10

Habitat Complexity of Tropical Coastal Ecosystems: An Ecosystem Management Perspective

Chandrashekher U. Rivonker, Vinay P. Padate, Mahabaleshwar R. Hegde and Dinesh T. Velip

Q0

CONTENTS

10.1 Introduction

10.1.1 Ecosystem Concept

An ecosystem was originally defined by Tansley (1935) as 'a biotic community or assemblage and its associated physical environment in a specific place'. This concept finds relevance in budgetary approaches (Odum and Odum, 2000), studies of individual processes (Agren and Bosatta, 1996) and studies of the reciprocal interactions between disparate organisms and their effects in particular sites (Holling, 1995). It can be an analytic or a synthetic concept (Golley, 1993), and it can support an impressive variety of kinds of models (Ulanowicz, 1997). Ecosystem science, starting from the basic definition of Tansley (1935), has expanded to include many kinds of studies (Likens, 1992; Jones and Lawton, 1995; Pickett et al., 1997).

10.1.2 Coastal Ecosystems

Coastal ecosystems, although occupying a narrow fringe of the marine realm, account for the major share of productivity and biological diversity of the oceans. These ecosystems (particularly in the tropical Indo–Western Pacific regions) are highly productive owing to interplay between shallow bathymetry, habitat complexity, intrinsic hydrodynamics, meteorological conditions and terrestrial inputs, as compared to the almost barren (oligotrophic) open ocean environments. In addition, the high productivity supports large-scale fisheries and is a source of livelihood for millions.

10.1.3 Oceanography Off Central West Coast of India

Based on atmospheric forcing, the seasonality along the central west coast of India could be divided into four seasons: Southwest or summer monsoon (June–August), fall inter-monsoon (September–October), Northeast or winter monsoon (November–February) and spring inter-monsoon (March–May). This is also reflected in the spatial–temporal variations in productivity. The inter-monsoon periods are marked by higher Q1 sea surface temperature (SST) (~28°C), shallow mixed layer depths (MLD) (20–30 m) and strong stratification. Moreover, they are additionally marked by low primary production (14–21 m mol C m^{-2} day^{-1}), chlorophyll (ca. 45 m mol C m^{-2}) and undetectable levels of nutrients, especially nitrate in surface waters (Madhupratap et al., 2001). With the onset of the Southwest monsoon, south-westerly winds along the west coast cause movement of the surface waters away from the coast, thereby bringing about upwelling of colder, nutrient-rich and often oxygen-depleted waters from the subsurface by means of Ekman transport. This leads to blooms of mostly diatoms and dinoflagellates and increased productivity. The upwelling off Mangalore commences in June, propagates northwards up to 16°N and prevails until late August/early September, after which it subsides. Simultaneously, a low-level atmospheric jet known as the Findlater jet occurs along the northern part of this region and brings about open ocean upwelling, leading to shallower MLD and higher productivity and biomass (80 m mol C m^{-2} day^{-1}, 170 m mol C m^{-2}). Another unique feature, winter cooling, occurs north of 15°N, where cold, dry continental air blowing into the northern Arabian Sea causes cooling (SST ~24°C), densification of surface waters and sinking. This leads to deep MLDs (>100 m) despite weaker winds, and convective mixing injects nutrients into the surface layers (2–4 μM), generating higher production (40 m mol C m^{-2} day^{-1}) (Madhupratap et al., 2001).

