

Life in the Oceanic Realms

Chandralata Raghukumar



Chandralata Raghukumar is an emeritus scientist at the National Institute of Oceanography, Goa. After obtaining a PhD in plant pathology, she worked for 5 years on fungal diseases of marine algae in the Institute for Marine Research, Bremerhaven, Germany. At NIO she worked on algal and coral pathology and marine fungal biotechnology. Her major interests are industrially important enzymes from marine fungi and physiology of deep-sea fungi.

The marine environment includes the nutrient-rich coastal waters, relatively nutrient-poor open oceanic waters, coral reef atolls, metal-rich hydrothermal vent fluids with temperatures of 200-350°C, cold-seeps, estuaries, mangrove swamps, intertidal beaches and rocky shores. Oceans are home to some of the most diverse and unique life forms. This article is an attempt to introduce some of the fundamentals of biological oceanography and marine biology to describe life in the sea.

*I'd like to be under the sea,
In an octopus's garden in the shade,
We would be warm below the storm,
In our little hideaway beneath the waves,
We would be so happy, you and me,
No one there to tell us what to do.*

May this song by the Beatles be an inspiration to a career in biological oceanography! The general notion about oceanography research revolves around scuba diving, killer whales, sharks, giant octopus and lobsters. But the oceans are much more than these. Oceans are home to some of the most diverse life forms. These vary from whales, several metres long to bacteria smaller than a micron, creatures drab to stunning looking, sedate to constant swimmers, those which eat from anything to everything and those which are choosy about their meals. The ocean is the engine that drives the earth's living system. It regulates climate, it is the source of water that makes life on land survive. The fluidity and constant motions of oceanic waters facilitate interactions between different ecosystems, the land and the atmosphere. As the ocean currents move around the globe, various types of circulation patterns are generated that affect the concentration and distribution of nutrients in different regions and depths. The

Keywords

Phytoplankton, zooplankton, primary and secondary producers, zooxanthellae.



ocean currents also influence the geographical distribution of marine organisms living in the water column. Changes in temperature variations in one part of the ocean are felt in locations far removed.

Oceanographic research started with simple observation of living creatures in the sand and on the rocks in the intertidal beaches. It advanced when sea-going expeditions lasting over years became a passion with some individuals in European countries. Several marine animals and plants were collected during such voyages by the researchers on board the vessels and systematically described. The HMS Beagle with Charles Darwin on board sailed around different oceans for nearly 4 years and this was the beginning of the science of marine biology. This was followed by another great expedition on board HMS Challenger, which collected an enormous number of biological samples from waters and sediments. The science of marine biology advanced thereafter with faster ships, better navigation systems, better instrumentation to facilitate collection of samples from various depths and a better measurement of physical and chemical characteristics of sea water. The advent of submersibles, remote operating vehicles, SCUBA diving and the establishment of oceanographic research institutions the world over made oceanography as a distinct discipline of science.

Classification of the Oceanic Realm

The oceans are vertically divided based on penetration of sunlight. In general, down to a depth of about 200 m is the sunlit zone also called **photic** zone where photosynthesis takes place. Below this is the **aphotic** zone (*Figure 1*). The aphotic zone is further divided into **mesopelagic** or the twilight zone, (200-1000 m depth), **bathypelagic** or the midnight zone (1000-4000 m), **abyssal** zone (4000-6000 m) and beyond 6000 m the **hadal** zone. Horizontally, the oceans are classified into the **neritic** province, which includes all open-water habitats between the high-tide water mark and the edge of the continental shelf and the **oceanic** province, which lies seaward of the continental shelf (*Figure 1*).

Oceanographic research started with simple observation of living creatures in the sand and on the rocks in the intertidal beaches.



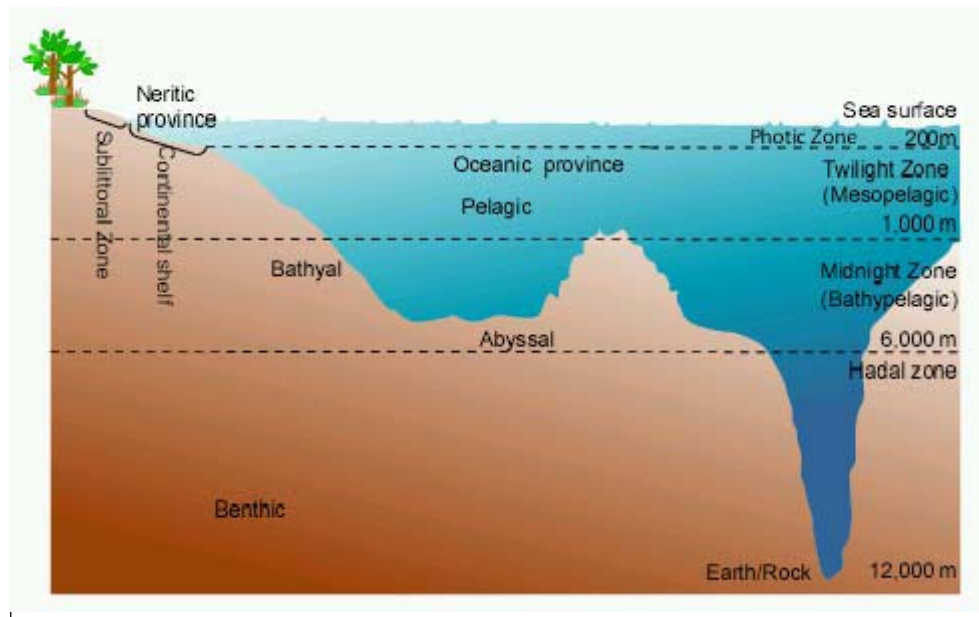


Figure 1. Spatial classification of the oceanic environment.

