ceratium*
			Gonyaulax
			Protoperidinium

Fig. 2.8 Seaweed (*Ulva lactuca*) on the brick path towards island village on the intertidal zone

physiological and electron microscopic studies are as follows: (a) photosynthetic pigments, (b) storage food products, (c) cell wall component, (d) fine structure of the cell and (e) flagella. Accordingly, algae are classified into three main groups, i.e. green (Chlorophyta), brown (Phaeophyta) and red (Rhodophyta).

Marine biologists have documented that the distribution of seaweeds is limited by the availability of sunlight at various depths. The evolution of a variety of accessory pigments that absorb those wavelengths of light that are able to reach the deeper zones of the ocean allows the algae to survive in these bottom habitats. Sea water selectively absorbs light with longer wavelengths, such as the reds and yellows, so the light that penetrates to the greatest depths is the short-wavelength blues and greens. Pigments such as fucoxanthin and phycoerythrin, which absorb blue and green light, allow algae to grow at greater depth than those algae that do not possess these or similar accessory pigments.

The distribution of macroalgae is also affected by temperature. The greatest diversity of algal species is in tropical waters. Farther north or south of the equator, the number of species decreases, and the species themselves are different. Many marine macroalgae found at the colder altitudes are perennials, which means they live longer than 2 years. During survival, a few cells, but most often a mass of stem-like structures appear. When the temperature warms up in the spring, this body part initiates new growth. Temperature is not usually a limiting factor for algae that live in tropical and subtropical seas, although for some species, the temperature in intertidal areas may be too warm.

Seaweeds are similar in the form with the higher vascular plants but the structure and function of the parts significantly differ from the higher plants. Seaweeds do not have true roots, stem or leaves, and whole body of the plant is called thallus that consists of the holdfast, stipe and blade. The holdfast resembles the root of the higher plants, but its function is for attachment and not for nutrient absorption. The holdfast may be discoidal, rhizoidal, and bulbous or branched depending on the substratum it attaches. The stipe resembles the stem of the higher plants, but its main function is for support of the blade for photosynthesis and for absorption of nutrients from surrounding sea water. The blade may resemble leaves of the higher plants and have variable forms (smooth, perforated, segmented, dented, etc.). The important functions of the blade are photosynthesis and absorption of nutrient. The blades may be flat, ruffled, feathery or even encrusted with calcium carbonate. The most significant difference of seaweeds from the higher plants is that their sex organs and sporangia are usually one celled or if multicellular, their gametes and spores are not enclosed within a wall formed by a layer of sterile or non-reproductive cells.

Carbohydrates produced by these floral communities provide nutrition to faunal members of the benthic habitats. The large biomass of seaweeds in the intertidal zone (Fig. 2.9) makes it an important primary producer of the marine and estuarine ecosystems.

The macroalgae are noted for their primary production. Efficiencies of solar energy trapped showed a maximum in *Enteromorpha intestinalis* (0.64 %) and *Ulva lactuca* (0.43 %) with an average of 0.35 % by this group. A research conducted on this aspect indicates that in the deltaic complex of Indian Sundarbans, *Enteromorpha intestinalis* and *Ulva lactuca* are the most productive species, followed by *Enteromorpha prolifera* and *Rhizoclonium grande* (Chaudhuri and Choudhury 1994). The gross and net primary productions and energetics of benthic macroalgae in this mangrove-dominated ecosystem are highlighted in Tables 2.4 and 2.5.

2.1.3 Seagrass and Salt Marsh Grass

Seagrass refers to the marine flowering plants (angiosperm) that grow luxuriantly in tidal and subtidal marine environment. They belong to the families Hydrocharitaceae and Potamogetonaceae. There are about 13 genera and 58 species of seagrass available all over the world. Of these, six genera (*Amphibolis*, *Heterozostera*, *Phyllospadix*, *Posidonia*, *Pseudalthenia* and *Zostera*) are mostly restricted to temperate seas and the remaining seven genera (*Cymodocea*, *Enhalus*,

Fig. 2.9 Seaweed biomass contributes to primary production

Table 2.4 Gross primary production (GPP) and energetics of benthic macroalgae

Species	GPP gC/m^2/day	Glucose g/m^2/day	Energy kcal/m^2/day	Efficiencies (%)
Chlorophyceae				
Enteromorpha intestinalis	3.84	9.60	35.91	0.64
E. prolifera	2.10	2.75	10.29	0.19
Ulva lacuta	2.54	6.35	23.75	0.43
Rhizoclonium grande	0.84	2.10	7.86	0.14
Rhodophyceae				
Bostrychea radicans	2.26	3.15	12.78	0.21
Bostrychea sp.	0.61	2.53	5.72	0.10
Catenella nipae	2.14	2.85	10.66	0.19
C. adnata	0.24	0.60	2.25	0.04
C. leprieurii	0.27	0.68	2.55	0.05
Gracilaria verrucosa	0.96	2.40	8.98	0.16
Total	12.80	32.01	119.72	2.14
Mean	2.28	3.20	12.97	0.22

Halodule, *Halophila*, *Syringodium*, *Thalassia* and *Thalassodendron*) are distributed in tropical seas. Seagrass species have world-wide distribution. They are found in tropical (hot), temperate (cool) and the edge of the Arctic (freezing) regions. They thrive luxuriantly in coastal water region (Fig. 2.10). Seagrasses are mostly found in patches, but these patches can expand to form huge seagrass beds, or meadows. The beds may sustain one species of seagrass, or multiple species.

Macroalgae or seaweeds also colonize the coastal zone, and they are often confused with seagrass species. The basic differences between seagrass and seaweeds are highlighted in Fig. 2.11 and Table 2.6.

Seagrasses anchor themselves to the seafloor with their root systems. A very strong root structure allows seagrasses to withstand strong currents and waves especially during storm events (Fig. 2.12). They accomplish their underwater reproduction by producing filamentous pollen grains that can be transported by water currents.

Salt marsh grasses are special type of halophytes that are adapted to continual and periodic flooding. These are found primarily throughout

Table 2.5 Net primary production (NPP) and energetics of benthic macroalgae

Species	NPP ($g/m^2/day$)	Glucose ($g/m^2/day$)	Energy ($kcal/m^2/day$)	Percentage of GPP	Net efficiencies
Chlorophyceae					
Enteromorpha intestinalis	3.26	8.150	30.48	85.00	0.55
E. prolifera	0.98	2.450	9.14	89.09	0.16
Ulva lacuta	2.25	5.630	22.04	88.58	0.38
Rhizoclonium grande	0.32	0.800	2.99	80.01	0.05
Rhodophyceae					
Bostrychea radicans	0.86	2.154	8.04	68.25	0.15
Bostrychea sp.	0.38	0.950	3.56	62.29	0.06
Catenella nipae	0.86	2.150	8.04	75.43	0.15
C. adnata	0.12	0.300	2.12	50.00	0.02
C. leprieurii	0.21	0.530	2.97	77.77	0.03
Gracilaria verrucosa	0.62	2.550	5.80	64.98	0.10
Total	9.86	24.660	92.18	76.99	2.65
Mean	0.97	2.470	9.22	77.18	0.17

Fig. 2.10 Seagrass patch in the coastal zone

the tropical, temperate and sub-Arctic regions. The tide is the dominating characteristic of a salt marsh. The salinity of the aquatic phase defines the plants and animals species that can survive in the marsh area. The vertical range of the tide determines flooding depths and thus the height of the vegetation, and the tidal cycle controls how often and how long vegetation is submerged. Two areas are delineated by the tide: the low marsh and the high marsh. The low marsh generally floods and drains twice daily with the rise and fall of the tide; the high marsh, which is at a slightly higher elevation, floods less frequently.

Salt marshes usually are developed on a sinking coastline, originating as mud flats in the shallow water of sheltered bays, lagoons and estuaries, or behind sandbars. They are formed where salinity is high, ranging from 20 to 30 psu. Proceeding up the estuary, there is a transitional zone where salinity ranges from 20 to less than 5 psu. In the upper estuary, where river input dominates, the water has only a trace of salt. This

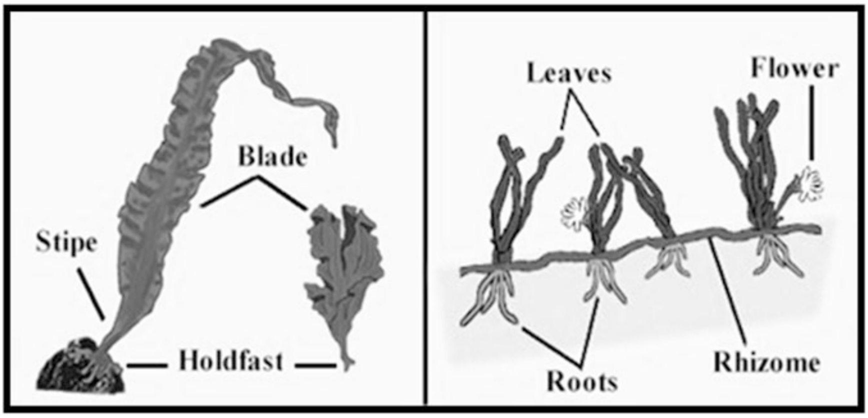

Fig. 2.11 Seaweed (*left*) and seagrass (*right*) structures

Table 2.6 Comparative study of seagrass and seaweeds

Point of difference	Seagrass	Macroalgae (seaweed)
Number of species world-wide	55	5,000–6,000
Plant category	Flowering plants (angiosperm)	Autotrophic organism (thallophytes)
Structure	Possesses roots, leaves and underground stems to anchor to substrate	Does not possess roots, leaves, but simple holdfast anchor them to hard substrates
Absorption of nutrients	Roots and rhizomes extract nutrients from sediment and leaves absorb the nutrients from water	Nutrients enter the tissue by diffusion mechanism
Transportation	The nutrients and dissolved gases are transported through a network of xylem and phloem distributed in the plant	Transportation does not occur
Reproduction	Reproduction occurs through flowers, fruits and seeds	Reproduction occurs through spores

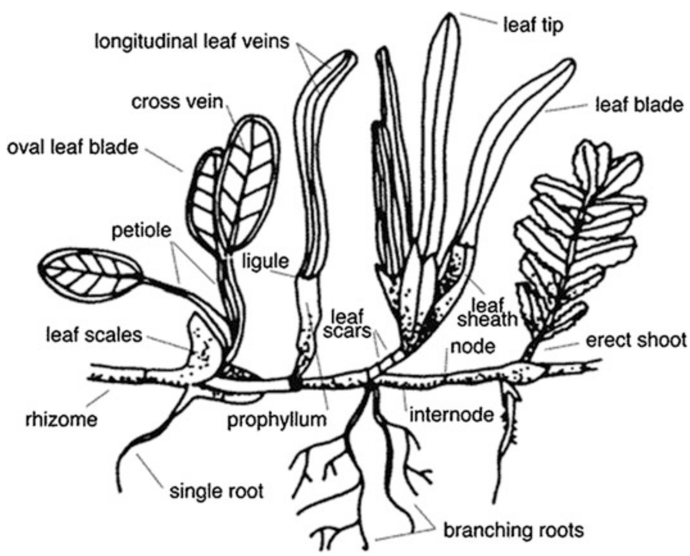

Fig. 2.12 A typical seagrass showing aboveground and belowground structures

varying salinity produces changes in the marsh—in the kinds of species and also in their number. Typically, the fewest species are found in the hypersaline zone and the greatest numbers of species are found in the freshwater tidal marsh. In Indian Sundarbans region, salt marsh grass *Porteresia coarctata* grows in Nayachar Island (21° 45′ 24″N and 88° 15′ 24″E), where the salinity of water touches almost 2 psu during monsoon. Also the species is abundant in the intertidal mudflats of islands located in the high-saline zone such as Sagar Island (21° 39′ 04″N and 88° 01′ 47″E), Gosaba (22° 15′ 45″N and 88° 39′ 46″E) and Satjelia Island (22° 11′ 52″N and 88° 50′ 43″E), where the salinity varies between 15 and 28 psu (Fig. 2.13). In this mangrove-dominated ecosystem, the species is the neighbour of mangroves (Fig. 2.14) and plays an important role to maintain stability of the islands (Mitra and Banerjee 2005). It is the

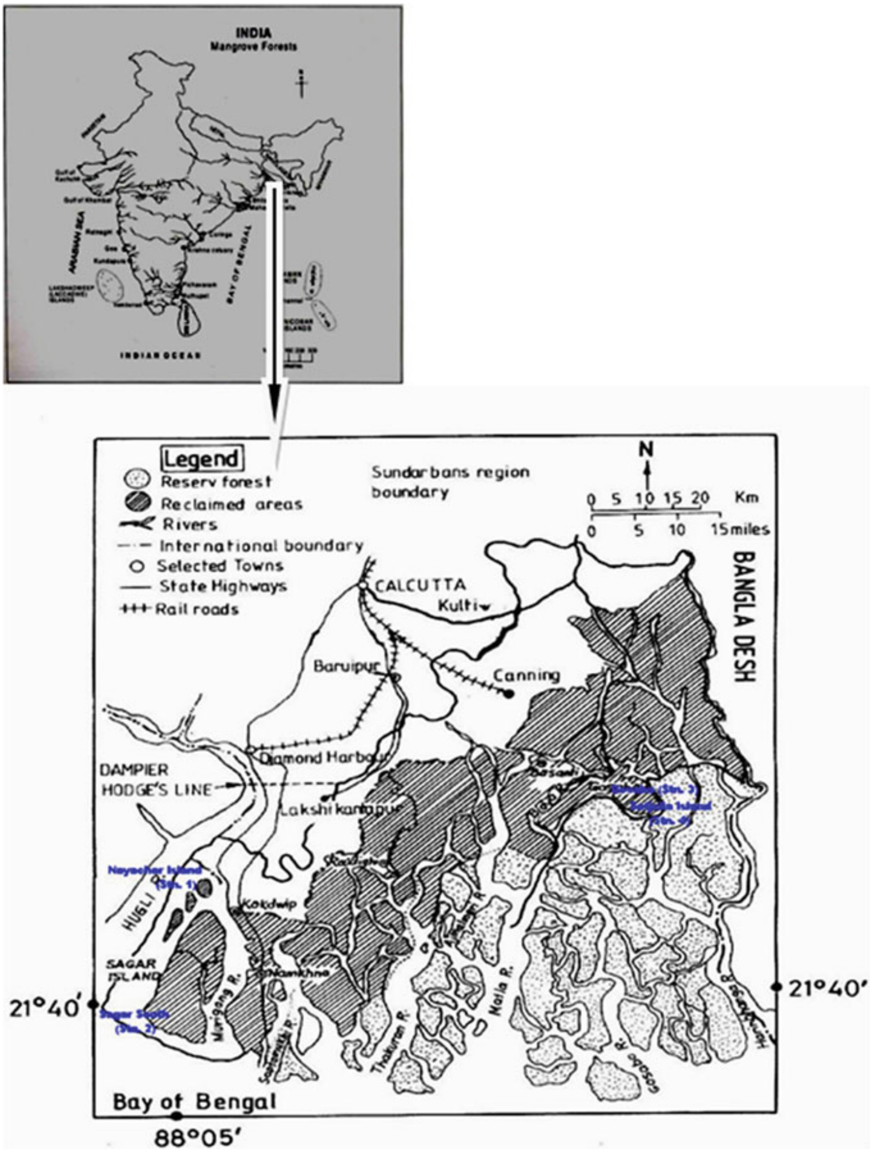

Fig. 2.13 Location of sampling stations (marked in *blue*) in the Indian Sundarbans

Fig. 2.14 View of *Porteresia coarctata* with few mangrove seedlings

pioneer species in the process of ecological succession. Studies carried out by researchers showed that salinity has a regulatory influence on the biomass and carbon content of *P. coarctata*. *P. coarctata* Tateoka (=*O. coarctata*) is a tetraploid ($2n = 4x = 48$) monotypic genus occurring as a halophyte, distributed along the coastal mangrove belt of India and Bangladesh. Taxonomically Tateoka (1965) classified *O. coarctata* as *P. coarctata* based on morphological and embryo anatomy. The plant contains useful traits including salt and submergence tolerance, perenniality, short internodal length conferring mechanical strength, all of which are little studied.

The salt marsh is one of the most productive ecosystems in nature and serves as a sediment sink, a nursery habitat for finfish and shellfish species, a feeding and nesting site for waterfowl and shorebirds, a habitat for numerous unique plants and animals, a nutrient source, a reservoir for storm water, an important erosion control component, and a site for aesthetic pleasures.

Seagrasses are monocotyledon that are not true grasses (true grasses belong to the family of Poaceae) (Fig. 2.14), but more closely related to lily family. Salt marsh grass such as *Porteresia coarctata* is under family Poaceae.

Scientists have identified four habitats where seagrasses and salt marsh grasses can grow along the coast. Different factors regulate their growth and survival in these highly delicate and vulnerable (to physical processes such as waves, tides, storms, high water) coastal habitats.

1. **River estuaries** are dominated by run-off (e.g. in Queensland, run-off is infrequent and on a massive scale) from the land that carries freshwater, sediment and nutrient into the ocean. Run-off can produce 'flood-plumes' that extend many kilometres from the coast and affect large areas. The examples of estuaries in the Ganges, Brahmaputra and Meghna basins are important in this context (Fig. 2.15), where salt marsh grasses are widely available. A comparative account of these three important basins is presented in Table 2.7. The estuaries of these basins are mostly connected with Himalayan glaciers due which many of them receive freshwater along with sediment load. Nutrient overloading is also an important issue in many of these estuaries, particularly the estuaries of the

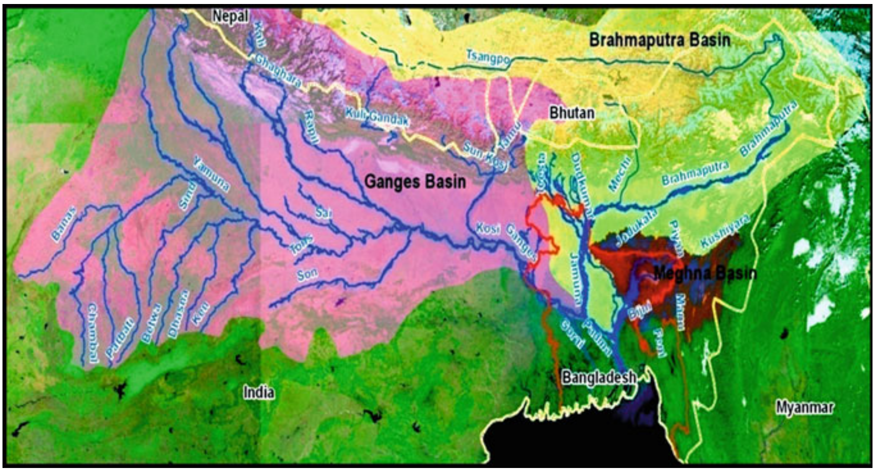

Fig. 2.15 Location of Ganges, Brahmaputra and Meghna basins in India, Bangladesh and Myanmar, respectively

Table 2.7 Comparative account of Ganges, Brahmaputra and Meghna basins

Features	Ganges basin	Brahmaputra/Jamuna basin	Meghna basin	Total
Catchments area (km^2)	1,000,000	573,000	77,000	1,650,000
Mean annual rainfall (mm)	1,200	1,900	4,900	8,000
Mean annual discharge (cumec)	11,000	20,000	4,600	35,600
Maximum discharge (cumec)	78,000	100,000	20,000	198,000
Sediment transport (m ton/year)	550	590	13	1,153

Source Delta plan 2100; http://www.partnersvoorwater.nl/wp-content/uploads/2012/07/MoUBangladeshDeltaPlan2100-22May20120001.pdf

Ganges basin. However, the abundance of salt marsh grass in all these estuaries indicates that unlike seagrasses (which are primarily dependent on transparency), salt marsh grass can thrive well in turbid water.