10.1.4 Physiographic and Climatological Setting of Goa, India

Goa (Figure 10.1 shows a geographical map of Goa indicating various coastal ecosystems), with a coastline of about 105 km along NNW–SSE facing the Arabian Sea, supports diversified geological and ecological features and forms an integral part of the central west coast of India (Wagle, 1993). The seabed consists of silty clay up to 50 m and sandy silt from 50 to 100 m (Modassir and Sivadas, 2003), with an average slope of 1.50 m km^{-1} up to a depth of approximately 55 m, and the submarine contours are approximately parallel to the coastline (Veerayya, 1972). The bathymetry is intermittently interrupted by coral reefs (Rodrigues et al., 1998; Hegde and Rivonker, 2013) and submerged rocky patches, which extend from the cliffs and promontories along the adjacent rocky shores (Wagle, 1993). Coral reefs occur mostly in patchy forms around near-shore islands (Grande Island), in the vicinity of submerged rocks across and off estuarine mouths. The overlying waters perennially receive nutrient-rich freshwater influxes from the adjoining estuaries, with the Mandovi–Zuari estuarine complex (between 15°25′N and 15°31′N and between 73°45′E and 73°59′E) in particular being the most prominent, with a catchment area of 1700 km^2 (Qasim, 2003). The two major rivers, the Mandovi and Zuari, are connected to the Arabian Sea by Aguada and Mormugao Bays respectively. Aguada Bay (4 km long) runs north–south (Shetye et al., 2007); Mormugao Bay (14 km long) runs in an east–west direction from the Western Ghats, and the rocky outcrops extending in a north-south line across the entrance of the bay separate it from the Arabian Sea (Rao and Rao, 1974). The other estuaries traversing the coastal region of Goa are Terekhol (26 km), Chapora (30 km), Sal (10 km), Talpona (9 km) and Galgibag (16 km) (Singh et al., 2004). Estuarine tides are of a semi-diurnal nature (Qasim and Sen Gupta, 1981) and carry seawater a considerable distance upstream.

This region experiences maximum precipitation during the Southwest monsoon, accompanied by stormy weather, while quieter conditions prevail during the rest of the year (Ansari et al., 1995). The intertidal estuarine marshy ecosystem is the transformation of the gentle slope of the near-shore banks of Mandovi and Zuari, which are filled with silt, clay and detritus transported by riverine influx from upper reaches, where mangrove vegetation occurs in high density. The marshy areas extend for a distance of 4 km and are inundated during high tide. The entire mudflats consist of loose muddy soil bordered by mangrove vegetation, making it highly productive for benthos, which support large numbers of economically important species (Ansari et al., 1995; Kulkarni et al., 2003). Moreover, rich mangrove vegetation exists along the banks of the Terekhol, Chapora and Sal estuaries (Singh et al., 2004).