The **intertidal zone** is the shoreward region of the seabed between the highest and lowest extent of the tides.

The Life Forms

The life forms in the pelagic waters are grouped under a) **planktons**, those which do not swim actively but wander, and b) the **nektons**, the active swimmers. All life forms in the water column are termed **pelagic** in contrast to **benthic** that reside on the sea floor. As on land, sunlight is the most basic requirement for photosynthesis. The planktons that make their own food by photosynthesis are called **phytoplankton** and those small-sized animals that cannot synthesize their own food but feed on organic food available are called **zooplankton**. The phytoplanktons, like the plants on land, are the **primary producers**, and the zooplankton (copepods, salps) that graze on phytoplankton, like the herbivorous animals on land are the **primary consumers**. Carnivorous zooplankton and fish that feed on herbivorous zooplankton are the **secondary consumers**, the next higher level in the **trophic pyramid**. Carnivorous fish, squid and turtles constitute the top of the trophic pyramid and are called **tertiary consumers**. These are



the major contributors in the **marine food chain**. Some 80–90% of organic matter or energy is lost during each feeding step, by incomplete digestion and metabolism of the predators.

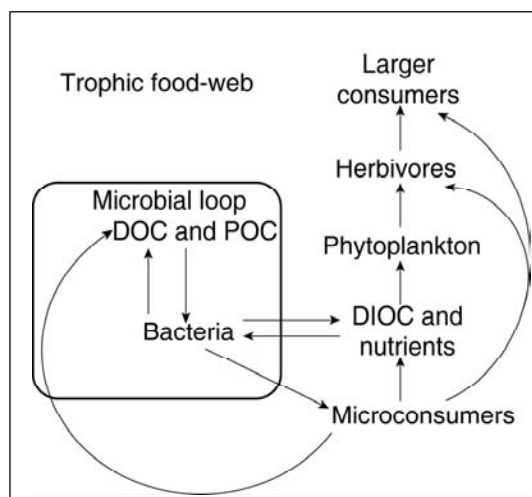
Almost all waste materials in the form of organic secretions, faeces and dead tissues are decomposed by bacteria and fungi. These **decomposers** remineralize the essential elements such as nitrogen, carbon and phosphorus locked up as organic constituents in plant and animal tissues. The decomposers catabolize them to inorganic forms that are available again for uptake by photosynthesizing, **autotrophic** organisms. The decomposers depend upon readily available organic food for their growth and metabolism and are called **heterotrophs**. In the ocean, there are also chemosynthesizers that are capable of oxidizing inorganic compounds like nitrite, ammonia, methane, sulphur in the absence of light. This mechanism of producing organic carbon is called **chemosynthesis**, which is mostly carried out by a group of bacteria called **chemoautotrophs**. Bacteria are eaten directly by microflagellate and ciliates (protozoans). These microconsumers also release dissolved inorganic nutrients, which are taken up by the autotrophs. The dissolved organic carbon (**DOC**) and particulate organic carbon (**POC**) released by lysis of bacteria, fungi and protozoa are used by bacteria. Thus, these processes form a **microbial loop** in the trophic food web (*Figure 2*).

Primary Production

The amount of plant tissue built up over time in an area is referred to as **primary production**, so called because photosynthetic production is the basis of most of the marine biological production. Microscopic plants the phytoplankton in the photic zone, are responsible for fixing carbon dioxide in the ocean through photosynthesis in the presence of sunlight and nutrient salts, a role similar to that of plants in the terrestrial system. The

Figure 2. Simplified schematic diagram of the oceanic food web.

(Modified from Oceans-Wikipedia, the free encyclopedia).



¹ Mineral nutrients (nitrate, ammonium, phosphate, silicate and iron) are essential for the growth and multiplication of phytoplankton. Physical processes such as upwelling (a process in which cooler waters from below are brought up), hydrographic fronts (regions over which a property like temperature or salinity changes sharply in the horizontal), eddies and cyclones are responsible for bringing up nutrients from deeper waters to the surface, thus stimulating primary production. The southwest monsoon along the west coast of India brings up nutrients from deeper waters through upwelling and is important for the high primary productivity and fish catch during this season. Cyclones are among the major cause of nutrient injection to the surface waters and elevated primary production in the Bay of Bengal. The fertility of the oceanic water column can be assessed by its chlorophyll content and phytoplankton abundance. Primary production in the Arabian Sea varies from 163–1782 mg C m⁻² d⁻¹ and that in Bay of Bengal ranges from 40–566 mg C m⁻² d⁻¹ during north east monsoon, south west monsoon and inter-monsoonal period.

source of carbon dioxide in these waters is by a) absorption of CO₂ from the atmosphere, b) release through respiration of bacteria and animals, and c) upwelling¹ of CO₂ from dissolved calcium carbonate in shells of benthic animals. Phytoplankton play an important role in the global carbon cycle by regulating atmospheric CO₂. Efforts are being made globally to increase primary production in the world oceans to reduce the atmospheric CO₂ (see *Box 1*).

More significantly, about 50-75% of the atmosphere's oxygen comes from marine phytoplankton. Besides, phytoplankton are also actively involved in the transport of nitrogen, phosphorus, iron and silica in the oceans. The relative availability of nutrients for phytoplankton, particularly of nitrate and ammonium, is used for classifying aquatic environment into **oligotrophic**, regions with low concentrations of essential nutrients and the consequent low primary productivity (0.05–0.5 mg chlorophyll l⁻¹), and **eutrophic**, regions with high concentrations of nutrients and high chlorophyll concentrations (1–10 mg l⁻¹ in surface waters).