2. **Coastal** seagrass and salt marsh grass habitats are dominated by physical disturbance caused by periodic events such as cyclones, storms and floods. Major floods in the Hervey Bay area have caused the temporary loss of the extensive seagrass meadows and the subsequent death of hundreds of dugong. Also strong currents that cause erosion damage the seagrass and salt marsh grass patches (Fig. 2.16).
3. **Deep-water** seagrass meadows are limited in their growth due to minimum availability of light. Sunlight is filtered by the water column with less light reaching the bottom in deeper water. As a result, seagrass growth is limited by the clarity of the sea water above it. Seagrasses can grow even at a depth of 60 m as in the Great Barrier Reef lagoon where the transparency is very high.
4. **Reef** seagrasses are limited by substrate type and shelter from waves. Most coral reef waters and sediments also have very limited nutrients available for seagrass growth.

2.1.4 Mangroves

Along the edges of continents, around islands, wherever land meets sea, seashores are found. At nearly 440,000 km, the coastline across the Earth's runs over a staggering distance and can encircle the equator almost 13 times over. These miles and miles of shoreline have fascinating diversity and are not the same everywhere. On the coasts along the tropics on either side of the equator are the regions where mangroves flourish. These areas are warm, humid and swampy inter-tidal zones where tropical rivers flow into the sea.

Fig. 2.16 Salt marsh grass bed exposed to tidal surges

The word 'mangrove' finds its origin from the Portuguese and English Words 'Mangue' and 'Grove', respectively, and indicates mangroves plants as well as a group of trees. According to Mepham and Mepham (1984), the term has been inconsistent and confusing in the past. Mangroves are basically evergreen sclerophyllous, broad-leaved trees with aerial root such as pneumatophore or stilt root and viviparously germinated seedlings (UNESCO 1973). They grow along protected sedimentary shores especially in tidal lagoons, embayment and estuaries (Macnae 1968). They also can grow far inland, but never isolated from the sea. These emergent, evergreen canopies are found along the sedimentary shores of both tropical and subtropical regions in association with intertidal flora and fauna commonly known as mangrove ecosystem, and the community of these mangroves was coined by Macnae (1968) as **Mangal**. Lear and Turner (1977) expressed the word 'mangrove' of coastal ecosystem in a holistic manner, including its common habitat or inhabiting fauna. The term 'mangrove' also denotes both the ecological group of flowering halophytic shrubs and trees of up to 30 m high belonging to several unrelated families, and the complete community or association of plants which fringe sheltered tropical shores. About 60–75 % of tropical coastline is fringed with mangroves (Reimold and Queen 1974). Duke (1992) defined mangroves as '…A tree, shrub, palm and ground fern, generally exceeding one half metre in height and which normally grows above mean sea level in the intertidal zone of marine coastal environments or estuarine margins…'. This definition is acceptable except that ground ferns should be considered as mangrove associates rather than true mangroves. The term 'mangrove' often refers to both the plants and the forest community. To avoid confusion, Macnae (1968) stated that 'mangrove' should refer to halophytic plant species, while the entire forest community including micro- and macro-organisms should be considered as 'mangal'. The mangal is therefore a broad domain encompassing the entire biotic community comprising of individual plant species, associated microbes (such as bacteria and fungi) and animals. The mangal and its associated abiotic factors constitute an ideal mangrove ecosystem, which is a unique ecosystem of the planet Earth.

The number of mangrove species and associated plants vary across different parts of the world. They are most prolific around South-East Asia, and most live within the Tropic of Cancer and Tropic of Capricorn. Yet there are a few species to be found even in the cooler, temperature climates. But whether in the hot, humid marshes or far away from the tropical sun, mangroves across the globe have one similarity. They have a remarkable ability to adapt and survive in their suffocating, salt-laden environment.

Among the less obvious role of mangroves is that they have a far-reaching effect on mitigating the effects of global warming. They not only serve as carbon sinks in tropical and subtropical coastal regions, but they also protect communities in these parts from storms and surges associated with global warming. Coastal studies that have analysed the carbon budget of mangroves have found that mangroves are highly effective carbon sinks. These trees absorb carbon dioxide, thus taking carbon out of circulation and reducing the amount of greenhouse gas in the environment. Studies on their photosynthesis, sap flow and other processes in leaves have shown that mangroves have an exceptional ability to assimilate carbon. Mangrove habitats are responsible for carbon sequestration where much of the carbon ends up in forest sediments and remains therefore thousands of years. Nearly 38 % of the biomass of mangrove forests is below the ground, which represents a potentially vital carbon sink. When mangroves are removed for other purposes the region changes from being a carbon sink

Mangroves are salt-tolerant forest ecosystems found mainly in the tropical and subtropical intertidal regions of the world. They encompass swamps, forest land within, and the surrounding water bodies. It is a matter of great surprise that mangrove floral species can thrive luxuriantly in saline habitat (which is basically physiologically dry in nature) through orientation of their morphological, anatomical and physiological systems. Thus, this vegetation is the most efficiently adapted biotic community in response to climate change induced sea level rise.

Mangroves are circumtropical in distribution and this forest community occupies approximately 75 % of the total tropical coastline. Northern extension of this coastline occurs in Japan (31° 22′N) and Bermuda (32° 20′N), whereas southern extensions are in New Zealand (38° 03′S), Australia (38° 45′S) and on the east coast of South Africa (32° 59′S). Globally, mangroves are distributed in 112 countries and territories. It is interesting to note that mangrove plants are not native to the Hawaiian Islands—six species have been introduced there since the year 1900. The mangrove diversity is more in South-East Asian countries (Fig. 2.17). The region holds nearly 75 % of the world's mangrove species with

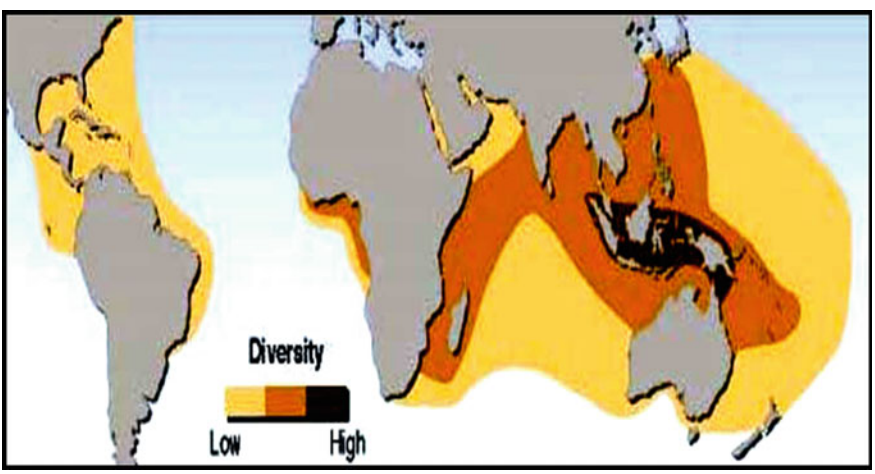

Fig. 2.17 Global distribution of mangrove diversity (after UNEP 2002)

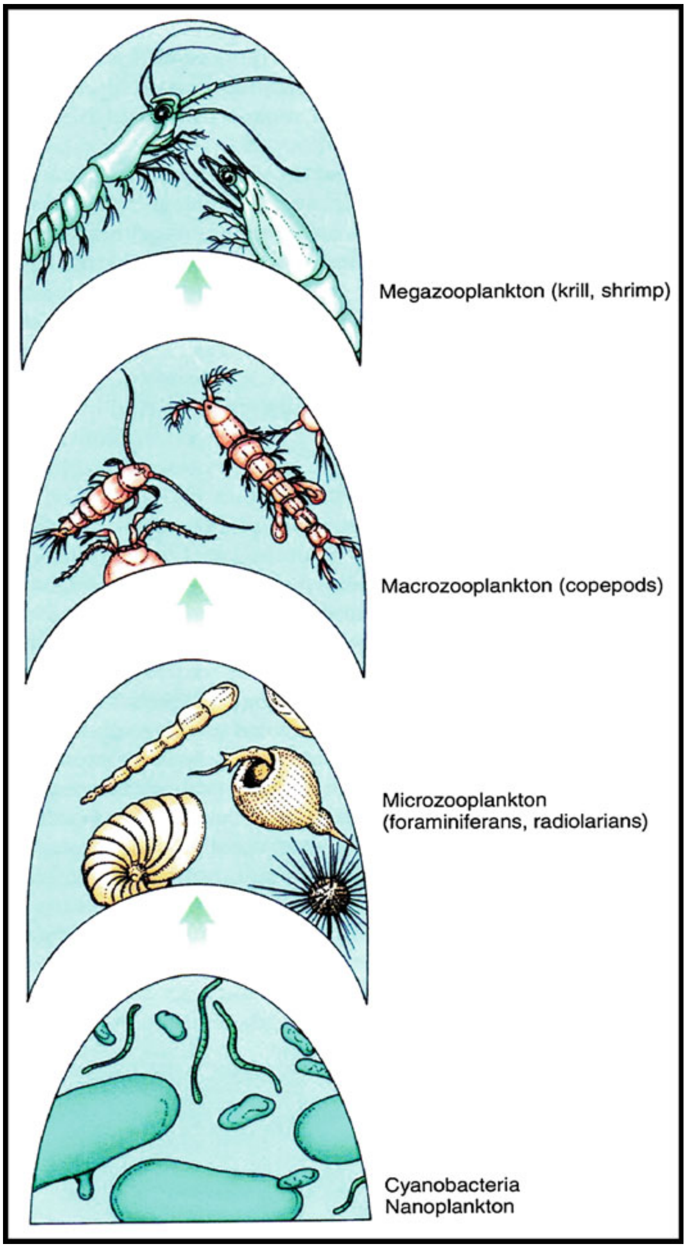

Fig. 2.18 Variation of zooplankton size

the highest species diversity found in Indonesia with 45 species, followed by Malaysia (36 species) and Thailand (35 species). India is no less in terms of the number of mangrove species (34 species of true mangroves) and hence is considered as one of the mega biodiversity countries in the world.

The total global coverage of mangroves has been variously estimated as 14–15 million hectares (Schwamborn and Saint-Paul 1996), 10 million hectares (Bunt 1992) and 24 million hectares (Twilley et al. 1992). Spalding et al. (1997) gave a recent estimation of global mangrove coverage around 18 million hectares with 42.4 % in South

Fig. 2.19 Copepod: a common holoplankton

Fig. 2.20 Larval stage (plankton) of *Macrobrachium rosenbergii*

and South-East Asia and additional 23.5 % in Indonesia. The most recent estimates suggest that mangroves presently occupy about 14,653,000 ha of tropical and subtropical coastline (Table 2.8) (Wilkie and Fortuna 2003).

A list of mangrove-dominated countries in and around Indian Ocean is shown in Table 2.9.

In the Indian Ocean region, the mangroves are found in a variety of coastal settings, ranging from arid areas through estuaries, lagoons and deltas to coastal fringes. The functional types of mangroves in the Indian Ocean region are as follows:

1. Overwash mangrove forests—small mangrove islands, frequently overwashed by the tides.
2. Fringing mangrove forests—found along the waterways influenced by daily tides.

Fig. 2.21 Adult stage (prefers substrate) of *Macrobrachium rosenbergii*

Table 2.8 Estimates of mangrove areas

Reference	Reference year[a]	No. of countries included	Estimated total area
FAO/UNEP (1981)	1980	51	15,642,673
Saenger et al. (1983)	1983	65	16,221,000
FAO (1994)	1980–1985	56	16,500,000
Groombridge (1992)	1992	87	19,847,861
ITTO/ISME[b] (1993)	1993	54	12,429,115
Fisher and Spalding (1993)	1993	91	19,881,800
Spalding et al. (1997)	1997	112	18,100,077
Aizpuru et al. (2000)	2000	112[c]	17,075,600
FAO (2003)	2003	112	14,653,000

[a] Except for FAO/UNEP (1981) and Aizpuru et al. (2000), the reference year is the year of the publications in which the estimate is cited, not the weighted average of all the national area estimates

[b] Combined figure from three publications by Clough (1993), Diop (1993) and Lacerda et al. (1993)

[c] New estimates were provided for 21 countries, and for the remaining countries the study relied on Spalding et al. (1997)

3. Basin mangrove forests—stunted mangroves, located in the interior of swamps.
4. Hammock mangrove forests—similar to basin type, but existing in more elevated sites.
5. Scrub mangrove forests—dwarf stands of mangroves, existing on flat coastal fringes.

The sheltered coasts support a luxuriant growth of mangroves and a higher biodiversity and this is because of the favourable conditions such as muddy sediment, frequent water exchange, high rainfall and high humidity, prevailing in the areas. The best examples are mangroves of Sundarbans (India and Bangladesh), Malaysia and Indonesia. In contrast, the arid regions of Arabian Gulf countries, Pakistan and Gujarat (India), where the sediment is sandy, highly saline and poor in nutrients have only dwarf mangrove stands.

Table 2.9 Mangrove-rich countries in the Indian Ocean region

Country	Area (in km^2)
Indonesia	42,500
Myanmar	6,950
Malaysia	6,410
India	4,871
NW Australia	4,513
Bangladesh	4,500
Madagascar	4,200
Mozambique	4,000
Pakistan	2,600
Thailand	1,900

The mangrove forests are highly productive ecosystems with productivity about 20 times more than the average oceanic production (Gouda and Panigrahy 1996). Moreover, it is a '**detritus-based**' ecosystem unlike other coastal ecosystems, which are usually '**plankton-based**'. The detritus supplied by the ecosystem saturates the ambient water with nutrients, which triggers the growth and development of planktonic community in the water bodies on which the fishery resource is also dependent. The greatest concentration of mangrove species is observed usually at the mouth of tidal creeks and rivers where salt and fresh water mix in ideal proportion and floodwaters deposit plenty of material to build up the banks. This unique coastal ecosystem of the world sustains a rich spectrum of floral and faunal community in and around its vicinity. The mangroves enrich the coastal waters with nutrients, yield commercial forest products, protect coastlines and support coastal fisheries (Kathiresan and Bingham 2001). Generally, the mangrove vegetations are well adapted to extreme conditions of salinity, tides, winds and temperature, although they show a preference for fresh water. There are no floral groups in the plant kingdom, which possess such well-organized and highly developed morphological, biological and physiological as well as ecological adaptations to extreme environmental conditions.

Mangrove plants tolerate salinity of the soil and water through three basic processes as listed here:

(i) **Salt excretion**: Mangrove plants take saline water as such through roots. However, in the tissues of some species of mangroves, only water molecules and essential salts are retained. Excess salts are excreted through **salt glands** that are present in the leaves. The salt-excreting species of mangrove community such as *Avicennia alba*, *Aegiceros corniculatum*, *Acanthus ilicifolius*, *Aegialitis rotundifolia* regulate their internal salt levels through foliar glands. In salt-secreting (excreting) mangroves, the NaCl concentration of xylem sap is relatively high, about one-tenth of the concentration of salt in sea water. So, the salt-excreting species allow more salt into the xylem than do the non-excretors, but still exclude about 90 % of the salts (Scholander et al. 1962; Azocar et al. 1992). Salt is only partially excluded at the roots. The absorbed salt is primarily excreted metabolically via specialized salt glands in the leaves. The salt in solution can crystallize by evaporation and either can be blown away or washed off. Since, in salt-excreting mangroves, superfluous salts are excreted by guttation through special salt glands, all these salt-excreting halophytes are often referred to as **crinohalophytes**.

   It is interesting to note that salt excretion is an active process, as evidenced by ATPase activity in the plasmalemma of the excretory cells (Drennan and Pammenter 1982). The process is probably regulated by leaf hypodermal cells, which may store salt as well as water (Balsamo and Thomson 1995).

(ii) **Salt exclusion**: In some of the mangrove plants the roots possess an **ultra-filtration** mechanism called **reverse osmosis** by which water and salts in the sea water are separated in the root zone itself and only water is taken inside and the salts are rejected. Many mangrove species can exclude 90 % of salt in the ambient sea water or estuarine system (http://www.epa.qld.gov.au/nature_conservation/habitats/mangroves_andwetlands/mangroves). *Rhizophora mucronata*, *Ceriops decandra*, *Bruguiera gymnorrhiza*, *Kandelia candal*, etc., are few salt excluders of mangrove community. Scholander (1968) demonstrated experimentally that the salt separation process in mangroves occurs at or near the root surface. This is mediated by physical processes alone, since it is not inhibited by poisons or high temperature, which may cause an inhibitory effect on metabolic process. In the root area, the physical mechanism for salt separation involves ultra-filtration which occurs either at the root surface (Epiblema) or at the root endodermis. However, the latter region might be the most preferable site (Tomlinson 1986) because the ultimate absorbing roots in most of the mangroves lack root hairs (e.g. capillary rootlets of *Rhizophora* sp.). This indicates that the absorbing area of mangroves is reduced in comparison to non-mangrove plants.

(iii) **Salt accumulation**: In this type of mangrove plants, the species possess neither salt glands nor ultra-filtration system, but they have the capacity to accumulate a large amount of salts in their leaves. This imparts succulence to their leaves. *Sonneratia apetala*, *Lumnitzera racemosa*, *Excoecaria agallocha*, *Sesuvium portulacastrum*, *Sueada maritima* and *Sueada nudiflora* are included in this category. Leaf succulence in mangroves has a simple explanation in terms of salt balance. The osmotic potential of the leaf cells of mangroves is high (Scholander et al. 1964) which is essential if mangroves are to draw water from the sea with its high negative water potential. However, Scholander (1968) noted that the salt concentration of mangrove leaves remain constant and independent of age. Measurement of salt content in xylem sap demonstrates incomplete salt exclusion at the roots. But mangroves accumulate salt, and so this accumulation is partly compensated by salt glands, mainly in the less efficient salt excluders. Since salt concentration is constant and independent of leaf age, salt must accumulate by an increase in the volume of the leaf cells inducing succulence. The leaf succulence in mangroves may therefore be accepted as a part of their adaptation in an environment that provides ample water at the expense of some compensation for high aquatic salinity.