The microscopic phytoplankton in the ocean can be grouped under diatoms, dinoflagellates, silicoflagellates, and nano and picoplanktonic cyanobacteria. Diatoms are the most dominant

Box 1.

Large portions of ocean surface waters are not very productive because of limited concentrations of available iron, an essential nutrient though required in trace quantities by phytoplankton. Thus, in the famous “iron experiment” in the eastern Pacific and near the South pole, a solution of iron was spread over a large area to promote phytoplankton growth. An increase in chlorophyll concentration and phytoplankton numbers was noticed. However, such experiments on a large scale, even if successful, could have unpredictable effects on the ecosystem. Therefore, they need to be conducted by a multidisciplinary group of oceanographers, who can simultaneously study the physical, chemical, biological and atmospheric effects of iron enrichment in the marine environment.



phytoplankton in oceanic waters. They are unicellular, ranging in size from 2 to over 1000 μm , forming large chains or aggregates, held together by mucilaginous threads or spines (*Figures 3a–d*). They have an external skeleton, designed into spines, ribs, pores and channels, and these patterns are distinct for individual species. The frustules are made up of silica, which contributes 4–50% of the dry weight of the cell. The diatom frustules are abundant in oceanic sediments and these deposits are referred to as diatomaceous ooze. Based on the shape and structure of the frustules, the diatoms are classified as **pennate** or **centric** forms.

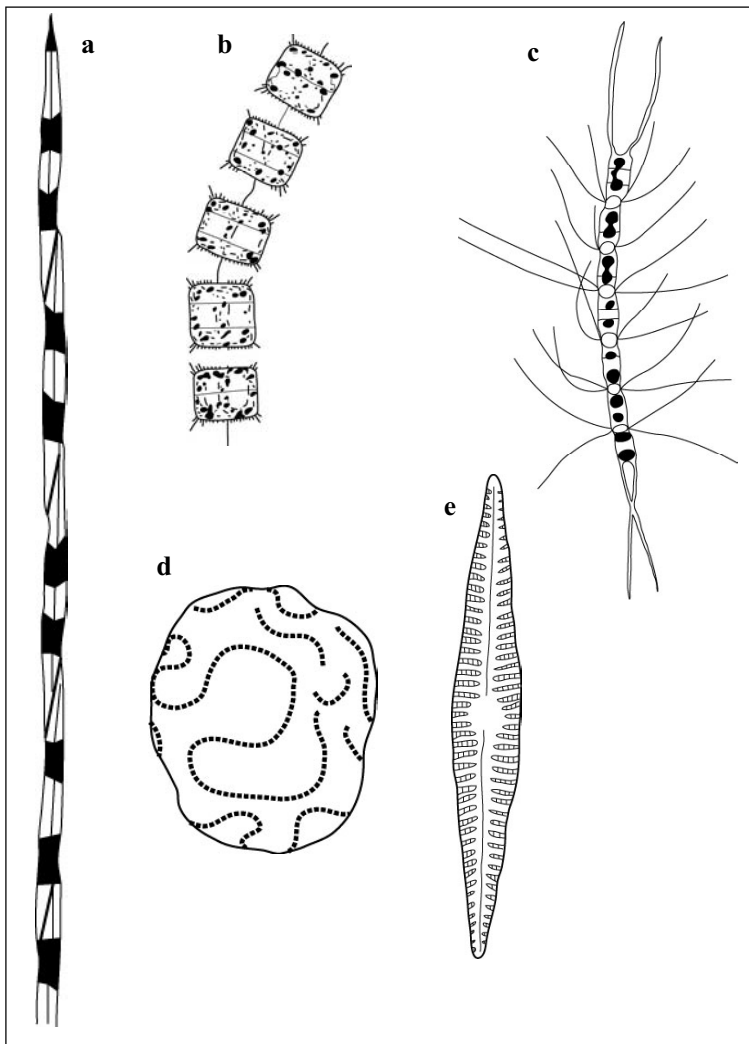


Figure 3. Some examples of diatoms.

a) Chain of dividing cells of *Nitzschia pungens*.

b) A chain of *Thalassiosira gravida* cells.

c) A chain of cells of *Chaetoceros lacinosus*.

d) Gelatinous colony formation by *Chaetoceros socialis* cells.

e) A benthic pennate diatom *Navicula* sp.

(Redrawn from various books on biological oceanography).

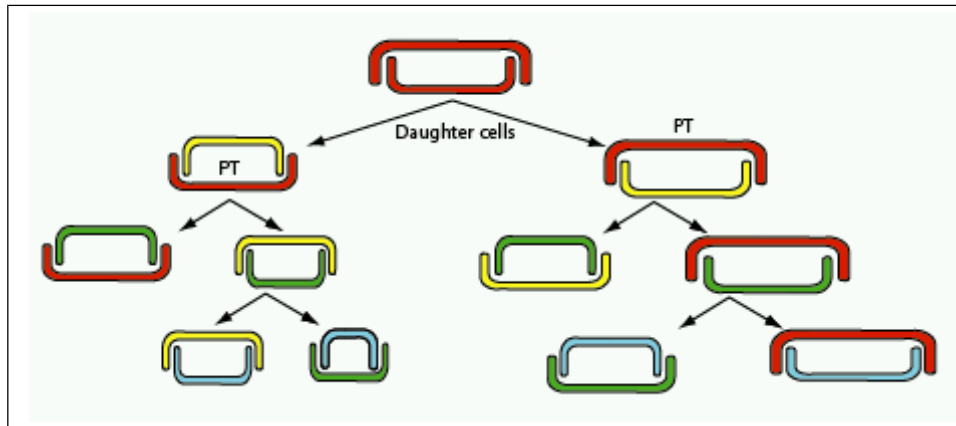


Figure 4. The life cycle of diatom showing division of cells and gradual decrease in size of cells.

Pennate forms are mostly benthic and have elongate shape (Figure 3e). Some of them exhibit gliding movement. The centric diatoms are more common. The planktonic diatoms are incapable of independent movement. In order to remain floating in the lighted zone for photosynthesis and to avoid sinking, these have several adaptations. They increase their surface area by chain or colony formation. Most species regulate their internal ionic concentrations in relation to that in seawater to remain afloat. They

also produce and store oil to reduce cell density. Diatoms have an external skeleton, the frustule, made of silica and is composed of two halves that are arranged like a soap box. Diatoms reproduce by simple asexual cell division, with one valve going to each daughter cell and serving as the larger half (Figure 4). A smaller valve is formed around each daughter cell (Figure 4), resulting in a gradual decrease in the cell size in successive generation. When the cell size reaches a lower threshold, the diatoms form auxospores (Figures 5a–e), which enlarge and cast off the valves, form new large valves, and continue their life cycle with asexual

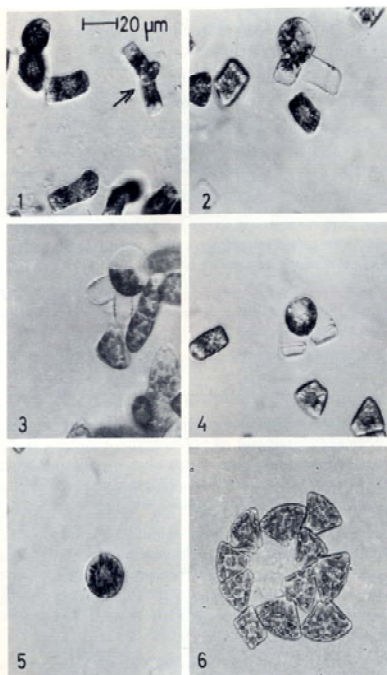


Figure 5 . Stages in auxospore formation in diatoms. 1) An early stage where cell contents are extruded. 2), 3) and 4) Auxospore formation. 5) A mature auxospore where the diatom walls from the mother cell are discarded. 6) New cells are developed from auxospores.

(C Raghukumar, *Veröff. Inst. Meeresforsch. Bremerh.*, Vol.17, pp.15–20, 1978).



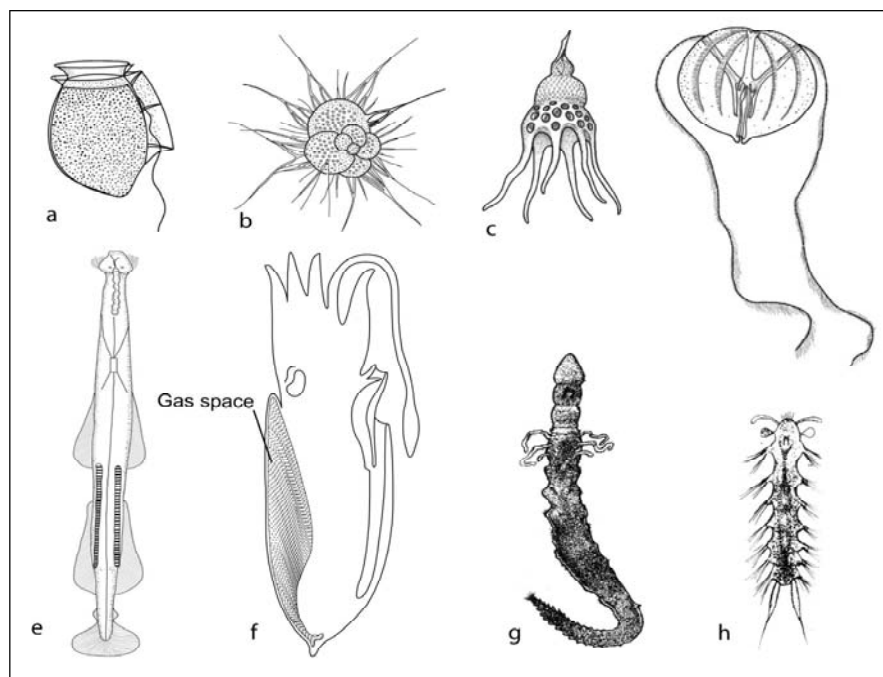
divisions. Depending on the environmental and nutritional conditions, the doubling time of diatoms can vary from 4-48 hours.

The other group of organisms contributing to primary production are the dinoflagellates. They are unicellular with two flagella and are covered with cellulose plates, also called the theca, whose pattern is distinct for each species (*Figure 6a*). Like diatoms, they reproduce by binary division and increase in population size rapidly. They also reproduce sexually forming resting stages or cysts, which sink to the bottom and can be regenerated as planktonic forms later. Owing to such rapid growth they are involved in red tides, wherein they form a dull reddish brown coloration of surface waters in oceans. Some dinoflagellates are bioluminescent and some produce deadly neurotoxins. Commercially exploited shellfishes consume these dinoflagellates and the toxin can remain residual inside their body and cause toxicity to human beings in the food chain. The sudden appearance of red tides are associated with rapid influx of nutrients into the sea. The cysts, dormant in the sediment, may be brought up along with nutrients

Figure 6.