Studies on salt tolerance in *Aegiceros corniculatum* and *Sesuvium partulacastrum* generated few interesting findings as follows: (i) NaCl salinity has considerable effect on the degree of succulence. With the increase of NaCl salinity in the ambient media, the mass and volume of the leaves increases due to increment in the water content. (ii) Effect of NaCl and Na_2SO_4 is more pronounced in *Sesuvium* sp. than *Aegiceros* sp. (iii) In *Sesuvium* sp., effect of chloride salinity is more prominent than that of sulphate salinity. (iv) NaCl is most effective salt in promoting succulence (Van Eijk 1939). Succulence is due to expansion of the cell wall leading to increase in the size of cells. (v) Accumulation of NaCl is more in *Sesuvium* than *Aegiceros* due to their difference in the mode of salt regulation. (vi) Chlorophyll content decreases sharply at high concentration of NaCl in both the plant species. (vii) High concentration of Na_2SO_4 stimulates the synthesis of chlorophyll in *Aegiceros corniculatum*, but inhibits the same in *Sesuvium* sp.

The mangroves not only stabilize the shoreline and act as a bulwark against the encroachment by the sea, but they also act as the abode of several species of fin fish, nursery of a wide range of finfish and shellfish juveniles and biopurifying matrix of wastes generated as a result of industrialization and urbanization. In mangrove ecosystem, different kinds of unrelated fauna and flora get themselves adapted to thrive under the influence of tidal inundation and brackish water. This ecosystem is thus a zone of adaptive convergence, which is a critical issue in the sphere evolutionary biology.

2.2 Consumer Community

2.2.1 Zooplankton

Zooplankton are found in almost all the layers of the photic zone of the ocean. They are potentially limited by two factors in the coastal and estuarine zones: firstly by turbidity which can limit phytoplankton production and thus restrict the ration supply for the zooplankton community, and secondly by currents which, particularly in small estuaries are dominated by high river flow that usually carries the zooplankton out to the sea. The zooplankton biomass can increase the fishery productivity because they chiefly consume the primary producers (phytoplankton) and form the major food source for members of higher trophic levels in which several species of osteichthyes and chondrichthyes exist. Zooplankton are classified according to their habitat, depth distribution, size and duration of planktonic life (Tables 2.10, 2.11, 2.12 and 2.13).

2.2.2 Osteichthyes

Bony fishes are found at all depths and in all the oceans, but their distribution is determined directly or indirectly by the abundance and biomass of primary producers. This is the basis of evaluating potential fishing zone (PFZ), which is detected from the satellites. It is very important to note in this context that satellites do not observe fish stocks directly, but measurements, such as sea-surface temperature (SST), sea-surface height (SSH), ocean colour, ocean winds and sea ice, characterize critical habitat that influences marine resources including fish stocks. Most of the spatial features that are important to marine ecosystems, such as ocean fronts, eddies, convergence zones, river plumes and coastal regions, cannot be adequately resolved without satellite data. Chlorophyll, present within the phytoplankton, is the only biological component of the marine ecosystem accessible to remote sensing (via ocean colour) and as such provides a key metric for evaluating the health and productivity of marine ecosystems on a global scale. Long-term ocean colour satellite monitoring provides an important tool for better understanding of the marine processes, ecology, fish

Table 2.10 Classification of zooplankton on the basis of habitat

Type	Description
Oceanic plankton	These are marine zooplankton that inhabit beyond the continental shelf
Neritic plankton	These zooplankton inhabit waters overlying continental shelves. These waters are often very productive as they receive the runoff from the adjacent landmasses that triggers the phytoplankton growth in these regions
Brackish water plankton	These zooplankton inhabit estuarine regions, where there is a continuous mixing of fresh water and sea water. The zooplankton species of this category have wide range of tolerance to different dilution factors. Such zooplankton are very common in the shrimp culture farms and form important diet of the prawns

Table 2.11 Classification of zooplankton on the basis of depth distribution

Type	Description
Neuston	The zooplankton of this category are restricted at the top few millimetres (usually 10 mm) of the surface microlayer
Pleuston	These are widely distributed at the surface of the sea (with parts of the body sometime projecting above the water)
Epipelagic	These are distributed between 0 and 300 m water column, e.g. siphonophores, arrow worms
Mesopelagic	The zooplankton of this category are restricted within the depth 300–1,000 m, e.g. euphausiids, chaetognath
Bathypelagic	These are restricted within the depth 1,000 and 3,000 m, e.g. foraminifera, euphausiids
Abyssopelagic	The waters overlying the vast abyssal plains of the ocean are inhabited by a variety of zooplankton species, which is often referred to as abyssopelagic zooplankton. These zooplankton are thus restricted between 3,000 and 4,000 m

Source Santhanam and Srinivasan (1998)

Table 2.12 Classification of zooplankton on the basis of size (see Fig. 2.18)

Type	Size range
Nannozooplankton	<20 µm
Microzooplankton	20–200 µm
Mesozooplankton	200 µm to 2 mm
Macrozooplankton	2–20 mm
Megazooplankton	>20 mm

Source Santhanam and Srinivasan (1998)

stock and the coastal environmental changes (Tang and Kawamura 2001). Modern oceanographic vessels are therefore linked to satellites via computers allowing scientists to use immediate data to plan their sampling programmes while at sea.

Fishes are mostly concentrated in upwelling areas, shallow coastal areas and estuaries. The surface waters support much greater populations of fish per unit volume of water than the deeper zones, where food resources are very less in terms of quality (diversity) and quantity. The presence of mangroves and other associate floral species also regulate the distribution of fishes in the marine and estuarine compartments.

The marine and estuarine ecosystem is the dwelling place of a wide spectrum of **ornamental fishes**, which have unique economic linkage. Marine aquarium trade is rapidly expanding and there is a growing demand for tropical marine aquarium fishes in the international market. Globally, the aquarium industry is valued at $4 to $15 billion. In USA, 89 million freshwater fishes are being maintained in 12.1 million tanks, while 5.6 million tropical marine fishes in 2.1 million tanks. In India, after the scientific and technological advancements in the sector of ornamental fishery, there has been an increased demand for tropical marine aquarium fishes in recent years. This has opened up new avenues for alternative livelihood and a lucrative money spinning trade for marine ornamental fishes.

Coral reefs (Fig. 2.22) also provide diverse ecological niches for shelter as well as food and thus sustain a wide variety of marine ornamental fish species (Fig. 2.23). About 400 species of ornamental fishes belonging to 175 genera and 50 families are reported from Indian waters.

2.2.3 Chondrichthyes

Elasmobranchs (**chondrichthyes**) constitute a vital segment of marine and estuarine nekton and are of great commercial importance all over the globe, apart from being a major component in marine food web. About 350 species of sharks and 320 species of rays are known to exist. Nearly all are marine, although a few species inhabit estuaries, and a very few are permanent inhabitants of fresh water. It has been observed that sharks usually prefer swimming in open waters, whereas rays tend to be found on or near the bottom.

Sharks are thus dominant species of elasmobranchs and play a vital role in both ecology and economics. The various direct and indirect products obtained from sharks are today used in food, tourism and pharmaceutical industries. Because of such multiple uses, the community is presently under threat due to overexploitation. Deterioration of water quality due to anthropogenic activities has increased the magnitude of threat. Few species of sharks are so sensitive in nature that they cannot withstand the alteration of

Table 2.13 Classification of zooplankton on the basis of duration of planktonic life

Type	Description
Holoplankton	This group includes organisms which are planktonic throughout their life cycle, e.g. tintinnids, cladocerans, copepods, chaetognaths, etc. Figure 2.19 shows a very common holoplankton found in the marine and estuarine waters of tropics
Meroplankton	This group encompasses those organisms which remain planktonic only for a portion of their life cycle, e.g. larvae of benthic invertebrates and fish larvae (ichthyoplankton). In the estuaries of Indian Sundarbans, larvae of prawn (*Macrobrachium rosenbergii*) are found in plenty (Fig. 2.20), which finally become a semi-benthic species in the adult stage (Fig. 2.21)

Source Santhanam and Srinivasan (1998)

Fig. 2.22 A view of coral reef: an amazing housing complex for marine flora and fauna

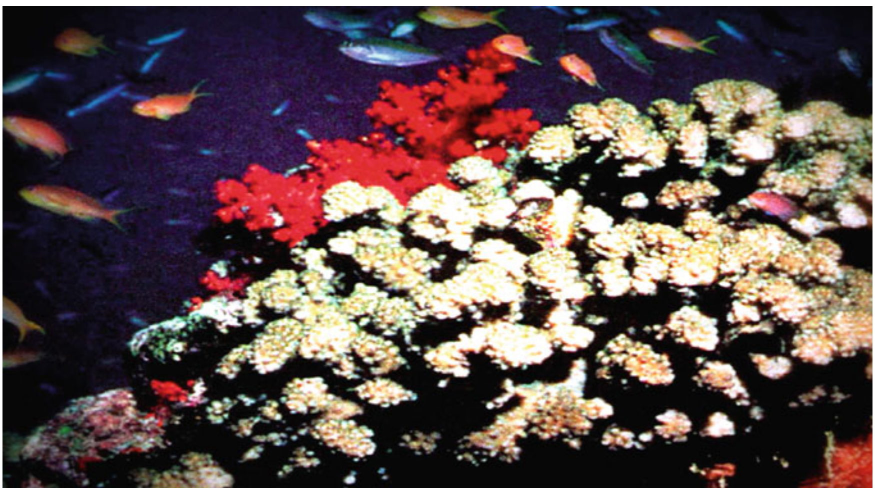

Fig. 2.23 Coral reefs are favourable habitats for ornamental fishes

water quality caused by rapid industrialization and urbanization.

In the Indian coastal waters, the common shark species are highlighted in Table 2.14.

2.2.4 Reptiles

Reptiles are predominant on both land and in the sea. The morphological physiological and anatomical modifications, which were responsible for the ancestors of reptiles to conquer land, were also useful in allowing their descendants to return to the saline water of the marine and estuarine systems. This was possible after the evolution of an **amniotic egg** some 340 million years ago, which is covered by protective shell and contains liquid-filled sac called **amnion** filled with yolk. The egg also contains a disposal sac (where the wastes accumulate), called the **allantois** and a membrane called **chorion** (which provides surface for gas exchange). This

Table 2.14 Common shark in Indian coastal waters

Sl. No.	Species	Distribution	Diet	Length	Reproduction
1	*Carcharhinus limbatus* (blacktip shark) (IUCN status: lower risk)	Cosmopolitan in distribution near the inshore regions of tropical waters. It is capable of tolerating reduced salinity, but never penetrates into freshwater	Fish such as sardine, mackerel, croaker, sole along with cephalopods and crustaceans	Matured ones are 2.5 m in length. Male matures at 140–150 cm and female matures at 150–160 cm	Produces an average of 6 embryos per litter. Size at births is 55–60 cm
2	*Carcharhinus sorrah* (spot-tail shark)	Commonly found in coral reefs region.	Bony fish such as mackerels, sardines and shellfish such as squids and prawns	Short in length, about 2.5 m. Male matures at 115 cm and female matures at 120 cm	Litter size is 2–6 usually delivered during March to May. The size at birth is around 40 cm
3	*Carcharhinus dussumieri* (Whitecheek shark) (IUCN status: lower risk)	Common species in inshore waters	Small fishes, squids and crustaceans	Matured ones are 1 m. Male matures at 65 cm and female matures at 75 cm	Produces an average of 2 embryos per litter. Size at birth is around 35 cm
4	*Carcharhinus melanopterus* (blacktip reef shark) (IUCN status: lower risk)	Indo-Pacific tropical shark migrates into estuaries and brackish waters for delivering its pups	Fish such as mullets, silver bellies, anchovies, hilsa, skate, prawns and squilla	Matured ones are about 2.5 m	Size at birth ranges between 45 and 50 cm
5	*Carcharhinus macloti* (hardnose shark)	Widely distributed in the inshore region	Small fishes, squids and crustaceans	Matured ones are 1 m in length. Male matures at 60 cm and female matures at 70 cm	Produces an average of 2 embryos per litter. Size at birth is 35 cm approximately
6	*Galeocerdo cuvier* (tiger shark) (IUCN status: lower risk)	Widely distributed tropical shark. It is capable of cruising in mid ocean and shows nocturnal movement into bays and estuaries	Eels, cat fish, parrot fish, flat fish, flying fish, skates, rays, marine turtle, sea snake, sea birds, sea lion, dolphin, etc.	Matured ones are about 7.4 m in length	Development is oviparous and the litter size is between 10 and 82. The size at birth is 50–75 cm
7	*Scoliodon laticaudus* (Indian dog shark) (IUCN status: lower risk)	West and south coasts of India, dominant in east coast and in Indian Sundarbans	Small fishes, crustaceans and squids	Majority of males is 50–55 cm and females are about 65 cm. Males and females mature at 30 cm and 35 cm, respectively	Produces up to 20 embryos per litter. The size at birth is 14.5 cm

(continued)

Table 2.14 (continued)

Sl. No.	Species	Distribution	Diet	Length	Reproduction
8	*Rhizoprionodon acutus* (Brazilian sharpnose shark)	Abundant in the shore waters, particularly in the west coast of India during September to February and east coast during summer months	Small fishes, squids, cuttle fish, crabs and shrimps	Matured ones are about 1 m in length	Produces an average of 2–6 embryos per litter, which are 26–27 cm long
9	*Sphyrna lewini* (hammerhead shark) (IUCN status: vulnerable)	Abundantly found in the Indian seas, notable for its unique migratory behaviour	Sardine, anchovies, mackerel, eel, milkfish, sole fish. It also feeds on sharks and rays	Matured ones are up to 4.2 m in length	Development is viviparous and produces an average of 15–30 embryos per litter. The size at birth is 45–55 cm
10	*Rhincodon typus* (whale shark) (IUCN status: vulnerable)	Appears occasionally at Indian coastal waters	Filter-feeder and is believed to sieve plankton as small as 1 mm diameter through the fine mesh of their gill rakers	Largest length up to 1,200 cm but mean length is around 700 cm	Ovoviviparous, embryo length varies from 48–58 cm
11	*Atelomycterus marmoratus* (coral cat shark)	Appears occasionally at Indian coastal waters	Squids, crabs, etc.		
12	*Glyphis gangeticus* (river shark) (IUCN status: extremely endangered; Wildlife Protection Act: Schedule I)	Hooghly–Ganges river system of West Bengal coast	Fish	Maximum length is around 200 cm. Matured males are about 178 cm	Viviparous. Newly born individuals are 56–61 cm long
13	*Glyphis glyphis* (sharptooth shark or speartooth shark)	Confined to turbid waters of rivers, estuaries and inshore waters of coastal West Bengal	Fish	Minimum length is around 100 cm	Live-bearing probably with yolk-sac placenta
14	*Glyphis siamensis* (Irrawaddy river shark)	Confined to turbid waters of rivers, estuaries and inshore waters of coastal West Bengal	Fish	Minimum length is around 63 cm	Live-bearing probably with yolk-sac placenta

Source Mitra and Banerjee (2005)

development of amniotic egg favoured the juveniles of reptiles to develop within the egg and prevent them from predation. It also allowed the eggs to be laid in dry place, out of reach from the aquatic predators.

The evolution of copulatory organs by reptiles allowed for increased efficiency of internal fertilization prior to the ovum being encased by a shell and being laid by female. There are further many other features of reptiles, which enable them to get adapted to both land and ocean. The circulatory system of reptiles is more advanced than fishes. The circulation through lungs and circulation through rest of the body is completely separated, which allows for efficient method of supplying oxygen to the animal tissues to support their active lifestyles. Their kidneys are very efficient in elimination of wastes and conserve water during dry regions and salty environment of the ocean. Reptiles usually have scales on their bodies with no glands, which allow them to resist losing water in the marine environment.

The ancestors of modern reptiles first began to appear around 100 million years ago. Modern-day reptiles include crocodiles, turtles, lizards and snakes, all of which are present in the marine environment.

Marine Crocodiles

Several species of crocodiles such as American crocodile (*Crocodylus acutus*), Nile crocodile (*Crocodylus niloticus*) and Asian saltwater crocodile (*Crocodylus porosus*) are best suited to the marine environment. The saltwater crocodile inhabits estuaries from India and South-East Asia to northern Australia covering more than several hundred kilometres. They are known for their long-distant travel. It has been documented that some individuals are able to travel more than 1,100 km (683 miles) from Malaysia to Cocos Island in the Indian Ocean.

Saltwater crocodiles are very large in size growing up to a length of 6 m (20 ft). They feed mainly on fishes and are sometimes known to attack and kill sharks close to their own size. They are very aggressive and often attack and kill human beings within their range. It drinks saltwater eliminating the excess salt through salt glands on their tongues. This animal lives in burrows along the shore, where it makes its nest and lay eggs.

Crocodylus porosus is one of the largest saline water reptiles, which is common in the estuaries adjacent to Bay of Bengal. They are also sighted in estuarine creeks (Fig. 2.24), where the water salinity drops down to 10 ‰ during the

Fig. 2.24 Crocodiles on the mudflat of Indian Sundarbans (photograph taken by Mr. Saumya Kanti Ray, Environmentalist under the supervision of Dr. Pradeep Vyas, IFS)

monsoon season (July to October). The species was indiscriminately killed for the purpose of making luxury goods from its skin in late 1960s and early 1970s. The level of poaching became so severe that the population subsequently declined, making the species endangered. The initiation of crocodile breeding programme by the Govt. of India in 1976 at Indian Sundarbans reversed the situation.

Sea Turtles

Sea turtles are cold-blooded and lung-breathing nekton belonging to class reptilian (Fig. 2.25). They appeared on the planet Earth millions of years ago and got adapted to an aquatic life.

Sea turtles are widely used by humans as food, ornaments and leather. They are now endangered and protected. Of the World's 12 living families and approximately 250 species of turtles, only 2 families are marine dwellers. They are Dermochelyidae (common leatherback comprising of **single** species) and Cheloniidae (comprising of **seven** species). These eight species have several common characteristics, including relatively non-retractile extremities, extensively roofed skull (Fig. 2.26), limbs converted to paddle-like flippers with one or two claws and little independent movements of the digits. All are large turtles; adults weighing about 35–500 kg and exhibit various adaptations to marine environment, such as presence of large salt gland to excrete the excess salt ingested with sea water and food.

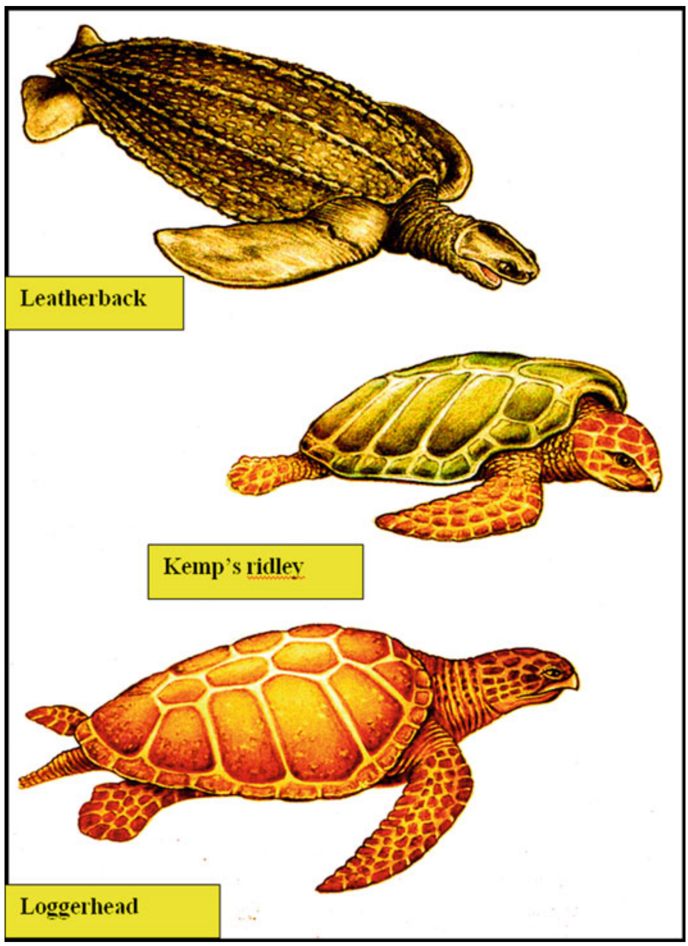

Fig. 2.25 Views of sea turtle species

Fig. 2.26 Structural design of green turtle skull [photographs taken by Ms. Ankita Mitra (environmentalist) on 10 November 2013 with the kind permission of Dr. Lubna Hamoud Al-Kharusi, Director General of Fisheries Research under Ministry of Agriculture and Fisheries Wealth, Muscat, Sultanate of Oman]

Sea turtles have specialized feeding habits, for example, green turtle is herbivore and the hawksbill subsists largely on sponges. Reproductive behaviour patterns are similar among the species, but some interesting variations are known. Sea turtles are famous for their remarkable feats of navigation. They return at two, three, four-year intervals to lay eggs on the beaches at which they are hatched. Homing behaviour can be a great advantage to any animal. If the parent survived its earliest childhood at this location, it will probably be a suitable place for hatching the next generation. The navigation of green sea turtles to tiny Ascension Island, an emergent point of the Mid-Atlantic Ridge between Brazil and Africa, has been extensively studied. Researchers have found that the turtles use solar angle (to derive latitude), wave direction, smell and visual cues first to find the island, then to discover the spot on the beach where they hatched perhaps 20 years before. The migration of Olive Ridley (*Lepidochelys olivacea*) to the mangrove-dominated beaches of Odisha (in the east coast of India) for laying eggs is also an interesting event, which has become a subject of interest for many researchers. A comparative account of the five species of marine turtles, widely distributed in and around Indian coastal waters, is highlighted in Table 2.15.

Marine Lizard

The marine iguana (*Amblyrhynchus subcristatus*), the only marine lizard, is native to the Galapagos Islands. These large lizards are descendents of green, vegetarian iguanas that still inhabit the tropical forests of the mainland. It is believed that in the distant past, chunks of riverbank from Central America may have broken loose and carried into the sea along with different other flora and fauna into the Galapagos islands, which might be the probable cause of this animal to have settled here. The iguanas travelled and wandered in the islands in search of food and vegetation that they used to feed in the forest. But though the Galapagos Island was dramatically different from the forests, it had adequate resources for its survival. The conditions of the island thus favoured the species to survive and propagate. The unusual lifestyle of the marine iguana was due to its adaptability in precarious condition, when it had

Table 2.15 Comparative account of the different species of turtles distributed in Indian coastal waters

Species	Description	Distribution	Food habits	Nesting	Status
Leatherback sea turtle (*Dermochelys coriacea*)	It is the largest of all living sea turtles, attaining a length of 150–170 cm in straight carapace (upper shell) length (SCL) and weights around 500 kg (rarely 900 kg)	This species is mostly found along the coast of Tamil Nadu, Andhra Pradesh, Kerala, Goa, Gujarat, Andaman and Nicobar Islands, Lakshadweep	They are water column feeders and feed especially on coelenterates and jelly fishes	Nesting season mainly from May to August which takes place at night	It is included in the Red Data Book of IUCN, Appendix 1 of CITES and in the Schedule 1 of Indian Wildlife Protection Act, 1972, which includes species threatened by extinction
Hawksbill (*Eretmochelys imbricata*)	It is the smallest of five species, with SCL less than 95 cm. Adults are easily recognized by their thick carapace scutes, often with radiating streaks of brown and black on a amber background and a strongly serrated posterior margin of the carapace	It typically forages near rock or reef habitats in clear shallow tropical waters and found mainly along the coast of Tamil Nadu, Andhra Pradesh, Odisha, Kerala, Gujarat, Andaman and Nicobar Islands and Lakshadweep	Hatchlings are carnivorous and the adult omnivorous subsisting mainly on sponges, molluscs, jelly fishes, seagrass and algae	Major nesting period is around monsoon months and it takes place at night hours	It is included in IUCN Red Data Book, Appendix 1 of CITES and also in the Schedule 1 of Indian Wildlife Protection Act, 1972
Olive Ridley (*Lepidochelys olivacea*)	A large head with upper jaw hooked, more than five pairs of pleural and prominent pores on the sides of the plastron. Presence of three distinct keels on carapace of young and average length of adult is 27.5 in.	This species is widely found along the coasts of Tamil Nadu, Andhra Pradesh, Odisha, West Bengal, Kerala, Goa, Gujarat, Maharashtra, Andaman and Nicobar Islands and Lakshadweep	They feed on molluscs, crustaceans, fishes and jelly fishes	The female turtle comes ashore above the high water mark at night to nest and lays about 100–150 eggs and the length of the incubation period varies from 50–55 days	It is included in Red Data Book of IUCN, Appendix 1 of CITES and Schedule 1 of the Indian Wildlife Protection Act, 1972
Green turtle (*Chelonia mydas*)	It is the largest hard-shelled sea turtle. The SCL is 102.5 cm and it weighs around 136 kg	Mostly found along the coasts of Tamil Nadu, Andhra Pradesh, Kerala, Maharashtra, Gujarat, Andaman and Nicobar Islands and Lakshadweep	Hatchling is carnivorous and after about one year of age becomes herbivorous in nature mainly subsisting on marine algae and seagrass	The nesting season is throughout the year, with peak from May–September and it takes place during the night hours	It is included in Red Data Book of IUCN, Appendix 1 of CITES and also in the Schedule 1 of Indian Wildlife Protection Act, 1972
Loggerhead sea turtle (*Caretta caretta*)	The SCL is about 92 cm and the mean body weight is about 113 kg. The brown hatchling weighs about 20 g, 45 mm long	It is rare or absent from mainland shores. More number has been recorded in Tamil Nadu coast especially in Mandapam area	They mainly feed on sponges, molluscs, crustaceans, jelly fishes and fishes	It lays 4–5 clutches a season, at an intervals of 12–15 days and the length of incubation period is around 60 days	It is included in Red Data Book of IUCN, Appendix 1 of CITES and in the Schedule 1 of Indian Wildlife Protection Act, 1972

to feed on the marine algae, which got exposed only during low tide. Although it was a foreign food, but its subsequent generations resisted and persisted this condition. This caused the present-day iguana to be completely different from its relatives on the mainland.

The marine iguana is 3-feet-long lizard and is entirely black; some are mottled red and black showing some hint of green during the breeding season. This dark colouration allows them to absorb more heat energy to raise their body temperature so that they can swim and feed in the cold Pacific waters. They are very good swimmers, using lateral undulations of their body and tail to propel them through waters. They avoid heavy surf and rarely venture more than 10 m from shore. When leaving the water, they tend to ride in with the swell and then swiftly crawl up the rocks. If they do not find their territory immediately, they touch the rocks with their tongues and carry scent to a receptor in the roof of the mouth. When they locate their own scent, they follow it to their territory, where they rest on the rocks, lying almost motionless above the high tide.

Sea Snakes

Snakes are descendants of lizards that have lost their limbs as an adaptation to maintain a burrowing lifestyle, a lifestyle that was later abandoned by many species. Although most species of snakes are terrestrial or arboreal, there are about 50 species that live in the marine environment, each one bearing venomous fangs. Sea snakes are less tied to the land than other marine reptiles, with only about half of the species coming onto land to lay their eggs. Like the ancient ichthyosaurs, females of the remaining species are ovoviviparous, retaining their eggs within their body until they hatch. The young that emerge are able to swim and feed immediately.

Although all sea snakes breathe air, some species can remain submerged for several hours. The animal's single lung reaches almost to its tail, and its trachea has become modified to absorb oxygen, thus acting as an accessory lung. Sea snakes can also exchange gases through their skin when they are under water. These adaptations allow the sea snakes to absorb large amounts of oxygen in a very efficient manner. Sea snakes are able to lower their metabolic rate so that they consume less oxygen when submerged, and some species may even be able to extract oxygen from swallowed water. Specialized valves in the snake's nostrils prevent water from entering when they are submerged.

Most sea snakes remain close to the shore, but the yellow-bellied sea snake (*Palamis platurus*) is pelagic, feeding on surface fish. On several occasions, it has been sighted hundreds of miles from land. This species has migrated east and west from the coast of Asia and can be found off the east coast of Africa and the west coast of tropical America. Most of the other species are found in warm coastal waters from the Persian Gulf to Japan and east to Samoa.

The mangrove swamp of Sundarbans at the apex of western Bay of Bengal is the homeland of several reptiles (Table 2.16) that are either aquatic or semi-aquatic in nature. Many species are well adapted in the upper estuarine stretch, where the salinity reaches zero during monsoon.

Table 2.16 List of reptilian fauna reported from Indian Sundarbans region

Species	Family	Habitat
Lissemys punctata (Bonaterre)	Trionychidae	Aquatic
Varanus bengalensis (Daudin)	Varanidae	Wetland associate
Varanus flavescens (Gray)	Varanidae	Wetland associate
Enhydris enhydris (Schneider) smooth water snake	Colubridae	Aquatic
Xenochropis piscator (Schneider) checkered keelback	Colubridae	Aquatic
Cerberus rhynchops (Schneider) dog-faced water snake	Colubridae	Aquatic
Naja naja kaouthia (Lacepede) monocellate cobra	Elapidae	Wetland associate

2.2.5 Marine Mammals

Marine mammals spend their life mostly or entirely in water and possess fins that adapt them for their aquatic lifestyle. This is the most advanced vertebrate group in the marine and estuarine system. They have an insulating body covering of hair to maintain their constant body temperature (homeothermic) and have mammary glands to suckle their young ones. They depend completely on food of marine origin. Marine mammals are placental mammals, which retain their young ones inside their body until they are ready to be born. This specialized organ, placenta is present only during pregnancy. Although marine mammals produce fewer offsprings than other faunal species of seas and estuaries, most of the young survive to adulthood because they receive a great deal of parental care.

Mammals are adapted both to the terrestrial environment and also in the sea. The presence of hair (fur) of some and the layers of blubber in others effectively reduce the loss of body heat to the surrounding water. Like other warm-blooded animals, mammals expend about 10 times more energy, and hence, they need more food to support their high metabolic rate. Being homoeothermic, marine mammals are active feeders around the clock and are adapted to wide range of habitats. For example, baleen whales feed closer to the base of the food chain, while sea otters and toothed whales are second order or higher consumers.

Most marine mammals are quite intelligent compared to other marine animals. This trait, combined with their generally friendly nature, makes them very popular with the common people. Unfortunately, marine mammals share another common characteristic as the bodies of many contain materials that are commercially valuable to humans. As a result, they have been hunted in large numbers over centuries. During the last 50 years, international conservation measures helped to reduce the decline in population and the number of some species is now increasing gradually.

About 4,300 species of marine mammals have been documented. The three living groups of marine mammals are the porpoises, dolphins and whales of order **Cetacea**; the seals, sea lions, walruses and sea otters of order **Carnivora**; and the manatees and dugongs of order **Sirenia**. Each of these orders arose independently from land ancestors. They exhibit the mammalian traits of being endothermic, breathing air, giving birth to living young that they suckle with milk from mammary glands and having hair at sometime in their lives. All marine mammals share four common features:

- Presence of *streamlined body shape* with limbs that is adapted for swimming in the aquatic phase. A slippery skin or hair covering reduces drag.
- Possess the power of *generating internal body heat* from a high metabolic rate and conserve this heat with layers of insulating fat, as in most cases fur. Their large size gives them a favourable surface-to-volume ratio; with less surface area per unit volume, they lose less heat through the skin.
- Possess a highly efficient *respiratory system*, which is modified to collect and retain large quantities of oxygen. The biochemistry of blood and muscle is optimized for the retention of oxygen during sleep, prolonged dives, etc.
- Reduction of the freshwater requirement through a number of *osmotic adaptations.* Minimal intake of sea water, coupled with their kidney's abilities to excrete concentrated and highly saline urine, permits them to meet their water needs with the metabolic water derived from the oxidation of food.

Order Cetacea

Cetaceans include the whales, which are the most beautiful denizens of the ocean and represent the present-day survivors of the ancient stock that reverted to the seas. The magnificence of whales is epitomized in the fact that whales are the largest animals ever to inhabit the earth. The blue whale for instance by reaching a length of 100 ft and the weight of 200 tonnes (as water can support its great weight) is 4 times heavier than the dinosaur that roamed the earth earlier. There are 79 living species of cetaceans which are thought to have evolved from hoofed land mammals related to today's horses and sheep, whose descendants spend most of their time in productive shallow waters searching for food. Modern whales range in size from 2.8 m (6 ft) to 33 m (110 ft) in length and weigh up to 100,000 kg (110 tonnes). Their paddle-shaped forelimbs are used primarily for steering, and their hind limbs are reduced to vestigial bones that do not protrude from the body. Mainly horizontal tail flukes moving up and down by powerful muscles at the animal's posterior end propel them.

Cetaceans are broadly divided into two sub-orders. Suborder **Odontoceti** includes the **toothed whales**, which are active predators and possess teeth to subdue their prey. Toothed whales have a high brain-weight-to-body-weight ratio and much of their brain tissue is involved in formulating and receiving the sounds on which they depend for feeding and socializing. Smaller whales in this group are the **killer whales** (the largest of all dolphins). The largest toothed whale is the sperm whale, which is 18 m in length and can dive at least 1,140 m (3,740 ft). It feeds mainly on large squids. Toothed whales search for prey using **echolocation**, which is otherwise the biological equivalent of sonar. Some common examples of toothed whales are beluga whale, pilot whale, pygmy sperm whale and false killer whale. The largest of the group is the sperm whale, which feeds primarily on the squids. The best-known toothed whales are the dolphins that perform in shows at numerous aquariums and oceanariums. The harbour porpoise is one of the smallest cetaceans and is a familiar site to both boaters and beach combers. The largest of the dolphins is the killer whale or orca. These are the only cetaceans to feed on warm-blooded animals mainly seals and penguins.

The ears of toothed whales are modified to receive a wide range of water vibrations. This adaptation improves the animal's ability to hear underwater and refines its hearing for the purpose of echolocation. Echolocation is similar to sonar.

Dolphins are strongly social animals. They exhibit problem-solving skills, have long periods to mature with many learning experiences and are capable of intraspecies and interspecies cooperation.

The term dolphin is generally used for small cetaceans having a slender body and beak-like snout, and porpoise for animals having a stocky body and blunt snout. Dolphin and porpoise are common names of two subtly different groups of small odontocete whales. Porpoise, as a term, refers to smaller members of the group, which have spade-shaped teeth, a triangular dorsal fin and a smooth front end tapering to a point. Black finless porpoise (*Neomeris phocaenoides*) is often sighted in the brackish waters of Indian Sundarbans. Dolphins are usually larger and have an extended bottlelike jaw filled with sharp round teeth. The small jumping whales in most oceanarium shows are dolphins and killer whales. However, this terminology has not been strictly followed in naming the species.

Habitat wise, the cetaceans of the Indo-Malayan region fall under three categories: (i) the river dolphin, (ii) coastal and estuarine forms and (iii) marine species which live in deep-waters. The latter may be resident of tropical waters or those, which mainly live in cold waters but migrate seasonally towards the tropics such as *Balaenoptera musculus*, *Balaenoptera physalus*.

The common species of dolphin found in the Gangetic stretch adjacent to coastal Bay of Bengal are Gangetic dolphin (*Platanista gangetica*) and Irrawaddy dolphin (*Orcaella brevirostris*). Gangetic oolphin is restricted in fresh water zone, whereas Irrawaddy dolphin is widely visible in the brackish water in and around the deltaic Sundarbans. The identifying characters, food preference, distribution and conservation status of these species are listed in Table 2.17.

The Ganges river (Hooghly estuary) is noted for pouring and draining huge freshwater and silt in the Bay of Bengal. This stretch is the homeland of *Platanista gangetica* (Gangetic dolphin), which is locally known as the '**susu**'. The species was once common in many of the rivers in India, Nepal and Bangladesh. However, it has disappeared from much of its former habitat over the last 100 years and its future is uncertain. There may be as few as 4,000–5,000 left. Dams and barrages are major threats to the future of this

Table 2.17 Identifying characters of dolphins distributed in Indian coastal waters

Species	Description	Distribution	Food habits	Status
Orcaella brevirostris (Irrawaddy dolphin)	It is of the size of Ganges river dolphin with bulging forehead, downwardly pointed mouth, everted lips, dorsal fin and ellipsoid flippers. Body bluish grey above, paler below, total length 2.0–2.75 m; newborn about 0.85 m, maximum age around 30 years, tail is horizontally flattened and notched in the middle	This species is mostly found along the coastal waters from East coast of India through Myanmar, Thailand and Indonesia to northern Australia; particularly found in larger rivers such as Ganga, Krishna, Irrawaddy and Mekong (Marsh et al. 1989). In India, this species is found in Visakhapatnam (Andhra Pradesh), Chilika Lake (Odisha) and Hooghly river (West Bengal)	Primarily takes fishes, also crustaceans and cephalopods	Protected from killing under Schedule II of Indian Wildlife (Protection) Act and from international trade under Appendix II of CITES
Platanista gangetica (Gangetic dolphin)	It is freshwater species weighing up to 90 kg. Its size varies between 2.0 m and 2.5 m, males are smaller than females. Maximum age is about 28 years. Females give birth within October to March with a peak in December and January after a gestation period of 1 year	It is typically found in freshwater zones along the Gangetic stretch of India. It is also found in the Brahmaputra, Karnaphuli and Meghna river from the foot of the Himalayas downstream to the upper limits of the tidal zone in India	Feeds mainly on fishes and aquatic invertebrates	It is included in IUCN Red Data Book, Appendix 1 of CITES and also in the Schedule 1 of Indian Wildlife Protection Act, 1972.

unique species, as they isolate the dolphins, preventing them from swimming freely up and down the rivers. Polluted waters flowing into the river from a number of tributaries are severely straining the habitat of these shy creatures. Irrigation canals in the Ganga river system is another major threat to the existence of dolphins. The drawing of water from the riverine stretch may be a boon to the agriculturists, but are basically curse for the unfortunate dolphins in the Ganga. As water is whisked away from barrages for irrigation, large tracts of rivers become too shallow for the dolphins to survive. (Care 4 Nature; An Ecological Footprint; WWF-India publication, May 4, 2004; http://www.care4nature.org/wildindia/dolphin/conservation.htm). The varied factors posing threats to Gangetic dolphin may be grouped into following points:

- Accidental killing through entanglement in fishing gear, most often nylon gill nets.
- Direct harvest generally for dolphin oil used as a fish attractant and for medicinal purposes.
- Water development projects (e.g. extension of irrigation facilities, construction of barrages, high dams and embankments).
- Increasing level of chemical pollution, such as from industrial discharges and the use of pesticides.
- Increasing levels of other forms of pollution, such as municipal sewage discharge and noise from vessel traffic, wastes discharged from shrimp farms.
- Overexploitation of prey, mainly due to the widespread use of non-selective fishing gear during the period of migrations and early juvenile growth.