- a) A dinoflagellate *Dinophysis acuta*.**
- b) A foraminiferan.**
- c) A radiolarian.**
- d) A comb jelly.**
- e) An arrow worm.**
- f) A cuttlefish with its cuttlebone.**
- g) A polychaete.**
- h) A polychaete with spines.**

(Redrawn from various books on biological oceanography)



The cyanobacteria, often called the blue-green algae (although they are not true algae) are photosynthesizing primary producers.

during storms, upwelling, and tidal actions and this may start the red tide when conditions are conducive for their growth.

The cyanobacteria, often called the blue-green algae (although they are not true algae) are photosynthesizing primary producers. The oceanic forms eg. *Synechococcus*, are extremely tiny and are called picoplankton (in the size range of 0.2–2 μm) and have been reported to contribute significantly to the primary production in the oceanic waters. The filamentous cyanobacterium *Trichodesmium*, is found in nutrient-poor oceanic waters. It is involved in the process of nitrogen fixation, in which gaseous nitrogen is converted to NH_4 , which is then available for incorporation into amino acids and proteins.

The Consumers

Zooplankton, the primary consumers, comprise taxonomically and anatomically diverse animals.

Zooplankton, the primary consumers, comprise taxonomically and anatomically diverse animals. Although zooplankton are capable of movement, most cannot swim against the current. They require synthesized organic material to build up their body biomass. Some of them are **herbivores**, feeding on phytoplankton and other plant material; some are **carnivores**, feeding on other smaller animals; the **omnivores** have mixed dietary habits. The **holoplankton** spend their complete life cycle in the water column, whereas the **meroplankton** are temporary residents of water column. These include fish eggs, fish larvae and larval stages of many benthic invertebrates. The **heterotrophic dinoflagellates**, those lacking chloroplasts (organelles required for photosynthesis), flagellated protists, the **zooflagellates**, **foraminifera**, characterized by calcareous perforated test and several chambers (*Figure 6b*), **radiolarians**, the spherical amoeboid protozoans with perforated capsules composed of silica the (*Figure 6c*), all belonging to the protozoan or protist group, dominate the zooplankton group. Planktonic ciliates, and especially **tintinnids**, are widely distributed in open seas and coastal waters. They feed upon diatoms and are food for large zooplankton. The tentacles of **jellyfish** and **siphonophores** (*Figure 6d*)



can range in size from a few millimetres to 3-6 m. **Arrow worms** or chaetognaths (*Figure 6e*) are carnivorous zooplankton that are capable of swift darting movements during pursuit of their prey. The shelled **pteropods** are holoplanktonic snails with thin external calcareous shells. The **copepods** are the most predominant widely distributed crustacean zooplankton. Known as the cattle of the sea, copepods are responsible for grazing on most of the primary production crops. The most evolved crustaceans are the **decapods**, which include shrimps, lobsters and crabs. The shrimps are strong swimmers and live below 150 m depth in daytime. **Salps** belonging to chordata are found in warm surface or near-surface waters and often form dense swarms and have high feeding rates. They are filter feeders, feeding on phytoplankton and bacteria by pumping large amount of water through their digestive tract. Their feeding activities can bring down the concentrations of phytoplankton considerably.

Although most plankton are not capable of strong locomotion, they show a strange phenomenon called diel vertical migration. Diel refers to events that occur within a 24-hour day and night rhythm. The zooplanktons move towards the surface in the night and migrate/sink to deeper waters in day time. There are several hypotheses put forward to explain this phenomenon and one of them, strongly supported by several scientists, is that the zooplankton leave the surface waters to avoid predators such as fish and diving birds during the day and come up in the nights to feed upon phytoplankton. Because of this strange diel migration, the species composition of zooplankton population taken during night and day time in the same area and same depths show differences. Large swarms of the zooplankton in the deep sea during vertical migrations are responsible for the production of deep scattering layers. These are sound-reflecting layers picked up by the sonar system of passing ships and give the impression of false sea-bottom. These deep scattering layers are caused by the movement of large zooplankton (shrimps, euphausiids) as well as by small fish (e.g. myctophids) that possess sound-reflecting air bladders.

Although most plankton are not capable of strong locomotion, they show a strange phenomenon called diel vertical migration.

Large swarms of the zooplankton in the deep sea during vertical migrations are responsible for the production of deep scattering layers.



There are about 20,000 species of fish inhabiting various habitats in the marine environment.

The nektons are capable of swimming with or against strong currents. Nektons include fishes, cephalopods (squids, octopus and cuttlefish), marine mammals and reptiles. The mammalian order includes the whales, dolphins and porpoises. These powerful swimmers are capable of migrating several thousands of kilometers in a day. Cephalopods dive from the surface to 200 m depth and regulate their bouyancy during such dives by altering gas and water proportions within rigid structures such as shells or cuttlebone made of calcium carbonate (*Figure 6f*). There are about 20,000 species of fish inhabiting various habitats in the marine environment. The cartilaginous fish such as sharks and rays have a skeleton of cartilage, whereas the bony fish like salmon and herrings secrete a true bony skeleton. They are active swimmers and thus have high oxygen requirement. They get their oxygen from water that flows over the gills. Haemoglobin in the blood is responsible for uptake and transport of oxygen to other tissues. Several species of fish move in a school (referring to a group containing thousands of individuals). Schools often confuse predators and the entire group moves away before the predator strikes. Thus, schooling provides protection against predation. Schooling also reduces drag and such aggregation helps in conserving energy during swimming. When an entire school of fish move in a pack, those in the centre and at the rear experience less drag and need to spend less energy per individual, a phenomenon similar to patterns of bird flocks form, while flying in the air.

Habitats of the Oceanic Realm

I shall now briefly discuss the various habitats in the oceanic realm such as intertidal, estuaries, deep-sea, mangroves and coral reefs.

Intertidal or littoral areas in the coastal zones are affected by rising or receding sea water.

Life in the Intertidal Environment

Intertidal or littoral areas in the coastal zones are affected by rising or receding sea water. Tides reflect periodic rise and fall of sea level over a fixed time interval. Most coastal areas experience



semidiurnal and some places experience diurnal tides referred to as low and high tides, during which the intertidal zone is exposed and covered by water twice or once in a day. The intertidal area includes sandy beaches and rocky shores. The animals and plants inhabiting this environment show special adaptations. The sand-dwellers burrow into soft sand or mud to prevent desiccation when water recedes. Animals on the rocky shores possess hard shells, which are closed tightly during low tides to retain moisture. Benthic algae or seaweeds found abundantly growing attached to rocks and phytoplankton in rock pools are the important primary producers here. The common seaweeds found along the Indian coast are the brown alga *Sargassum*, the green algae *Enteromorpha* and *Ulva* species. It also supports high diversity of **macrofauna** (animals with dimension more than 1 mm in size) such as crustaceans, bivalves and polychaete worms. At lower tide levels sea cucumbers, sea urchins and many more animals are found. The **meiofauna** (retained by 0.1–1.0 mm mesh sieve) are the most diverse and dominant group in sandy beaches (Figure 6g, h). Most of them are **interstitial**, living in spaces between the sand grains. They are either attached to sand grains or move in spaces between the sand grains. The majority of them are mobile and feed by grazing or are detritus feeders. The meiofauna are eaten by deposit-feeding macrofauna capable of mobility and chemosensing (eg. Polychaetes). **Microbenthos** are less than 0.1 mm in size.

Life in Estuaries

Estuary is a region where the river enters the sea and experiences tides. Estuaries are among the most productive marine ecosystems. They are the home for sea grasses, the flowering plants (angiosperms) that grow submerged in seawater, and the mangrove plants. The plant and animal community is adapted to grow in highly fluctuating salinity, varying from 5 to 25 parts per thousand, temperature and turbidity. Estuaries are rich in nutrients as a consequence of land-drainages. They are also subjected to pollution. Generally, on seaward side of the estuary sand bars

Estuary is a region where the river enters the sea and experiences tides. Estuaries are among the most productive marine ecosystems.



Box 2. Estuaries of India

In India, there are about 50 estuaries, of these, 23 are located along the east coast and 27 are on the west coast. The largest estuarine area is the Ganges–Brahmaputra delta region along the east coast of India in West Bengal. Hooghly river estuary, forms one of the main distributaries of this region.

are present; they are colonized by benthic diatoms and cyanobacteria. The largest estuarine system in India is (see *Box.2*) the Hooghly Ganges-Brahmaputra which drains enormous amount of fresh water and silt into the Bay of Bengal. This deltaic formation encompasses the famous Sundarbans mangrove forests.

Coral Reefs

Coral reefs, with their rich biodiversity, are underwater tropical forests. They are high-productivity zones in the midst of nutrient poor oceanic waters and are thus like oases in the deserts. Corals reefs are generally restricted to waters of around 20°C, salinities of 32 to 35 parts per thousand, high light levels and clear (no sediment to low load of suspended particles) waters. They are sensitive to high concentrations of settling and suspended sediment, which can clog their feeding mechanisms. High turbidity also cuts off light, which is essential for their photosynthesizing algal symbionts, the **zooxanthellae**. The zooxanthellae in all corals belong to a single genus of dinoflagellate, *Symbiodinium*, with different species or strains specific to particular coral species. The reef-building stony corals, also called **hermatypic** corals, are colonial animals. Each coral colony has numerous polyps housed in a skeleton of calcium carbonate. Each polyp has tentacles with which they catch their prey, usually the zooplankton in vicinity. The photosynthetic endosymbiotic zooxanthellae live within the cells lining the gut of coral polyps. They can reach up to 30,000 cells per mm³ of coral tissue and are responsible for the pigmentation typical of corals. When the corals are subjected to stress, these zooxanthellae are immediately expelled, resulting in **bleaching** of corals (see *Box 3*). Hermatypic corals are divided into massive or branched corals. The **ahermatypic** corals are not reef-building corals and they do not harbour zooxanthellae. Similar photosynthetic symbionts are present in several other reef inhabitants.

The symbiotic association between algae and their hosts results in nutrients being tightly recycled in the reef ecosystem, which is in turn responsible for the high productivity in oligotrophic tropical



Box 3.

Corals grow best in shallow, clear waters with low nutrients. They require light for their symbiotic algae, the zooxanthellae. The zooxanthellae in corals are responsible for imparting color to the corals. The zooxanthellae are expelled when the corals are subjected to stressful environmental conditions like increase or decrease in temperature, altered salinity, high ultraviolet radiation, increased nutrients or chemical pollutants. When devoid of zooxanthellae, the coral skeleton appears chalk white and this phenomenon is referred to as bleaching. There was a severe bleaching of corals worldwide in 1998. About 80 % corals in the Andamans showed partial bleaching during this period. However, most of these coral have recovered and new coral recruits are growing over the dead coral skeletons.