The Gangetic dolphin distributed in all the rivers associated with Bay of Bengal has declined in numbers compared to historical levels. Conservation-related measures have already been initiated to check further decline of their population. In this context, WWF-India established a Dolphin Action Group in May 1997, to strengthen the ongoing efforts for the protection of the Indian River dolphin. Few approaches adopted to conserve the species are listed here:

- Strengthening community awareness and participation.
- Encouraging community ownership and management of fisheries.
- Regular monitoring of the status of dolphins and environmental conditions in the aquatic stretch of river Ganga and adjacent estuaries connecting Bay of Bengal.
- Promoting oil synthesis from the fish scraps as an alternative of using dolphin oil as fish attractant.
- Educating government agencies, local fisherman and other stakeholders associated with River Ganga and adjacent estuaries. The industries situated on the bank of the river and coastal industries also come under this scheme.
- Conducting focused conservation efforts in areas where dolphins are found in greatest abundance.

Irrawaddy River dolphin is widely distributed in the brackish water area and estuarine sector of Bay of Bengal, where the salinity fluctuates between 5 and 30‰. The maximum age is around 30 years. The species is rarely found in isolated condition and are sighted in groups of 3–10 individuals. Males are generally larger than females. Current population of this species in Chilika Lake (Odisha) in India is isolated and in danger of extermination (Dhandapani 1992). About 20 dolphins are estimated to be present in the Lake though only 5 were sighted during 1985 and 1987. The species is common in lower parts of Irrawaddy but exact estimate is not known (Leatherwood et al. 1984). About 100–150 dolphins are reported from Mahakam River, Pola River and Semayang Lake in E. Borneo (Kalimantan).

In India and Myanmar, the oil of the species is considered as a cure for rheumatism, when applied externally. Meat is utilized for human consumption. In the coastal waters of Bay of Bengal, hunting for oil as well as catching of dolphins accidentally in gill nets appears to be the main threat to the survival of this species. Pollution of water through industrial wastes, sewage, etc., silting of the lakes and rivers and introduction of prawn fishery in mass scale in Chilika Lake is further adversely effecting the population of Irrawaddy dolphin. The Indian Wildlife Protection

Act (1972) has stated about the protection of the species, and several agencies (e.g. Chilika Development Authority) have undertaken several initiatives to conserve the species through creation and ecorestoration of habitats.

Suborder **Mysticeti** includes the whalebone or baleen whales, who have no teeth. They are not deep divers and are mainly filter feeders and feed actively on krill, few metres below the surface. They have baleen plates, which help in screening plankton engulfed along with sea water. The baleen consists of keratin fibres that are fused together and function to strain the plankton, mainly krill on which the animal feeds from the water. Baleen whales include right whales, rorquals and grey whales. The largest animal is the blue whale, which requires 3 metric tonnes of krill per day during the feeding season. Some species migrate annually from polar to tropical waters and back. Some common examples of baleen whales are humpback whale, bowhead whale, minke whale, right whale, fin whale, sei whale and gray whale.

The Bay of Bengal is a bay that forms the north-eastern part of the Indian Ocean. It occupies an area of 2,172,000 km^2. It is bordered by India and Sri Lanka to the west, Bangladesh to the north, and Myanmar and the southern part of Thailand to the east. Its southern boundary extends as an imaginary line from Dondra Head at the southern end of Sri Lanka to the northern tip of Sumatra. A number of large rivers—Ganges, Brahmaputra, Irrawaddy, Godavari, Mahanadi, Krishna and Cauvery—flow into the Bay of Bengal. The Ayeyarwady River of Myanmar also flows into the bay. This river-influenced bay sustains diverse population of marine mammals.

Schools of dolphins can be seen, whether they are the bottlenose dolphin (*Tursiops truncatus*), pantropical spotted dolphin (*Stenella attenuata*) or the spinner dolphin (*Stenella longirostris*). Tuna and dolphins are usually residing in the same waters. In shallower and warmer coastal waters, the Irrawaddy dolphins *(Orcaella brevirostris*) can be found. A list of marine mammals sighted in and around the bay is highlighted in Table 2.18.

Order Carnivora

This order includes land predators ranging from dogs and cats to bears and weasels, but the **suborder Pinnipedia** (that includes seals, sea lions and walruses) are exclusively marine. Unlike the cetaceans, the gregarious pinnipeds leave the ocean for varying periods of time to mate and raise their young. **Pinnipeds** have four limbs that are modified into flippers. Although they are more at home in the water, they possess the capability to come on the land, mainly to mate, give birth, and moult. Their bodies are spindle-shaped and many species have several layers of fat under the skin to provide insulation. **Seals** are important members of suborder Pinnipedia. Seals have smooth head with no external ear flaps, which enhances further streamlining of the body. They are graceful swimmers and generally their diet consists of small fishes. The rear appendages of hind limbs are fused partially and always point back from the hind end of the body. The elephant seal, named for its long snout and large size, holds the diving depth record for air-breathing vertebrates. Eared seals, which include fur seals and sea lions, have visible external ears. True seals and walruses lack external ears. Eared seals primarily use their front limbs to propel themselves through the water. True seals use their hind limbs and walruses use a combination of both. The hind limbs of eared seals can be rotated at right angles to the body axis and act as legs on land. **Sea lions** have a coarse coat of nothing but hairs, while fur seals have a thick coat of fur. Fur seals were at times relentlessly hunted for their coats, but now they are protected by international law. The populations of sea lions are mainly concentrated in the Pacific coast. California sea lions (*Zalophus californianus*) are found in the near-shore waters along the Pacific coast from Vancouver Island, British Columbia to Baja Mexico. North of southern California, the hauling out grounds are occupied by males only, who migrate north for the winter. The females and their pups remain in California all year. Males often reach 850 pounds and 7 ft in length and females can acquire a weight of 220 pounds and up to 6 ft in length. They are extremely social animals. The main haul-out areas along the Oregon coast are

Table 2.18 List of whales, dolphins and porpoise found in and around Bay of Bengal

Species	Common name	Distribution	Status
Neophocaena phocaenoides	Black finless Porpoise	Coastal waters and estuaries throughout the Indian subcontinent	Schedule I of Wildlife Protection Act and Appendix I of CITES
Steno bredanensis	Rough-toothed dolphin	Tropical and warm temperate waters; Nicobar Island, Sri Lanka and Java	Schedule II of Wildlife Protection Act and Appendix II of CITES
Stenella attenuata	Pantropical spotted dolphin	Tropical and subtropical waters both coastal and offshore; Indian Ocean from Sri Lanka, Sundarbans, etc.	Schedule II of Wildlife Protection Act and Appendix II of CITES
Delphinus delphis	Common dolphin	Warm temperate to tropical waters, both coastal and offshore; Indian Ocean, Bay of Bengal (Madras coast), Sri Lanka, Maldives Island Andaman Island, etc.	Schedule II of Wildlife Protection Act and Appendix II of CITES
Peponocephala electra	Melon-headed whale	Tropical and subtropical waters, mainly in equatorial waters; Mekran coast of Indian Ocean	Schedule II of Wildlife Protection Act and Appendix II of CITES
Feresa attenuata	Pigmy killer whale	Tropical and subtropical waters of the world; recorded from Trincomalee, Sri Lanka	Schedule II of Wildlife Protection Act and Appendix II of CITES
Pseudorca crassidens	False killer whale	Tropical and warm temperate oceans; In India, Calicut, Trivandrum, Gulf of Cambay, Cape Comorin and Port Blair	Schedule II of Wildlife Protection Act and Appendix II of CITES
Globicephala macrorhyncha	Short-finned pilot whale	Warm temperate and tropical waters; Indian Ocean and Bay of Bengal	Schedule II of Wildlife Protection Act and Appendix II of CITES
Kogia breviceps	Pygmy sperm whale	Throughout tropical and warm temperate oceans; eastern coast of India	Schedule II of Wildlife Protection Act and Appendix II of CITES
Kogia simus	Dwarf sperm whale	All tropical and warm temperate oceans; eastern and western coasts of India	Schedule II of Wildlife Protection Act and Appendix II of CITES
Megaptera novaeangliae	Humpback whale	Polar to tropical waters: Reported from India (Travancore), Sri Lanka (off Colombo and Gulf of Mannar)	Schedule II of Wildlife Protection Act and Appendix I of CITES
Balaenoptera musculus	Blue whale	Prefers cold waters and open seas; northern Indian Ocean, recorded around Sri Lanka, east and west coast of India (Mangalore, Cochin, Tuticorin, Calicut, etc.)	Schedule II of Wildlife Protection Act and Appendix I of CITES
Balaenoptera physalus	Fin whale	Migrating from temperate feeding ground in summer towards the tropics in winter; reported from Indian Ocean, Sri Lanka, eastern (Calcutta) and western coasts of India (Bombay)	Schedule II of Wildlife Protection Act and Appendix I of CITES
Balaenoptera edeni	Bryde's whale	Tropical and warm temperate waters; Indian Ocean and Bay of Bengal	Schedule II of Wildlife Protection Act and Appendix I of CITES

Rogue Reef, Three Arch Rocks, Cascade Head and Shell Island of Simpson reef. Stellar sea lions (*Eumetopias jubatus*) are found in the Pacific Ocean from Japan to southern California. This species has a tendency to remain offshore or haul-out in unpopulated areas. Stellar sea lions are much larger and lighter in colour than California sea lions. The males weigh up to 2,200 pounds and can be 8–11 ft, while the females are comparatively smaller weighing around 600–800 pounds and growing up to 6–8 ft long. Stellar sea lions roar rather than bark and are much larger and lighter in colour than California sea lions. Presence of a thick neck representing a lion's mane is a striking characteristic of the species. The breeding grounds of stellar sea lions occur along the north Pacific Rim from Ario Nuevo Island in Central California to the Kuril Islands, north of Japan, with the greatest concentration in the Gulf of Alaska and the Aleutian Islands.

Walruses are much larger than either seals or sea lions and may reach an average weight of 1,800 kg. Walruses resemble true seals—they too have no external ears. But the true seal and the eared seal have 18 teeth, while walruses have 34. Walruses can walk on their four fins unlike other pinnipeds, which have to drag their body around. Despite having a heavy body, a walrus can move as fast as man. The Pacific walrus inhabits the coast along the Berring Sea and its neighbouring waters, while the ones in the Atlantic are found in the Arctic from the Kara Sea till the Hudson Bay. Walruses have tusks, which can grow as long as 68 cm and is seen among both males and females. The thicker and longer the tusk, the higher is the bull's rank. Walruses also use their tusks to pull themselves out of water and crack breathing holes in the ice during harsh, cold winters. Walruses usually feed on fishes, crustaceans, echinoderms and molluscs. At times, these animals were slaughtered for their ivory tusks but now law protects them.

The suborder **Fissipedia** includes only one ideal marine representative known as the **sea otter**. The otters rarely exceed 120 cm in length, eat voraciously, playful and intelligent. Their daily diet includes molluscs, echinoderms, crustaceans, which constitute 20 % of their body weight. **Sea otters** inhabit the northern Pacific Ocean. Instead, of thick layers of blubber, this animal has a thick coat of fur to keep it warm. Sea otters mainly stay close to shores, favouring areas near coral reefs and kelp beds. They are on the verge of extinction on account of hunting, because of their valuable fur, and are now coming back after international protective measures were enacted. *Lutra lutra* (Eurasian otter) has been documented in Indian Sundarbans.

Order Sirenia

The bulky lethargic small-brained dugongs and manatees collectively called sirenians are the only herbivorous marine mammals. They spend their life grazing on seagrasses, marine algae and estuarine plants in coastal temperate and tropical waters of North America, Asia and Africa. Some species also live in fresh water. The largest sirenians reach 4.5 m (15 ft) in length and weigh 680 kg. Sirenians have been hunted extensively, and only 10,000 individuals are now thought to exist worldwide.

Manatees and dugongs represent sirenians. These animals were widely distributed at times in the past, but they are now restricted to coastal areas and estuaries of the tropics. The primary differences between manatees and dugongs are in anatomy and habitat. Manatees inhabit both the sea and inland rivers and lakes. Dugongs are strictly marine mammals living in coastal areas, where they can feed on shallow water grasses. The head of the dugong is larger and the flippers are shorter than those of the manatee. The dugong's tail is notched, whereas the manatee's tail is rounded.

There are three species of **manatee**. The northern manatee (*Trichechis manatus*) is found from the south-eastern United States to northern South America. The Brazilian manatee (*Trichechis inunguis*) is a freshwater species endemic to the Amazon and Orinoco rivers. The African manatee (*Trichechis senegalensis*) is found in coastal habitats, rivers and lakes of western Africa. All three species of manatee have been extensively hunted and law in Florida now protects the northern species.

Manatees mate and give birth under water and the male remains with his mate even after the breeding season. The females give birth to a single calf after 11-month gestation period. Manatees are strict vegetarians and consume large amounts of shallow water plants. A single manatee may consume at least 27 kg (60 pounds) of aquatic plants per day. When manatees eat, they guide the water plants to their mouths with their flippers. This observation may account for the association with mermaids.

Dugongs are interesting marine mammals. They live up to 70 years and grow up to a length of 3 m. They are commonly called as 'sea cows' since they graze only on seagrass meadows. Modified according to the medium, in which they live, dugongs have got a streamlined body with a massive head and a small mouth with nostrils situated on top of the head for surface breathing. They have got a whale-like fluked tail for swimming. A pair of clawed limbs in the front is used for balancing and turning. Body is grey or bronze grey in colour dorsally and white or flesh coloured ventrally. Adult males possess tusk-like incisors useful for tilling the grass meadows while feeding. Dugongs mostly prefer to dwell at depths below 1 fathom where seagrasses grow in plenty. They feed predominantly on seagrass species of the genera *Halophila* and *Halodule*, which are pioneer species that are low in fibre, low in available nitrogen and very easily digestible. An average adult consumes an estimated biomass of 25 kg a day. When seagrass is scarce, marine algae are also consumed. Decline in dugong numbers due to habitat loss was documented in India during 1964 cyclone. At Palk Bay, large quantities of sand brought by floods were deported over seagrass and algal beds and completely destroyed them. This led to the near total absence of turtles and dugongs in the late 1960s and early 1970s. In this area, *Cymodacea serrulata* and *C. isoetifolida* form the major food items of dugong. The same phenomenon occurred in 1992 at Hewey Bay, Australia, where the seagrass bed was lost due to flood leading to the death of dugongs. Dugongs are related more to elephants than to other marine mammals. Dugongs are found in waters around South-East Asia, Africa and Australia. Presently the growth of human populations has posed an increasing hunting pressure on the dugong in the southern Pacific. Another close relative, Stellar's cow, which was present along the Pacific coast from Mexico to Japan, was commercially hunted to extinction by 1768. Dugongs are also being given the same kind of barbarous treatment even after more than two hundred years of development in human civilization.

It is interesting to note that sea mammals such as sea lion, whale and sea otter thrive and depend on the blue carbon domain such as kelp community. Thus, carbon flows from seaweeds to members of higher trophic level in the marine ecosystem (Fig. 2.27).

2.3 Decomposer Community

The marine and estuarine environments are the nursery and survival place for a large variety of bacterial strains. The abundance of microbes in the neritic zone of this ecosystem may be related to the discharge of huge amount of untreated sewage into this system, run-off from the adjacent forest or mangrove ecosystem containing litter and detritus, discharge from the aquacultural farms, etc. In the Indian subcontinent, a very important picture has been obtained regarding the trend of bacterial load while approaching from the inshore to the offshore region. The bacterial population is very high and variable all along the nearshore coastal waters, which, however, decreases towards the offshore region. This is primarily because of grossly inadequate sanitation in coastal areas and discharge of untreated sewage and other effluents through land drainage (Table 2.19). In Indian Sundarbans region, a case study conducted by the present authors during 1990–2012 in three stations, viz. Harinbari (inshore region; marked as 1 in Fig. 2.28), Chemaguri (midshore region; marked as 2 in Fig. 2.28) and Jambu Island (offshore region; marked as 3 in Fig. 2.28), exhibited unique spatial variation of nitrate and phosphate level. The gradual decrease of nitrate and phosphate level (which are primarily liberated from sewage)

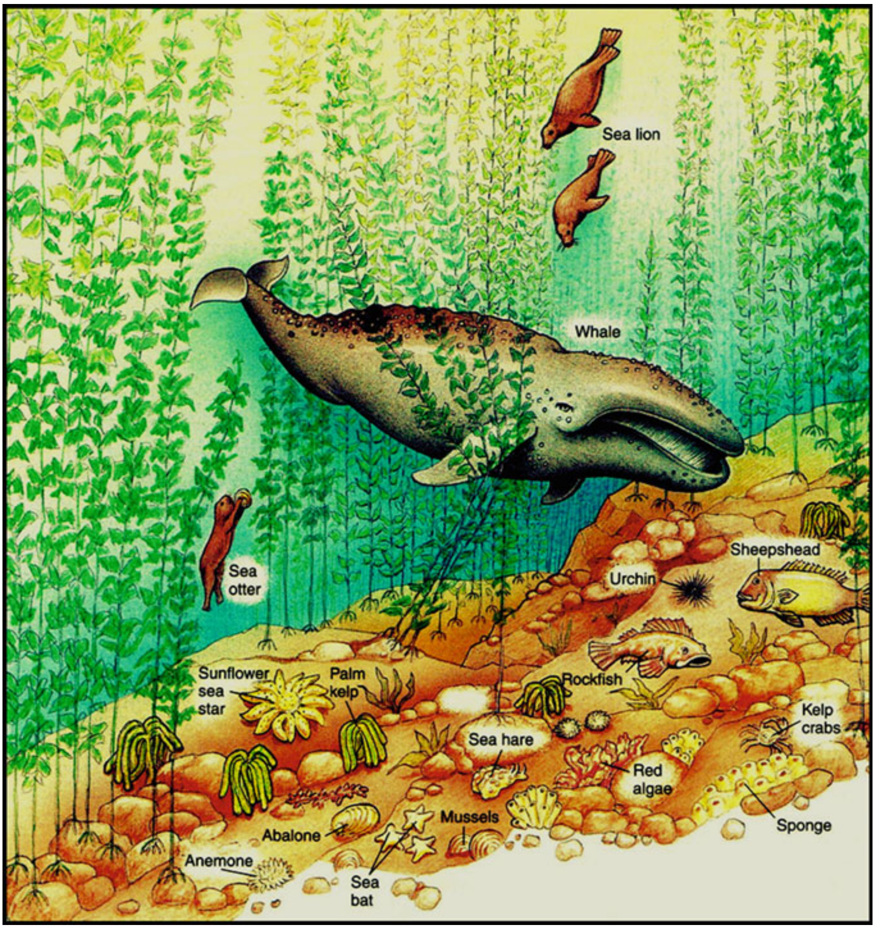

Fig. 2.27 Marine mammals in the kelp bed (diagrammatic)

while approaching from the inshore to the offshore waters (Figs. 2.29, 2.30, 2.31, 2.32, 2.33 and 2.34) speaks in favour of severe anthropogenic pressure along the nearshore waters.

The coliform groups of bacteria are used as an indicator to bacterial contamination of water. These groups of bacteria consisting of 16 families and 256 species originate from the intestinal tracts of human and other warm-blooded animals and therefore may occur in both terrestrial and marine environments (Bhattacharyya 1996).

Mangrove vegetation is very common in the coastal and estuarine regions of the tropical countries. In fact mangroves are woody plants that grow at the interface between land and sea in tropical and subtropical latitudes (Fig. 2.35) and are characterized by the presence of pneumatophores, salt glands, lateral roots and cryptoviviparous germination.

These plants, and the associated microbes, fungi, plants and animals constitute the mangrove forest community or mangal (Kathiresan and Bingham 2001). The mangrove ecosystem provides a unique ecological environment for diverse bacterial communities. The bacteria occupy a number of niches and are fundamental to the functioning of these habitats. They are particularly important in controlling the chemical environment of the mangal. For example, sulphate-reducing bacteria (e.g. *Desulfovibrio*, *Desulfotomaculu*, *Desulfosarcina* and *Desulfococcus*) are the primary decomposers in anoxic mangrove sediments (Chandrika et al. 1990; Loka-Bharathi et al. 1991). These bacteria largely control iron, phosphorous

Table 2.19 Statewise annual mean profile of salinity and bacterial load along inshore, coastal and offshore stations

State	Length of stretch (km)	Zone	Salinity (psu)	Bacteria no./ml
Gujarat	1663	Inshore	13.33	360
		Coastal	20.60	180
		Offshore	26.23	40
Maharashtra and Goa	720	Inshore	31.72	210
		Coastal	32.73	160
		Offshore	33.35	60
Karnataka	290	Inshore	31.77	210
		Coastal	33.62	180
		Offshore	33.98	37
Kerela	560	Inshore	15.07	437
		Coastal	32.52	72
		Offshore	33.72	51
Tamilnadu	884	Inshore	33.10	340
		Coastal	33.42	120
		Offshore	34.60	50
Andhra Pradesh	930	Inshore	17.80	280
		Coastal	26.30	160
		Offshore	28.60	40
Odisha	430	Inshore	11.89	180
		Coastal	22.39	60
		Offshore	23.59	30
West Bengal	220	Inshore	15.03	290
		Coastal	16.19	90
		Offshore	18.99	25

Source Coastal Pollution in the seas around India (1996)

Fig. 2.28 Map showing three selected stations in the inshore, midshore and offshore region of Indian Sundarbans

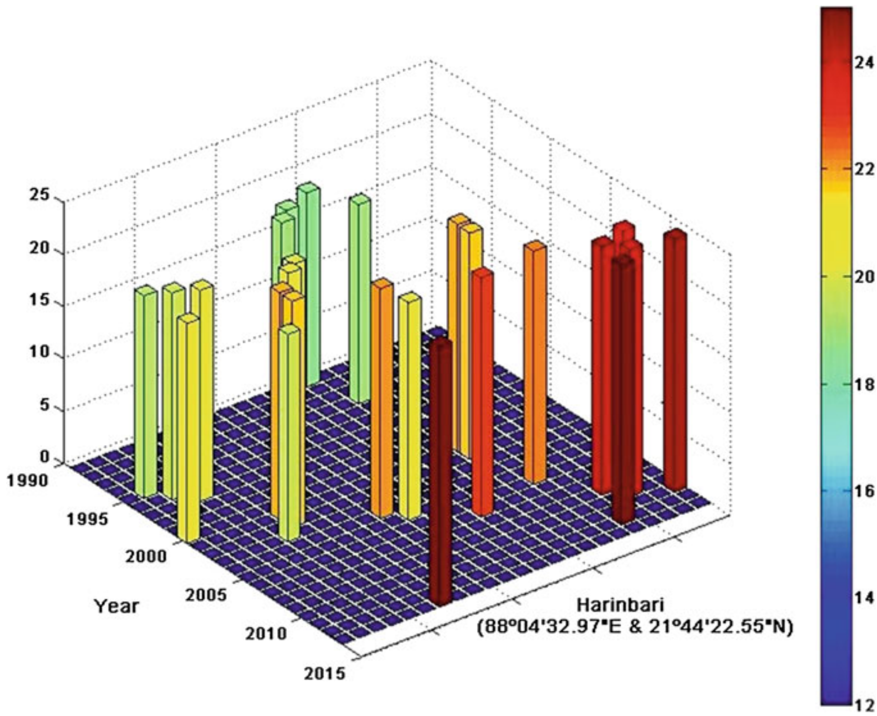

Fig. 2.29 Nitrate level (in µg at l^{-1}) in the inshore region of Indian Sundarbans (graph designed by Dr. Nibedita Mukhopadhyay, Environmentalist)

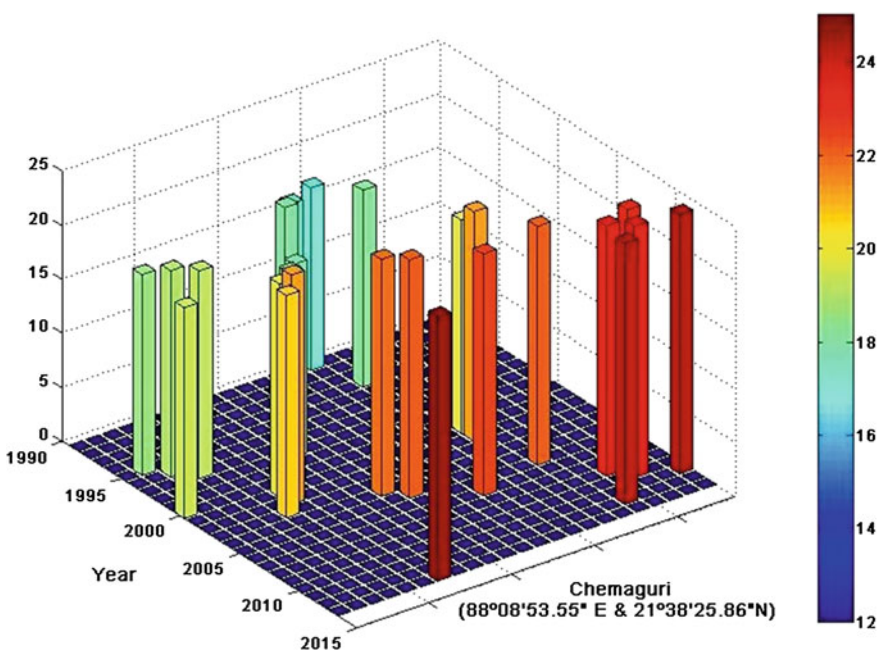

Fig. 2.30 Nitrate level (in µg at l^{-1}) in the midshore region of Indian Sundarbans (graph designed by Dr. Nibedita Mukhopadhyay, Environmentalist)

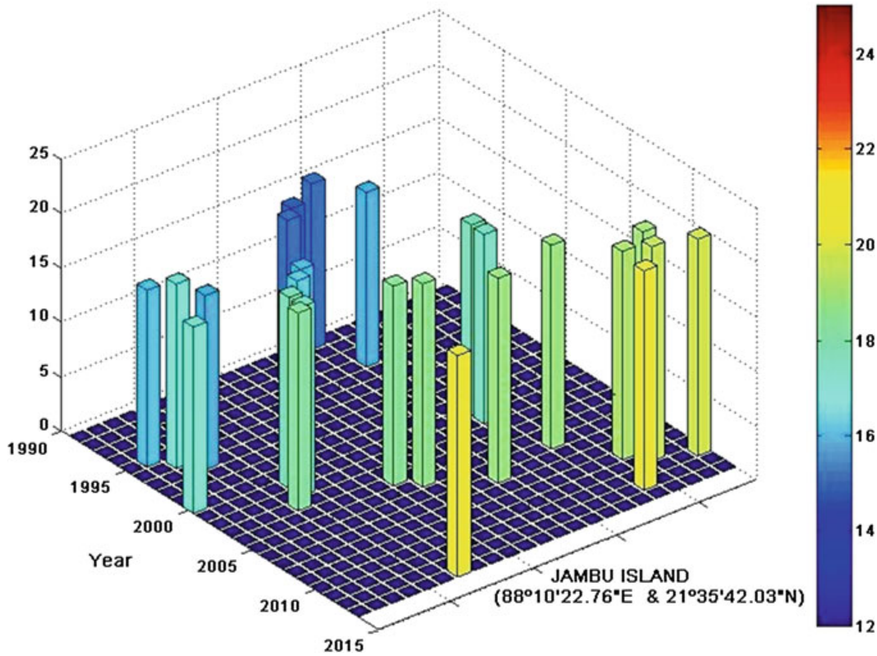

Fig. 2.31 Nitrate level (in μg at l^{-1}) in the offshore region of Indian Sundarbans (graph designed by Dr. Nibedita Mukhopadhyay, Environmentalist)

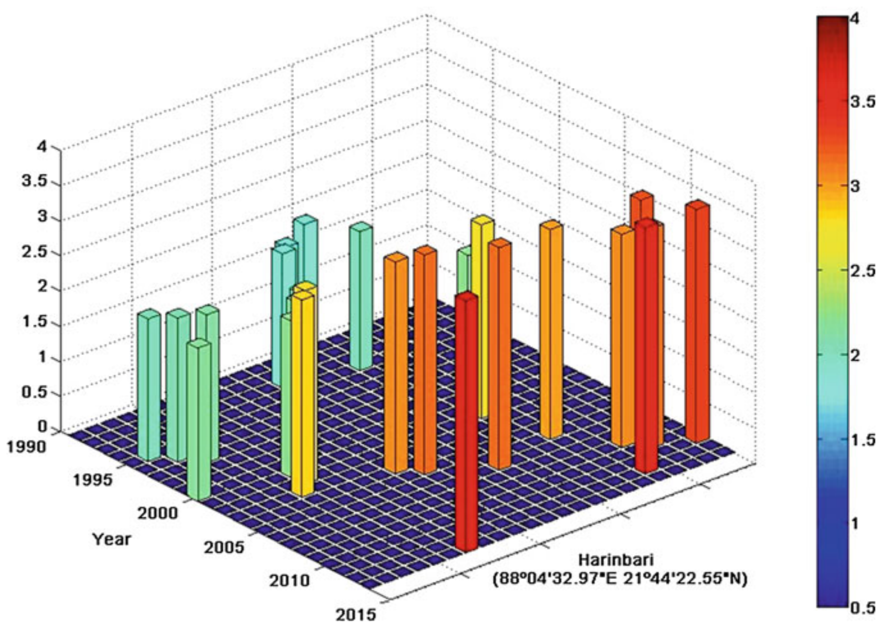

Fig. 2.32 Phosphate level (in μg at l^{-1}) in the inshore region of Indian Sundarbans (graph designed by Dr. Nibedita Mukhopadhyay, Environmentalist)

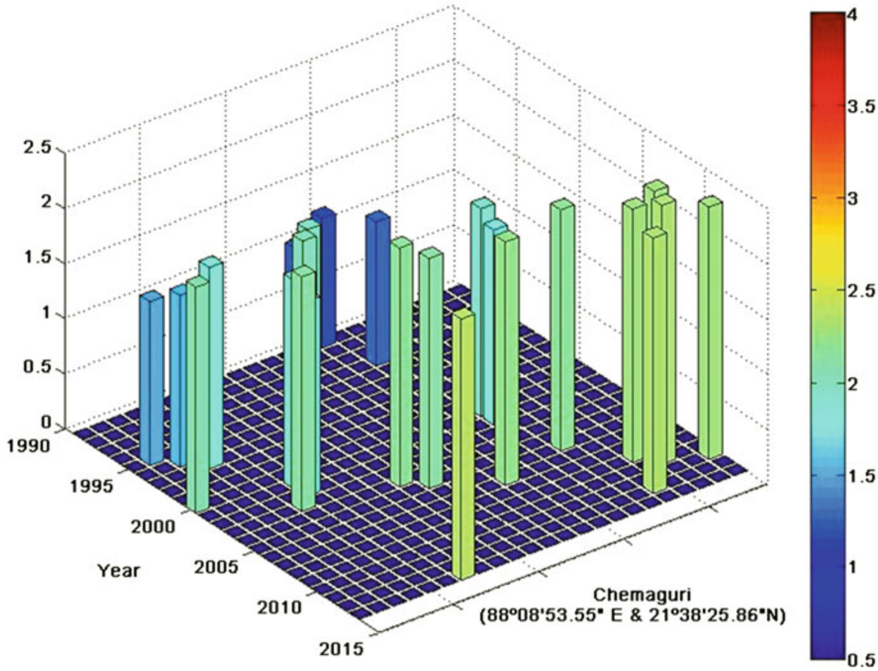

Fig. 2.33 Phosphate level (in µg at l^{-1}) in the midshore region of Indian Sundarbans (graph designed by Dr. Nibedita Mukhopadhyay, Environmentalist)

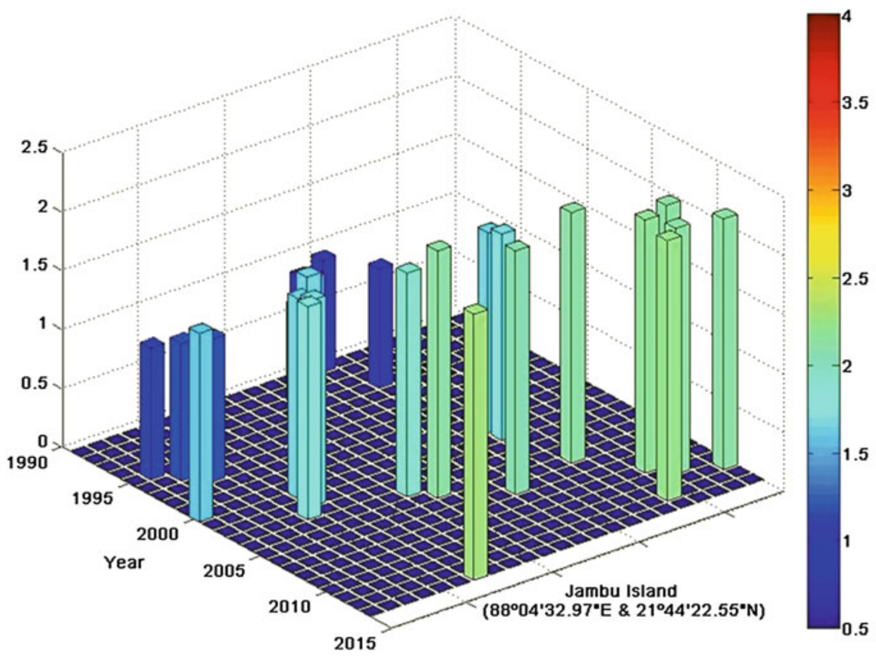

Fig. 2.34 Phosphate level (in µg at l^{-1}) in the offshore region of Indian Sundarbans (graph designed by Dr. Nibedita Mukhopadhyay, Environmentalist)

Fig. 2.35 Mangrove mudflats and vegetation are the survival ground for wide spectrum of microbial strains

and sulphur dynamics and contribute to soil vegetation patterns (Sherman et al. 1998). Methanogenic bacteria are seasonally abundant in sediments where *Avicennia* species dominate (Ramamurthy et al. 1990; Mohanraju and Natrajan 1992). Subsurface bacterial communities (along with epibenthic microalgae) may sequester nutrients and hold them within nutrient-limited mangrove mud (Alongi et al. 1993; Rivera-Monroy and Twilley 1996).

A comparative study done in two selected stations of Indian Sundarbans showed unique variation of microbial population, which may be attributed to the presence of mangrove flora. It was found that the total bacterial density was high in the soil collected from mangrove belt rather than the non-mangrove habitat. Seasonal variation of microbial load was also recorded in both the stations. Abundance of microbes in Zobell's marine agar was recorded almost three times greater in pre-monsoon at mangrove-dominated area in comparison to non-mangrove zone (Tables 2.20 and 2.21). The bacterial density in the other media (nutrient agar) also exhibited the same trend.

The high microbial density in the monsoon season in both the mangrove and non-mangrove zones as revealed in Tables 2.20 and 2.21 may be attributed to the presence of excessive nutrient concentrations in the ambient aquatic phase due to run-off from the adjacent landmasses and the supporting vegetation matter (Banerjee et al. 2001).

The marine and estuarine environments, the mangrove ecosystem and the brackish water aquacultural farms have also become the dwelling spots of variety of pathogenic organisms. These organisms known as coliform bacteria are discharged from the human intestine and their

Table 2.20 Seasonal distribution of different types of microbes at mangrove-dominated zone during March 1998 to February 1999

Medium	Nutrient agar	Zobell's marine agar	Proteolytic medium
Season			
Pre-monsoon (March–June)	13	20	08
Monsoon (July–October)	19	45	10
Post-monsoon (November–February)	08	13	05
Dilution factor 10^3/l ml			

Table 2.21 Seasonal distribution of different types of microbes at non-mangrove-dominated zone during March 1998 to February 1999

Medium	Nutrient agar	Zobell's marine agar	Proteolytic medium
Season			
Pre-monsoon (March–June)	05	07	04
Monsoon (July–October)	11	09	06
Post-monsoon (November–February)	03	06	02
Dilution factor 10^3/l ml			

presence indicates the possibility of the presence of pathogenic organisms. The coliform group comprises all of the facultative and aerobic Gram-negative, non-spore-forming rod-shaped bacteria that ferment lactose with gas formation within 48 h at 37 °C. The *Coliform* bacteria include in genera *Escherichia*, *Citrobacter*, *Enterobacter* and *Klebsiella*. Studies on the faecal coliform load in the Hooghly estuarine complex of West Bengal revealed a range between 55.29 and 183.06 mg/l, which is not a healthy picture of the estuarine ecosystem.

Mangals of the brackish water system are home to a group of fungi called 'manglicolous fungi'. These organisms are vitally important to nutrient cycling in these habitats (Hyde and Lee 1995; Kohlmeyer et al. 1995). Kohlmeyer and Kohlmeyer (1979) were the first to review this group. They recognized 43 species of higher fungi, including 23 Ascomycetes, 17 Deuteromycetes and 3 Basidiomycetes. Hyde (1990a) listed 120 species from 29 mangrove forests around the world. These included 87 Ascomycetes, 31 Deuteromycetes and 2 Basidiomycetes.