Bleached corals in the Andamans in 1998.

waters. The algal-coral relationship is beneficial to both species. Corals provide carbon dioxide released during respiration to the zooxanthellae, besides providing protected environment. The host also provides the zooxanthellae with inorganic nutrients such as ammonia, nitrate and phosphate released in the waste products. The zooxanthellae in turn produce oxygen and remove the waste and provide their host with organic products of photosynthesis. The symbiotic algae also help their hosts to synthesize CaCO_3 . The two independent process of fixing CO_2 , one through photosynthesis and another through calcification, is a phenomenon unique to corals. $2\text{HCO}_3^- + \text{Ca}^{2+} \rightleftharpoons \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$. The CO_2 evolved during calcification is also available to the symbiotic algae for photosynthesis.

Corals also capture their prey using their tentacles. Many coral species feed on suspended particles by producing mucus filament that entrap food, which is then drawn to the mouth by movement of cilia on the tentacles. Mucus also helps the corals keep free from overgrowth by other organisms. Due to abundant species diversity, there is an acute competition for space in coral reef



Mangrove forests, also called mangals, are intertidal plant communities rooted in soft, nearly anoxic, marine, water-logged sediments.

ecosystem, which has resulted in organisms having highly specialized habitats, defence mechanisms, reproduction strategies and feeding habits.

Coral reefs can be divided into atolls or coastal reefs. Atolls are horse-shoe or ring-shaped islands of volcanic origin. Coastal reefs are elongate structures that border a continental coast. The Great Barrier Reef off the east coast of Australia is a 2000 m long coastal reef. A thin band of subtidal corals forms a fringing reef off Mandapam on the Indian east coast. Besides corals, calcified algae, especially the green alga *Halimeda* species, also contribute to some extent to the process of reef-building in coral islands.

Mangrove Swamps

Mangrove forests, also called mangals, are intertidal plant communities rooted in soft, nearly anoxic, marine, water-logged sediments. They are exclusively tropical or subtropical, salt-tolerant plants found along the marine coasts and estuaries (see *Box 4* for the Indian mangroves). Mangals are dominated by shrub or tree-like flowering plants, the leaves of which fall into the water below, disintegrate by grazing and microbial activity and contribute to a huge reserve of **detrital** material. The plants have special roots called **pneumatophores** that are directed upwards into the air for uptake of oxygen directly from the atmosphere (see *Box 4*). Mangrove trees also have prop roots that grow midway from the stem downwards and give extra support to the plants growing in the water-logged sediments. Several mangrove plants produce seeds that germinate on the tree, the **viviparous** seedling that drop down into soft sediments and root or float in the water (see *Box 4*). Mangroves have mechanisms to exclude salt from their system. The leaves have salt glands that secrete salt. Roots are capable of the uptake of salt to a certain extent.

Detritus generated through degradation of leaves is a major source of food to the resident animals here. Some of them remove detritus by filter feeding, the deposit feeders use organic material in the sediments and others capture large particles of detritus and



Box 4.

In India mangrove forests are found in Sundarbans in West Bengal, Kendrapara and Bhadrak in Orissa, Godavari in Andhra Pradesh, Pitchavaram in Tamil Nadu, Gulf of Kachchh in Gujarat, Andaman and Nicobar Islands, Mumbai in Maharashtra, Goa and Karnataka and very sparsely in Kerala. The largest mangrove forest is in Sundarbans with an area of 2081 km², the next largest being in Andaman and Nicobar island with an area of 789 km², followed by Kachchh with an area of 854 km². Out of a total 101 species of mangrove plants recorded, 71 are reported to be present in India. About 11 species of seagrasses are found in the mangroves of the east coast, 7 species in the Andaman & Nicobar Islands, and 2 species on the west coast. The Royal Bengal tiger is exclusively found in the mangrove forests of the Sundarbans. A) The breathing roots (pneumatophores) below a mangrove tree, B) viviparous seedling germinating on the tree itself (arrow). (from personal collection of pictures)



feed on them. The **mudskipper**, found exclusively in the mangrove sediment, is a small fish with excellent eyesight, capable of slithering on the surface of the intertidal mudflat and even climbing low branches! Cyanobacteria, algae and seagrasses growing in this habitat contribute to the primary production. Being nutritionally rich and protected from large-scale tidal influences, mangroves are ideal breeding grounds for many varieties of neretic fish and prawns.

Life in the Deep Sea

The average depth of the oceans is around 3800 m, the maximum being 11 km in Mariana Trench in the Pacific Ocean. This enormous third dimension of the oceans results in unique abiotic and biotic characteristics. The water column below the photic



zone is generally called the deep sea. The hydrostatic pressure increases by 1 bar for every 10 m depth and therefore at 200 m depth, the hydrostatic pressure is already 20 bar. The temperature decreases with increasing depth. In the absence of photosynthesis, the deep-sea bottom depends upon the sinking organic material from the surface. The processes of photosynthesis in the upper photic zone, excretion, death and decay throughout the water column release organic matter to the deep sea. In the cold waters of the deep sea, oxygen is carried down from the surface by the cold, dense currents produced by the extreme cooling (that enhances dissolution of oxygen) of Arctic and Antarctic surface waters. These waters also carry inorganic nutrients to the deep sea. In the abyssal waters, the salinity is almost constant (35 parts per thousand). Though the biomass of living organisms is much lower than the surface waters the biological diversity is high in spite of such darkness, low temperatures, high pressure and sporadic availability of organic nutrient environment. The distribution of **benthos** (animals living on the sea floor) is highly patchy. Sponges, starfish, sea cucumbers are some of the most abundant benthos. While soft-bodied or calcareous sponges dominate the shallow waters, the deep-sea sponges are with siliceous spicules and are commonly referred to as glass sponges. Slender branching colonies of black corals (devoid of symbiotic zooxanthellae common in shallow-water corals), crinoids and stalked sea-lilies are found in depths exceeding 5000 m. Benthic foraminiferans and related protozoans are abundant and also contribute to about 97% of the biomass in some areas of the South Pacific and the Central Indian Basin.