Work in individual habitats has revealed surprisingly diverse fungal communities (e.g. Hyde 1990b; Hyde 1996). Chinnaraj (1993a) identified 63 species of higher fungi in mangrove samples from Andaman and Nicobar Islands alone. Similar samples from Lakshadweep Island yielded 32 species (Chinnaraj 1992), and 39 species were found in mangrove samples from the Maldives (Chinnaraj 1993b). Ravikumar and Vittal (1996) found 48 fungal species in decomposing *Rhizophora* debris in Pichavaram, South India. On the Indian Ocean coast of South Africa, Steinke and Jones (1993) identified 93 species of marine fungi, including 55 from mangrove wood (particularly *Avicennia marina*). Table 2.22 lists some of the fungal species identified in these studies.

Table 2.22 Fungal species isolated from mangrove

Species
Aigialus striatispora
Aniptodera longispora
Aniptodera salsuginosa
Calathella mangrovei
Cryptovalsa halosarceicola
Eutypa bathurstensis
Falciformispora lignatilis
Halophytophthora kandilae
Halophytophthora kandilae
Halophytophthora vesicular
Halophytophthora spinosa
Halosarpheia munuta
Hapsidascus hadrus
Hypoxylon oceanicum
Julella avicenniae
Khuskia oryzae
Lophiostoma asiana
M. ramunculicola
Massarina armatispora
Massarina velatospora
Payosphaeria minuta
Pedumispora sp.
Phomopsis mangrovei
Saccardoella sp.
Trematospaeria lineolatispora

2.3.1 Taxonomy of Micro-organisms in the Blue Soup

The marine environment is the dwelling place of a diverse group of micro-organisms such as bacteria, filamentous fungi, yeasts, microalgae and protozoa. All these groups of marine micro-organisms have different divisions and subdivisions as stated here in tabular forms (Tables 2.23, 2.24 and 2.25).

2.3.2 Habitats of Marine Micro-organisms

Marine micro-organisms inhabit various types of habitats. They are distributed at the surface of the sea as **neuston** (also known as **pleuston**) or at the photic zone of the pelagic region as plankton or at the epibiotic habitats (attached communities). They are also present inside the tissues of other marine organisms (endobiotic habitats). Many marine microbes are also distributed on the seabed.

Approximately 5,000 species of nekton swim freely through the neritic and pelagic zones of the ocean. The important members of nekton are fishes, reptiles and mammals. These animals also produce organic debris referred to as **seston** which contribute significantly to nutrition of the micro-organisms.

Epibiotic habitats may be inanimate (such as biofouling communities) or animate surfaces on which attached communities occur. The endobiotic usually denotes the environment within the tissues of other larger organisms. Here, the relationship with the host may be beneficial (mutualism), detrimental to the host (parasitism) or may cause diseases (pathogenesis).

The intertidal zone of the marine environment is rich in seagrass, salt marsh grass, seaweeds, etc., which offer unique site for dwelling of marine microbes. Evidences suggest that grasses pose a narrower range of micro-organisms than seaweeds. Sieburth et al. (1974) observed that cord grass *Spartina alterniflora* is colonized initially by fungi notably *Sphaerulina pedicellata*, whereas eel grass (*Zostrea marina*) mostly possess the pinnate diatom, *Cocconeis scutellum*. On seaweeds diatoms, yeast and bacteria thrive luxuriantly.

Microbes are also available in plenty in the rhizosphere of mangroves. The rhizosphere is the narrow region of soil that is directly influenced by root secretions and associated soil microorganisms. Soil which is not part of the rhizosphere is known as bulk soil. The rhizosphere contains several strains of bacteria that feed on sloughed-off plant cells, termed rhizodeposition, and the proteins and sugars released by roots. Protozoa and nematodes that graze on bacteria are also more abundant in the rhizosphere. Thus, much of the nutrient cycling and disease suppression needed by plants occurs immediately adjacent to roots. We enumerated microorganisms in the rhizosphere and non-rhizosphere soil samples of mangroves and mangrove associate species and observed that the rhizosphere soil sample contained higher microbial populations compared to non-rhizosphere soil (Figs. 2.36, 2.37 and 2.38).

Most of the bacteria in mangrove rhizosphere belong to Gram-negative type. Gram-positive bacteria constituted less than 15 % of the total bacterial population in the rhizosphere zone of Indian Sundarban mangroves. *Arthrobacter* and endospore-producing forms *Bacillus* and *Clostridium* (Family: Bacillaceae) have also been isolated. Majority of bacteria belong to the families Pseudomonadaceae and Vibrionaceae. Most rhizosphere zone occupied by bacteria is aerobic or facultatively anaerobic. Nitrogen-fixing bacteria such as members of the genera *Azospirillum*, *Azotobacter*, *Rhizobium*, *Clostridium* and *Klebsiella* were isolated from the sediments, rhizosphere and root surfaces of various mangrove species, where the soil pH is slightly acidic in nature.

The deep-sea environment is also an important site of marine micro-organisms. Turner (1979) observed bacteria on the surface of faecal pellets and concluded that many of the deep-sea micro-organisms have their origin at the surface layer of the ocean. This view has been supported to some extent by the results of experiments which demonstrated an enhanced rate of

Table 2.23 Bacterial genera indigenous to the marine environment

Category	Family	Genus
Phototrophs	Chromatiaceae	*Chromatium*, *Thiospirillum*, *Thiocystis*, *Thiocapsa*
	Thiocapsaceae	*Chlorobium*, *Prosthecochloris*, *chloroherpeton*
	Related genus	*Ectothiorhodopsira*
	Ectothiorhodopiraceae	*Rhodocyclus*,
	Rhodospirillaceae	*Rhodomicrobium*,
		Rhodopseudomonas
		Rhodospirillum
		Erythrobacter
	Related genus (Chroococcacean)	*Synechocystis*
		Synechococcus
	(Nostocacean)	*Nostoc*
	(Oscillatorian)	*Lyngbya*, *Oscillatoria*
		Plectonema, *Spirulina*
		Trichodesmium
	(Pleurocapsean)	*Dermocarpa*
	(Rivularian)	*Calotrhix*, *Dichothrix*
		Richelia, *Haliarachne*
		Dactyliococcopsis, *katagnymene*, *Nodularia*, *Pegalothrix*
Other phototrophic prokaryotes	Prochloraceae	*Prochloron*
Gliding bacteria	Cytophagaceae	*Cytophaga*, *Flexibacter*
		Flexithrix, *Herpetisiphon*, *Saprospira*
		Sprocytophaga, *Microscilla*
	Related organisms	*Beggiatoa*, *Thioploca*
	Beggiatoaceae	*Leucothrix*, *Thiothrix*
	Leucotrichaceae	
Budding and appendaged bacteria	Caulobacteraceae	*Caulobacter*
	Hyphomicrobiaceae	*Hyphomicrobium*
		Hyphomonas
		Pedomicrobium
	Plantomycetaceae	*Planctomycetes*, *Pirella*,
		Prosthecomicrobium
Aerobic/microaerophilic non-motile/motile, helical/vibroid gram-negative bacteria	Spirillaceae	*Bdellovibrio*
		Oceanospirillum
	Spiromaceae	*Flectobacillus*

(continued)

Table 2.23 (continued)

Category	Family	Genus
Gram-negative aerobic rods and cocci	Halobacteriaceae	*Halococcus*, *Halobacterium*,
		Methylophaga
	Methylococcaceae	*Actinetobacter*
	Neisseriaceae	*Pseudomonas*
	Pseudomonadaceae	*Alcaligenes*, *Alteromonas*
	Alcaligenaceae	*Chromobacterium*, *Deleya*
		Flavobacterium
		Janthinobacterium
		Marinomonas, *Paracoccus*
		Shewanella, *Halomonas*
Facultatively aerobic rods	Enterobacteriaceae	*Serratia*
	Vibrionaceae	*Photobacterium*, *Vibrio*
		Listonella
Gram-negative anaerobic rods and cocci	Haloanaerobiceae	*Halobacteroides*
	Desulfurococcaceae	*Desulfobacter*
		Desulfobulbus
		Desulfosarcina
		Desulfuromonas
		Desulfovibrio
Gram-negative chemolithotrophs (ammonia-or-nitrite-oxidizing bacteria)	Nitrobacteraceae	*Nitobacter*, *Nitrococcus*, *Nitrosococcus*, *Nitrospina*, *Nitromonas*, *Nitrosospira*, *Nitrospira*
(Sulphur bacteria)	–	*Macromonas*, *Thiobacillus*, *Thiomicrospora*, *Thiovulum*, *Thiobacterium*, *Achromatium*
	Achromatiaceae	
Methane bacteria	Methanobacteriaceae	*Methanobacterium*
		Methanospirillum
	Methanococcaceae	*Methanococcus*
	Methanomicrobiaceae	*Methanococcoides*
		Methanogenium
		Methanomicrobium
	Methanoplanaceae	*Methanoplanus*
	Methanosarcinaceae	*Methanosarcina*
	Micrococcaceae	*Micrococcus*
		Staphylococcus
	Planococcaceae	*Marinococcus*
Endospore-forming rods and cocci	Bacillaceae	*Bacillus*
	Clostridiaceae	*Clostridium*
Actinomycetes and related bacteria	Actinomycetaceae	*Actinomycetes*
	Micromonosporoceae	*Micromonospora*
	Nocardiaceae	*Nocardia*, *Rghodococcus*
	Mycobacteriaceae	*Mycobacterium*
	Streptomycetaceae	*Streptomyces*
		Coryneforms (*Arthobacter*, *Brevibacterium*, *Corneybacterium*, *Curtobacterium*)
Spirochaetes	Spirochataceae	*Crispispira*, *Sprirochaeta*

Table 2.24 Filamentous fungi recovered from the marine environment

Subdivision	Class	Family	Genus
Ascomycotina	Discomycetes	Orbiliaceae	*Orbilia*
	Plectomycetes	Eurotiaceae	*Amylocarpus*, *Eiona*
	Pyrenomycetes		*Laboulbenia*
	Incertae sedis	Laboulbeniaceae	*Buergenerula*
	Loculoascomycetes	Physosporellaceae	*Spathulospora*
		Spathulosporaceae	*Gnomonia*
		Diaporthaceae	*Aniptodera*, *Bathyacus*
		Halosphaeriaceae	*Carbosphaerella*,
			Ceriosporopsis,
			Chadefaudia, *Corollospora*, *Haligena*, *Halosarpheia*, *Halosphaeria*, *Lignincola*, *Lindra*, *Lulworthia*, *Nais*, *Nautosphaeria*, *Trailia*, *Halonectria*, *Nectriella*
		Hypocreaceae	*Haloguignardia*, *Phycomelaina*, *Biconiosporella*, *Zopfiella*
		Polystigmataceae	*Abyssomyces*, *Chaetosphaeria*
		Sodariaceae	*Pontogeneia*
			Pharcidia, *Turgidosculum*
		Sphariaceae	*Oceanitis*, *Ophiobolus*, *Savoryella*, *Torpedospora*, *Herpotrichiella*
		Verrucariaceae	*Leiophloea*
			Didymella, *Mycosphaerella*
	Incertae sedis		*Bankegyia*, *Kymadiscus*, *Didymosphaeria*, *Halotthia*, *Helicascus*
		Herpotrichiellaceae	*Keissleriella*, *Leptosphaeria*
	Loculoascomycetes	Mycoporaceae	*Manglicola*, *Massarina*
		Mycosphaerellaceae	*Microthelia*, *Paraliomyces*, *Phaeosphaeria*, *Pleospora*
		Patellariaceae	*Pontoporeia*, *Thalassoascus*
		Pleosporaceae	*Trematosphaeria*, *Crinigera*, *Orcadia*, *Sphaerulina*
	Incertae sedis		
Basidiomycotina	Gasteromtcetes	Melanogastraceae	*Nia*
	Hymenomycetes	Corticiaceae	*Digitatispora*
		Incertae sedis	*Halosyphina*
	Teliomycetes	Tilletiaceae	*Melanotaenium*
Deuteromycotina	Hyphomycetes	Agronomytcetaceae	*Papulospora*
		Moniliaceae	*Blodgettia*, *Botryophilalophora*, *Clavatospora*, *Varicosporina*
		Dermatiaceae	*Asteromyces*, *Cirrenelia*, *Cladosporium*, *Clavariopsis*, *Cremasteria*, *Dendryphiella*, *Dictoyosporium*, *Derchslera*, *Humicola*, *Monodictys*, *Orbimyces*, *Periconia*, *Sporidesmium*, *Stemphylium*, *Trichocladium*, *Zalerion*, *Allescheriella*, *Tubercularia*, *Dinemasporium*, *Sphaceloma*, *Ascochyta*, *Ascochytula*
		Tuberculariaceae	*Camarosporium*, *Coniothyrium*, *Cytospora*
		Excipulaceae	*Diplodia*, *Macrophoma*
		Melanconiaceae	*Phialophorophoma*, *Phoma*
		Sphaerioidaceae	*Rhabdosphora*, *Robillardo*, *Septoria*, *Stagonospora*
	Coelomycetes		

Based on Kohlmeyer and Kohlmeyer (1979), Kohlmeyer (1986)

Table 2.25 Marine yeasts

Subdivision	Family	Genus
Ascomycotina	Metschnikowiaceae	*Metschnikowia*[a]
	Saccharomycetaceae	*Debaryomyces*, *Hanseniaspora*, *Hansenula*, *Klayveromyces*[a], *Pichia*[a], *Saccharomyces*
Basidiomycotina	Sporobolomycetaceae	*Leucosporidium*[a], *Rhodosporidium*[a], *Sporobolomyces*
Deutermycotina	Torulopsidaceae (yeast-like cells)	*Candida*[a], *Cryptococcus*[a], *Kloleckera*, *Rhodotorula*[a], *Sterigmatomyces*[a], *Torulopsis*[a], *Trichosporon*, *Aureobasidium/ Pullularia*

[a] Contains obligate marine species. After Kohlmeyer and Kohlmeyer (1979)

metabolic activity of marine micro-organisms with a reduction of pressure (Jannach and Wirsen 1982). This helps to draw an inference that the activity of marine micro-organisms is more in the shallow water and decreases with the increase of depth and pressure.

Micro-organisms are also distributed in the deep-sea sediments. Deming and Colwell (1985) used epifluroscence microscopy to determine the vertical distribution of bacteria in deep-sea sediments. Thus, using core samples collected at depths exceeding 4,000 m, it was recorded that bacterial populations at the surface layer of sediment amounted to 4.65×10^8 bacteria/gm dry weight. However, there was a doubling in numbers to 8.29×10^8 bacteria/gm dry weight at a sediment depth of 3 cm followed by progressively decline to 1.7×10^7 bacteria gm dry weight in a core sample at 15 cm from the surface of the sediment. Parallel results were obtained in a second core collected from a similar depth. Higher counts of approximately 3.07×10^{10} bacteria/gm dry weight were recorded from faecal pellets. These counts were 9-folds to 72-folds higher than in the underlying surface sediment (Deming 1985).

An outline search performed by us on the habitat of marine microbes (http://www.geocites.com/RainForest/Vines/4301/microbe/html) revealed the estuarine environment highly favourable for the survival of diverse strains of microbes. This is because the constantly changing environmental parameters can create a wide diversity of ecological niches in this brackish water ecosystem (Atlas 1998). Estuaries have high nutrients and high photon energy and are the most productive ecosystem for photosynthetic aerobes. The range of saline concentrations creates three types of niches: fresh water, brackish water and saline water. Each niche is occupied by organisms that are adapted for those conditions. This form of ecological portioning reduces exploitative competition and enhances growth of different types of microbial communities (Campbell 1993). Similarly, the continental shelf and the coral reefs are areas of high productivity due to high nutrients and photon energy, but without the extreme salinity gradient (Atlas 1998).

Conversely, the ocean zones are not as highly productive except for the pleuston layer where there is adequate light for microbes that are dominant primary producers. The pelagic offshore zone does not have enough nutrients at the surface to support significant microbial growth. The primary producers lyse and sink to the deep benthic zone. The benthic zone, rich in nutrients, does not have enough light energy to support primary productivity. Other forms of energy deep in the hadal trenches, combined with fresh outpourings of chemical nutrients from the molten core, provide the congenial environmental conditions for islands of deep undersea communities of rare bacteria and peculiar species (National Geographic 1979). The deep-sea vents occur in the ocean floor where the ocean crustal plates spread apart and cause plumes of hot lava to erupt into the ocean. The high concentrations of electron-rich elemental compounds are very congenial for the growth and survival of eubacteria such as the chemoautotrophs (Campbell 1993). Each type of bacteria has special adaptations that enable the organism to obtain

Fig. 2.36 Rhizosphere of *Avicennia marina* with soil clinging on the roots

Fig. 2.38 Rhizosphere of *Portrersia coarctata*, a common salt marsh grass of lower Gangetic delta region

Fig. 2.37 Rhizosphere of mangrove associates with soil clinging on the roots

metabolic energy and to withstand the extreme environmental conditions of high pressure and temperature (over 100 °C).

Moving away from the deep-sea vents, the concentration of microbial population drops dramatically (Atlas 1998). There are heterotrophic bacteria in the sea floor sediments which feed on photoautotrophic cyanobacteria that drift down attached to sediment particles.

2.3.3 Role of Marine Micro-organisms in the Carbon Cycle

In sea water, there are 34,500 billion tonnes of carbon, the cycling of which occurs in a steady state (Hobbie and Melillo 1984). Carbon dioxide fixation to form organic molecules is performed by producers such as algae, cyanobacteria and various green and purple photosynthetic bacteria. Global estimates of important fluxes or transfers between reservoirs are shown in Fig. 2.39. Net primary production (NPP = gross photosynthesis-respiration) is approximately equal in terrestrial and marine environments. Approximately 20 % of the ocean NPP occurs in the coastal ocean; 80 % of this is deposited in surface sediments. Turnover or residence times for the reservoirs range from

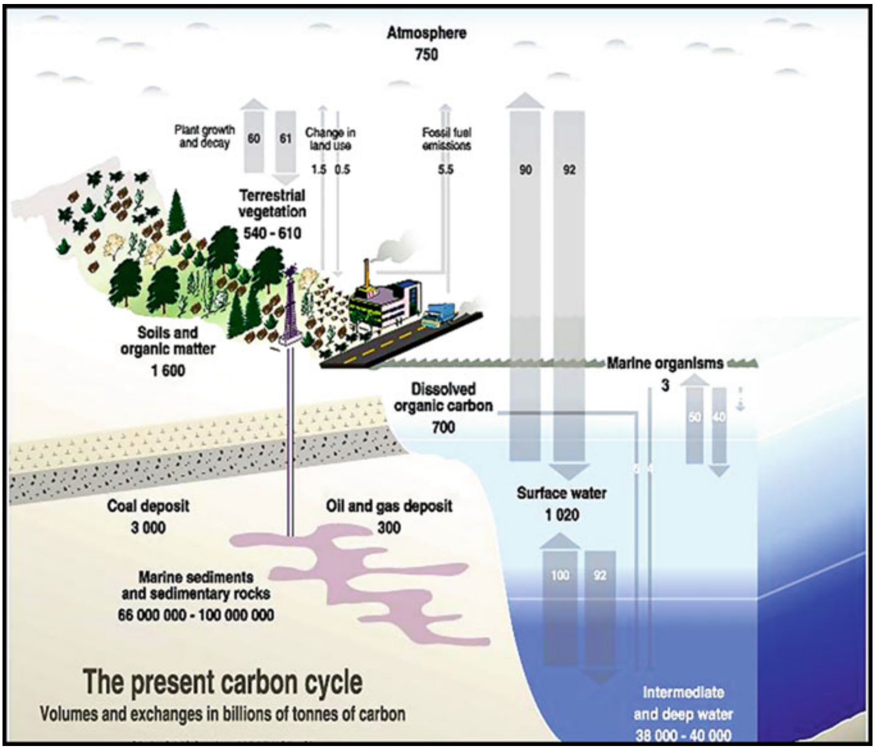

Fig. 2.39 Carbon reservoirs and fluxes. *Sources* http://www.grida.no/publications/vg/climate/page/3066.aspx—Center for climatic research, Institute for environmental studies, University of Wisconsin at Madison; Okanagan University College in Canada; World Watch, November–December, 1998; Climate Change, 1995; The Science of Climate Change, contribution of Working Group 1 to the second assessment report of the Intergovernmental Panel on Climate Change; UNEP and WMO, Cambridge Press University, 1996; www.un.org/earthwatch/about/docs/ewwp4wp6.htm

$>10^6$ year for kerogen in the sediment reservoir to 10^3–10^5 year for peats and soil carbon, to about three years for atmospheric carbon dioxide and less than one year for ocean biomass. Because of its small size and relatively slow equilibration with the ocean reservoir, the atmospheric carbon reservoir is presently out of balance. The difference between atmospheric sources (deforestation and combustion) and sinks annual atmospheric increment and the difference between ocean influx and efflux) is the 'missing link' of 1.8 Gt Cy^{-1}. The major long-term sink for carbon is burial in deep-sea sediments. This removal of a small portion (0.1 %) of annual NPP is responsible for oxygen in the Earth's atmosphere. Protection of photosynthetically fixed organic carbon from oxidation by photosynthetic oxygen (respiration) has permitted accumulation of oxygen in the atmosphere and ocean over geological time. The carbon cycle is completed by weathering of uplifted marine shales or by combustion of fossil fuels. Conversely, methanogens reduce carbon dioxide anaerobically to form methane, which in turn is used by comparatively few organisms. Heterotrophs are also important players in the carbon cycle, by generating carbon dioxide through the activity of respiration. The process of decomposition of plant materials (particularly coastal litter generated from mangroves, salt marsh, seagrass, seaweeds, etc.) also plays a major role in completing the carbon cycle.

The flow and exchange of carbon dioxide between two types of vegetation in the marine and estuarine environments is a unique feature of marine carbon cycle. Seagrasses are closely associated with mangrove habitats in many parts of the world's marine ecosystem. In the Andaman Sea, there are three mangrove-associated seagrasses, *Thalassia hemprichii*, *Enhalus acoroides* and *Halophila ovalis* (Poovachiranon and Changsang 1994). Intertidal mangrove areas in the Gazi Bay, Kenya, are colonized by *Thalassia hemprichii*, *Halophila ovalis* and *Halodule wrightii* (Coppejans et al. 1992). *Halophila baccarii* occurs on intertidal mudflats of the Indian mangals (Jagtap 1991). Tussenbrock (1995) found that seagrass growth, biomass and primary production were all higher in the vicinity of mangrove discharges than they were in other habitats. Respiratory carbon dioxide derived from mangrove particulate organic matter (POM) could be a carbon source for seagrass and could promote faster growth.

In the present *era*, great emphasis has been given on the study of methanogenesis, which may be regarded as the final step in the process of mineralization of organic matter. It has been recorded that oceanic water is supersaturated with methane, attributed to its in situ production (Seiler and Schmidt 1974).

Methanogens are strict anaerobes, being inactivated by the presence of oxygen. The organisms are abundant below Eh values of −200 mV (Mah et al. 1977) and are unable to compete with sulphate reducers until the sulphate has been depleted. In marine sediments, only the upper few millimetres are oxygenated. Below this layer for a few centimetres, NO_3^- serves as the electron acceptor. Then, below this level for a further few centimetres, SO_4^{2-} is the electron acceptor and, in the deeper sediment, methanogenesis proceeds. The energy yield also decreases from oxygen to methane. Moreover, there is a decrease in the range of energy substrates which can be utilized, i. e., this is unique picture of decline in nutritional versatility. Organic carbon may be oxidized to carbon dioxide in the anaerobic layers of methanogens (such as *Methanococcus vanielii*), which have been recovered from the anaerobic environment of the ocean floor. The methane generated by methanogens is undoubtedly re-oxidized to carbon dioxide at the sediment surface, before assimilation by **chemolithotrophs**. Complete mineralization inevitably involves many different organisms (Jorgensen 1980).

References

Aizpuru M, Achard F, Blasco F (2000) Global assessment of cover change of the mangrove forests using satellite imagery at medium to high resolution. EEC research project no. 15017-1999-05 FIEF ISP FR—Joint Research Centre, Ispra

Alongi DM, Christoffersen P, Tirendi F (1993) The influence of forest type on microbial-nutrient relationships in tropical mangrove sediments. J Exp Mar Biol Ecol 171:201–223

Atlas R (1998) Microbial ecology: fundamentals and applications. Benjamin Cummings, Menlo Park, p 694

Azocar A, Rada F, Orozco A (1992) Water relations and gas exchange in two mangrove species with contrasting mechanisms of salt regulation. Ecotropicos 5:11–19

Balsamo RA, Thomson WW (1995) Salt effects on membranes of the hypodermis and mesophyll cells of *Avicennia germinans* (Avicenniaceae): a freeze-fracture study. Am J Bot 82:435–440

Banerjee K, Mitra A, Bhattacharyya DP (2001) Abundance of microbial population in deltaic Sundarbans, West Bengal. Indian J Environ Ecoplantation 5(3):471–473

Bhattacharyya RN (1996) Coastal pollution in the seas around India: an overview. In: The manual of integrated coastal zone management. Departement of Environment, Government of West Bengal, pp 183–194

Bunt JS (1992) Introduction. In: Robertson AI, Alongi DM (eds) Tropical mangrove ecosystem. American Geophysical Union, Washington, DC, pp 1–6

Campbell N (1993) Biology, 3rd edn. Benjamin Cummings, Redwood City, p 1190

Chandrika V, Nair PVR, Khambadhkar LR (1990) Distribution of phototrophic thionic bacteria in the anaerobic and micro-aerophilic strata of mangrove ecosystem of Cochin. J Mar Biol Assoc India 32(1–2):77–84

Chaudhuri AB, Choudhury A (1994) Mangroves of the Sundarbans, vol 1. IUCN—The World Conservation Union, India, pp 165

Chinnaraj S (1992) Higher marine fungi of Lakshwadweep Islands and a note on *Quintaria lignatilis*. Crytogamie Mycol 13(40):313–319

Chinnaraj S (1993a) Higher marine fungi from mangroves of Andaman and Nicobar Islands. Sydowia 45 (10):109–115

Chinnaraj S (1993b) Manglicolous fungi from atolls of Maldives, Indian Ocean. Indian J Mar Sci 22(2):141–142

Clough BF (1993) Constraints on the growth, propagation and utilization of mangroves in arid regions. In: Lieth H, Al Masoom A (eds) Towards the rational use of high salinity tolerant plants, vol 1. Kluwer Academic Publishers, Amsterdam, pp 341–352

Chakraborty P (1996) 'Map-info' in coastal zone management. In: Ghosh AK and Sanyal P (eds) Integrated Coastal Zone Management—A Manual. Published by Department of Environment, Government of West Bengal, pp 44–49

Coppejans E, Beeekman H, Wit MDe (1992) The seagrass and associated macroalgal vegetation of Gazi Bay

(Kenya). In: Jaccarini V, A1artens E (eds) The ecology of mangrove and related ecosystems. Hydrobiologia 247:59–75
Deming JW (1985) Bacterial growth in deep-sea sediment trap and boxcore samples. Mar Ecol Prog Ser 25:305–312
Deming JW, Colwell RR (1985) Observations of barophilic microbial activity in samples of sediment and intercepted particulates from the Demerara Abyssal Plain. Appl Environ Microbiol 50:1002–1006
Dhandapani P (1992) Status of Irrawaddy river dolphin *Orcaella brevirostris* in Chilka Lake. J Mar Biol Assoc India 34(1–2):90–93
Diop ES (1993) Conservation and sustainable utilization of mangrove forests in Latin America and Africa regions. Part II—Africa, pp 245–261. Mangrove ecosystems technical reports, vol 3. ITTO/ISME project PD 114/90. ISME, Okinawa, p 262
Drennan P, Pammenter NW (1982) Physiology of salt secretion in the mangrove *Avicennia marina* (Forsk.) Vierh. New Phytol 91:1000–1005
Duke NC (1992) Mangrove floristics and biogeography. In: Robertson AI, DM Alongi (eds) Tropical mangrove ecosystems. American Geophysical Union, Washington, DC, p 100
FAO, UNEP (1981) Tropical forest resources assessment project. Forest resources of tropical Africa. Part II: country briefs FAO, UNEP, 586 p
FAO (1994) Mangrove forest management guidelines. FAO forestry paper no. 117, Rome
Fisher P, Spalding MD (1993) Protected areas with mangrove habitat. Draft Report World Conservation Centre, Cambridge, 60 p
Groombridge B (1992) Global biodiversity: status of the earth's living resources. WCMC/The National History Museum/IUCN/UNEP/WWF/WRI. Chapman & Hall, London, 594 p
Gouda R, Panigrahy RC (1996) Ecology of phytoplankton in coastal water of Gopalpur, East coast of India. Indian J Mar Sci 2:13–18
Hobbie JE, Melillo JM (1984) Comparative carbon and energy flow in ecosystems. In: Klug MJ, Reddy CA (eds) Current perspective in microbial ecology. American Society in Microbiology, Washington, DC, pp 389–393
Hyde KD (1990a) A comparison of the intertidal mycota of five mangrove tree species. Asian Mar Biol 7:93–108
Hyde KD (1990b) A new marine ascomycete from Brunei, *Aniptodera longispora* sp. nov. from intertidal mangrove wood. Bot Mar 33(4):335–338
Hyde KD (1996) Biodiversity of micro-fungi in north Queensland. Aust Syst Bot 9(2):261–271
Hyde KD, Lee SY (1995) Ecology of mangrove fungi and their role in nutrient cycling: what gaps occur in our knowledge? Hydrobiologia 295:107–118
ITTO/ISME (1993) The world of mangroves. Part I. Japan, pp 1–63
Jagtap TG (1991) Distribution of seagrasses along the Indian coast. Aquat Bot 40(4):379–386
Jannasch HW, Wirsen CO (1982) Microbial activities in undecompressed and decompressed deep sea water samples. Appl Environ Microbiol 43:1116–1124
Jorgensen BB (1980) Mineralization and the bacterial cycling of carbon, nitrogen and sulfur in marine sediments. In: Ellwood DC, Hedger JN (eds) Contemporary microbial ecology. Academic Press, New York
Kathiresan K, Bingham BL (2001) Biology of mangrove ecosystems. Adv Mar Biol 40:81–251
Kohlmeyer J (1986) Taxonomic studies of the marine Ascomycotina. In: Moss ST (ed) The biology of marine fungi. Cambridge University Press, Cambridge, pp 199–210
Kohlmeyer J, Kohlmeyer E (1979) Marine Mycology. Academic Press, New York, p 690
Kohlmeyer J, Bebout B, Volkmann-Kohlmeyer B (1995) Decomposition of mangrove wood by marine fungi and teredinids in Belize. Mar Ecol 16:27–39
Lacerda LD, Carvalho CEV, Rezende CE, Pfeiffer WC (1993) Mercury in sediments from the Paraiba *do Sul* river continental shelf, SE Brazil. Mar Pollut Bull 26:220–222
Lalli GM, Parsons TR (1997) Energy flow and nutrient cycling. In: Biological oceanography: an introduction, 2nd edn. Open University, pp 112–146
Lear R, Turner T (1977) Mangroves of Australia. University of Qld Press, Brisbane
Leatherwood S, Bowles AE, Krygier E, Hall JD, Ingell S (1984) Killer whales (*Orcinus orca*) in Southeast Alaska, Prince William Sound, and Shelikof Strait: a review of available information. Rep Int Whaling Comm 34:521–530
Loka-Bharathi PA, Oak S, Chandramohan D (1991) Sulfate reducing bacteria from mangrove swamps. Their ecology and physiology. Oceanol Acta 14 (2):163–171
Macnae W (1968) A general account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific region. Adv Mar Biol 6:73–270
Mah RA, Ward DM, Baresi L, Glass TL (1977) Biogenesis of methane. Annu Rev Microbiol 31:309–341
Marsh H, Lloze R, Heinsohn GE, Kasuya T (1989) Irrawaddy dolphin—*Orcaella brevirostris* (Gray, 1866). In: Ridgway SH, Harrison SR (eds) Handbook of marine mammals river dolphins and the larger toothed whales, vol 4. Academic Press, London, pp 101–118
Mepham RH, Mepham JS (1984) The flora of tidal forests —a rationalization of the use of the term 'mangrove'. S Afr J Bot 51:75–99
Mitra A, Banerjee K (2005). In: Banerjee SR (eds) Living resources of the sea; focus Indian sundarbans. WWF India, South 24 Parganas, p 96
Mohanraju R, Natrajan R (1992) Methanogenic bacteria in mangrove sediments. Hydrobiologia 247:187–193
National Geographic (1979) Strange world without sun. Natl Geogr Mag 156(5):680–705
Poovachiranon S, Changsang H (1994) Community structure and biomass of seagrass beds in the Andaman Sea and mangrove-associated seagrass beds. Res Bull Phuket Mar Biol Centre 59:53–64
Ramamurthy T, Raju RM, Natarajan R (1990) Distribution and ecology of methanogenic bacteria in

mangrove sediments of Pichavaram, east coast of India. Indian J Mar Sci 19(4):269–273
Ravikumar DR, Vittal BPR (1996) Fungal diversity on decomposing biomass of mangrove plant *Rhizophora* in Pichavaram estuary, east coast of India. Indian J Mar Sci 25:142–144
Reimold JR, Queen WH (1974) Ecology of halophytes. Elsevier Science and Technology Books, New York. ISBN-100125864507
Rivera-Monroy VH, Twilley RR (1996) The relative role of denitrification and immobilization in the fate of inorganic nitrogen in mangrove sediments (Terminos Lagoon, Mexico). Limnol Oceanogr 41 (2):284–296
Santhanam R, Srinivasan A (1998) Distribution and biomass of copepods in the coral reef areas of Tuticorin, South India. Paper presented in the conference on coastal zone Canada '98, Victoria, BC, 30 Aug–3 Sept 1998
Scholander PF, Hammel HT, Hemmingsen EA, Bradstreet ED (1964) Hydrostatic pressure and osmotic potential in leaves of mangroves and some other plants. Proc Natl Acad Sci USA 52:119–125
Scholander PF (1968) How mangroves desalinate water. Physiol Plant 21:251–261
Scholander PF, Hammel HT, Hemmingsen E, Garey W (1962) Salt balance in mangroves. Plant Physiol 37:722–729
Schwamborn R, Saint-Paul U (1996) Mangroves—forgotton forests? Nat Res Dev 43(44):13–36
Saenger P, Hegerl EJ, Davie JDS (1983) Global status of mangrove ecosystems. Commission on ecology papers no. 3. IUCN. Gland, Switzerland, 88 p
Seiler W, Schmidt U (1974) Dissolved nonconservative gases in seawater. In: Goldberg ED (eds) The sea, vol 5. Wiley, New York, pp 219–243
Sherman RE, Fahey TJ, Howarth RW (1998) Soil plant interactions in neotropical mangroves forests: iron, phosphorous and sulfur dynamics. Oceologia 115:533–556
Sieburth JMcN, Brooks RD, Gessner RV, Thornas CD, Tuttle JL (1974) Microbial colonization of marine plant surfaces as observed by scanning electron microscopy. In: Colwell RR, Monta RY (eds) Effect of the ocean environment on microbial activities. University Park Press, Baltimore, pp 418–443
Spalding M, Blasco F, Field C (1997) World mangrove atlas. The International Society for Mangrove Ecosystems, Okinawa, p 178
Steinke TD, Jones EBG (1993) Marine and mangrove fungi from the Indian coast of South Africa. S Afr J Bot 59(4):385–390
Tang DL, Kawamura H (2001) Long-term series satellite ocean colour products on the Asian waters. In: Proceedings of the 11th PAMS/JECSS workshop. Hanrimwon Publishing (CD-ROM: 0112-PO3), Seoul, pp 49–52
Tateoka T (1965) Porteresia, a new genus of Graminae. Bull Natl Sci Museum (Tokyo) 8:405–406
Tomlinson PB (1986) The botany of mangroves. Cambridge University Press, London
Turner JT (1979) Microbial attachment to copepod fecal pellets and its possible ecological significance. Trans Am Microsc Soc 98:131–135
Tussenbrock BI (1995) *Thalassia testudinum* leaf dynamics in a Mexican Caribbean coral reef lagoon. Mar Biol 122(1):33–40
Twilley RR, Chen RH, Hargis T (1992) Carbon sinks in mass and their implications to carbon budget of Tropical coastal ecosystems. Water Air Soil Pollut 64:265–288
UNEP (2002) Global distribution of coral, mangrove and sea grass diversity. http://maps.grida.no/go/graphic/distributionofcoralmangrove-and-seagrass-diversity. Retrieved 26 May 2007
UNESCO (1973) International classification and mapping of vegetation. United Nations Education, Scientific and Cultural Organisation, Paris
Van Eijk M (1939) Analyse der Wirkung des NaCl auf die Entwicklung Sukhulenz and Transpiration bei *Salicornia herbacea*, Sowie untersuchungen uber den Einfluss der Salzauf Nahme auf die Wurzelatmung bei *Aster tripolium*. Recueil des Travaux. Botaniques Neerlandais 36:559–657
Wilkie ML, Fortuna S (2003) Status and trends in mangrove area extent worldwide. Forest resources assessment working paper no. 63. FAO, Rome. Available at www.fao.org/forestry/mangroves/statistics

Internet References

http://www.geocites.com/RainForest/Vines/4301/microbe/html
http://www.care4nature.org/wildindia/dolphin/conservation.htm
http://www.epa.qld.gov.au/nature_conservation/habitats/mangroves_andwetlands/mangroves
http://oceanlink.island.net/ask/pollution.html
http://www.grida.no/publications/vg/climate/page/3066.aspx
http://www.partnersvoorwater.nl/wp-content/uploads/2012/07/MoUBangladeshDeltaPlan2100-22May20120001.pdf
www.un.org/earthwatch/about/docs/ewwp4wp6.htm

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Blue Carbon Reservoir of the Blue Planet
Mitra, A.; Zaman, S.
2015, XII, 299 p. 383 illus., 360 illus. in color.,
Hardcover
ISBN: 978-81-322-2106-7