Suggested Reading

- [1] C M Lalli and T R Parsons, *Biological Oceanography, An Introduction*, Butterworth Heinemann, 1993.
- [2] J S Levinton, *Marine Biology, Function, Biodiversity, Ecology*, Oxford University Press, 2001.

Gigantism is seen in some animal groups such as the benthic foraminifera and xenophyophore, whereas some animals show miniaturization. Deposit-feeding animals that live buried in the soft sediments of the deep sea (the infauna) contribute to about 80% of the species diversity. As the bottom currents are slow and do not disturb compacted sediments, the topographic features produced by these animals persist for long periods. Faecal mounds, burrows, trails and tubes are some of the biological



features that are commonly recorded in the deep-sea sediments by remotely operated cameras. Various biological processes such as metabolism, growth, maturation and population increase are slower in deep-sea animals than in shallow-water-inhabiting animals (see *Box 5*).

Life in Hydrothermal Vents

The volcanically active mid-oceanic ridges have a series of fissures from which hot water is spewed with great velocity. The molten rocks heat up the sea water, which is ejected out through smoking chimneys. The water is often superheated to several hundred degrees celcius (because it is under hydrostatic pressure) and rich with high concentrations of metals and dissolved sulfide. A special group of animals are found growing around these vents in temperatures ranging from 5° to 160°C. These include clams, mussels, limpets, shrimps and tube worms. The high species diversity (nearly 55 different animal species identified so far) is maintained by chemosynthetic bacteria that provide food to the vent animals. These bacteria derive energy from the oxidation of sulphide and multiply rapidly, forming mats on rocky surfaces and on sediments. In the absence of sunlight, chemosynthetic bacteria are responsible for “primary production” in vent sites. Animals such as limpets, crabs, bivalves and shrimps graze upon these bacterial mats. A fantastic “live and let live” approach by symbiotic associations is very common in hydrothermal vent organisms. (see *Box 6*).

The bacteria near the vent site get energy from methane or sulfide and have been found to be among the most primitive organisms known. A separate kingdom, the **Archaea**, was created to accommodate these primitive but highly diverse and versatile group of bacteria. This has led to the theory of origin of life in the ocean ridges. Another interesting aspect of vent fauna is their dispersal from one vent system to another as the life span of most vents appears to be between a few hundred to a few thousand years. As the vents are thousands of kilometres apart, how do these animals

Box 5.

Nearly fresh sandwiches and apples were obtained from a sunken research submersible, Alvin, ~10 months after the mishap. The submersible had remained at a depth of 1540 m and 3°C temperature for 10 months. Food stored at a similar temperature in a refrigerator in the dark generally gets spoiled. The elevated hydrostatic pressure, in combination with low temperature, kept the metabolism of bacteria low. Subsequently, it was demonstrated that bacterial metabolism is 10 to 100 times slower than that of equivalent bacterial densities maintained in the dark at low temperature and atmospheric pressure. This observation led to a new line of research in food preservation technology by using elevated pressure and low temperatures. Effect of hydrostatic pressure on the metabolism, cell membrane and proteins are some of the exciting topics of research in deep-sea biology.



Box 6.

The most interesting of the hydrothermal vent fauna is the tube worm. *Riftia pachyptila* is without a mouth or an anus and can grow up to 1 m in length. It lives in a tube made of chitin and protein and has a rapid growth rate. The tube worms have a specialized organ, the trophosome which contain sulfide-oxidizing bacteria. The animal digests these and derives nutrition. *Riftia* has a specialized haemoglobin, which binds to both sulfide and oxygen. The sulfide is transported to the trophosome, where it is used by the symbiotic sulfide bacteria for growth.

Address for Correspondence
Chandralata Raghukumar
National Institute of
Oceanography
Dona Paula
Goa 403 004, India.
Email:lata@nio.org

migrate. Do they disperse to non-vent habitats as well, or are they genetically different populations arising at different sites? These are some of the challenging topics for research.

Conclusion

Each of the above is a unique habitat and we need to protect their biological diversity for posterity. India has a coast line of 7500 km and exclusive economic zone (EEZ) of 2,172 million km² which is about two-third of the landmass of the country. Its living and nonliving resources, oceanography, coastal environment and related social issues directly influence several million people living along this coastline. Some of the exciting topics that need more studies are 1) understanding the factors that influence photosynthesis in the sea, since autotrophs are important in removal of atmospheric carbon dioxide and sequestering it into organic carbon; 2) understanding the phenomenon of bleaching in corals and its influence on fish population; 3) telemetry technology for tracking marine animals such as horse-shoe crab, turtles and mammals for their conservation; 4) understanding roles of defence and resistance in predator-prey interactions; 5) the role of secondary metabolites in plant-herbivore interactions within the reef system; 6) larval transport and their settlement among corals and hydrothermal vent organisms; 7) documenting changes in a habitat at larger scales of space and time by using recent development in satellite imagery, remote sensing and GIS technology; 8) use of molecular genetic techniques in defining geographical distribution of populations and taxonomic relationships among species; 9) effect of human activities on various marine habitats; 10) understanding biodiversity for management, conservation and assessing environmental impacts on the health of marine ecosystems. These offer immense opportunities and challenges for a career in the field of marine biology/biological oceanography.