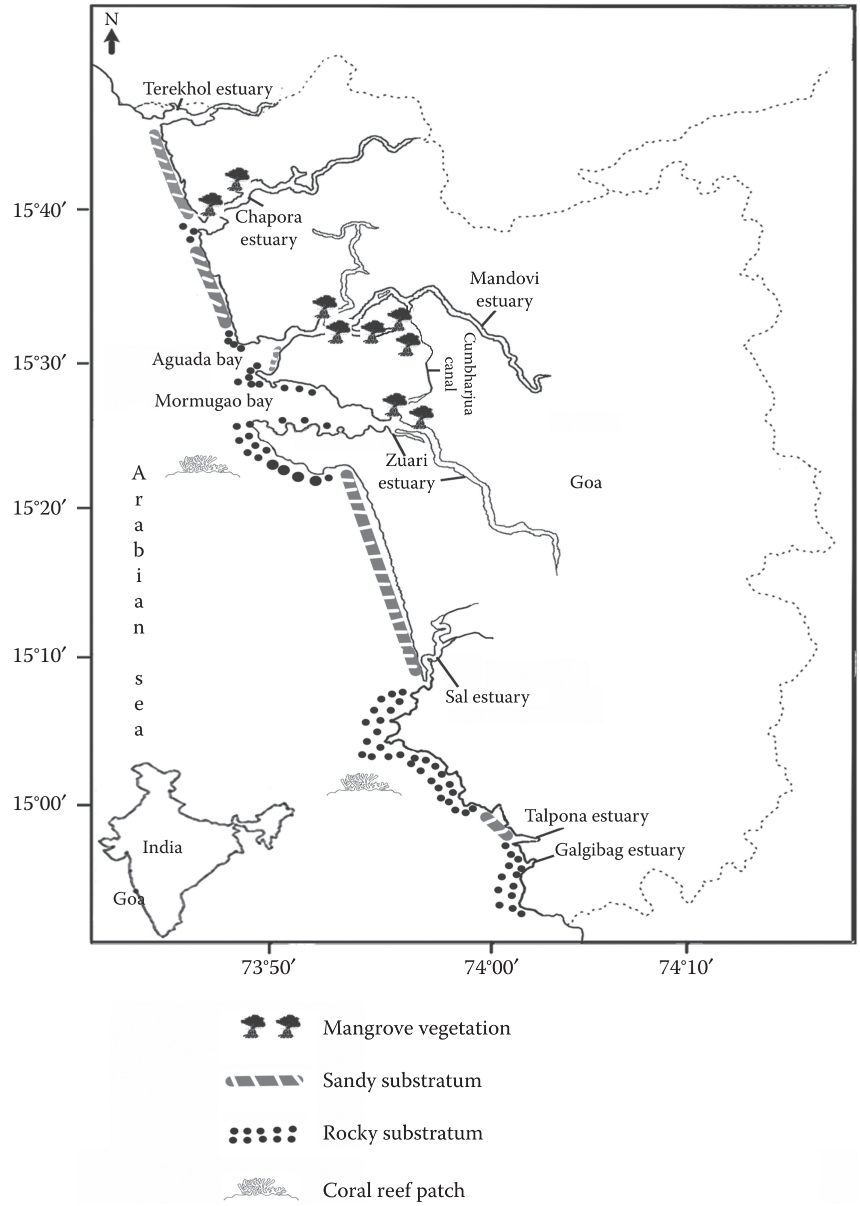

FIGURE 10.1
Map of Goa, central west coast of India, indicating various coastal ecosystems.

10.2 Coastal Ecosystems

10.2.1 Coral Reefs

Coral reefs are the most spectacular environments and are now being treated as endangered ecosystems. Biological diversity in these ecosystems is very high, with myriad varieties and an abundance of plant and animal life. They are ecologically distinct and are highly productive, with gross productivity of about 1800 gc m^{-2} $year^{-1}$. However, their surrounding waters are nutrient deficient, wherein the primary and secondary productivity is very small. Reef-building corals are anthozoan coelenterates of Class Scleractinia characterized by an ability to produce $CaCO_3$ as an external skeleton. They grow in a cumulative manner, giving rise to massive formations. Corals occur in subtropical and tropical environments in clear, transparent waters with temperatures above 18°C. The richest assemblages of coral reefs are known from Melanesian – South-East Asian areas representing about 700 species from 50 genera. On the other hand, the Caribbean Sea in the Atlantic supports 100 species from about 26 genera. Corals possess endosymbiotic zooxanthellae – photosynthetic organisms that are essential for the calcification process, as evident from the direct correlation between photosynthesis and calcification rate. The growth of corals is confined to a depth of 10 m, and as the depth increases, the growth declines, indicating a direct relationship with photosynthesis. These ecosystems also support a variety of reef fishes, mainly represented by herbivores, damselfish and sturgeon. Recent extensive biological sampling surveys (2005–2011) along Goa's coast have revealed 20 new records of rare reef species (Hegde et al., 2013), including *Caesio cuning* (Padate et al., 2010a) and *Temnopleurus decipiens* (Hegde and Rivonker, 2013), which are the first records of them outside their respective known geographical ranges (Figure 10.2 indicates the geographic distributional ranges of the two aforementioned species and their present occurrence along Goa's coast). Q2

Moreover, the occurrence of reef fishes in bottom trawl hauls taken from the vicinity of submerged ships suggests that these structures also act as artificial reefs and enable the recruitment of reef fish larvae and subsequent inhabitation by adult fishes (Padate et al., 2010a).

10.2.1.1 Primary Productivity

Primary production in coral reef areas is made by all conceivable types of primary producer, which are highly diverse, ranging from zooxanthellae to seagrasses. The gross primary productivity in coral reefs ranges from 2 to 5000 g C m^{-2} $year^{-1}$. However, respiration by consumers is also of similar magnitude, indicating that most of what is being produced is consumed within the community. Therefore, zooxanthellae form one of the major primary producers of reef, fixing carbon at about 0.9 g C m^{-2} $year^{-1}$. The other components of primary producers in this ecosystem are mainly comprised of different types of benthic algae, coralline algae, seagrasses and filamentous algae attached to coral rubble.

10.2.1.2 Calcification

Individual coral polyps are measured in millimetres, yet coral reefs extend for hundreds of kilometres. These integrated structures are capable of withstanding cyclones and insidious effects of countless boring and grazing organisms. Reef-building corals require sunlight, warm water and zooxanthellae. However, the role of zooxanthellae has been the subject of great debate. Goreau and Goreau (1959) demonstrated very clearly using ^{45}Ca as tracer that zooxanthellae are essential in the calcification process. They demonstrated that growth rates of most corals (*Acropora prolifera*) in light were considerably higher than in the dark. They also observed that when the corals were held in dark for several weeks, they extruded their zooxanthellae in the water, although polyps remained apparently healthy and active in food collection. Further, it was reported that the corals treated in this manner had a reduced rate of calcification even in light.

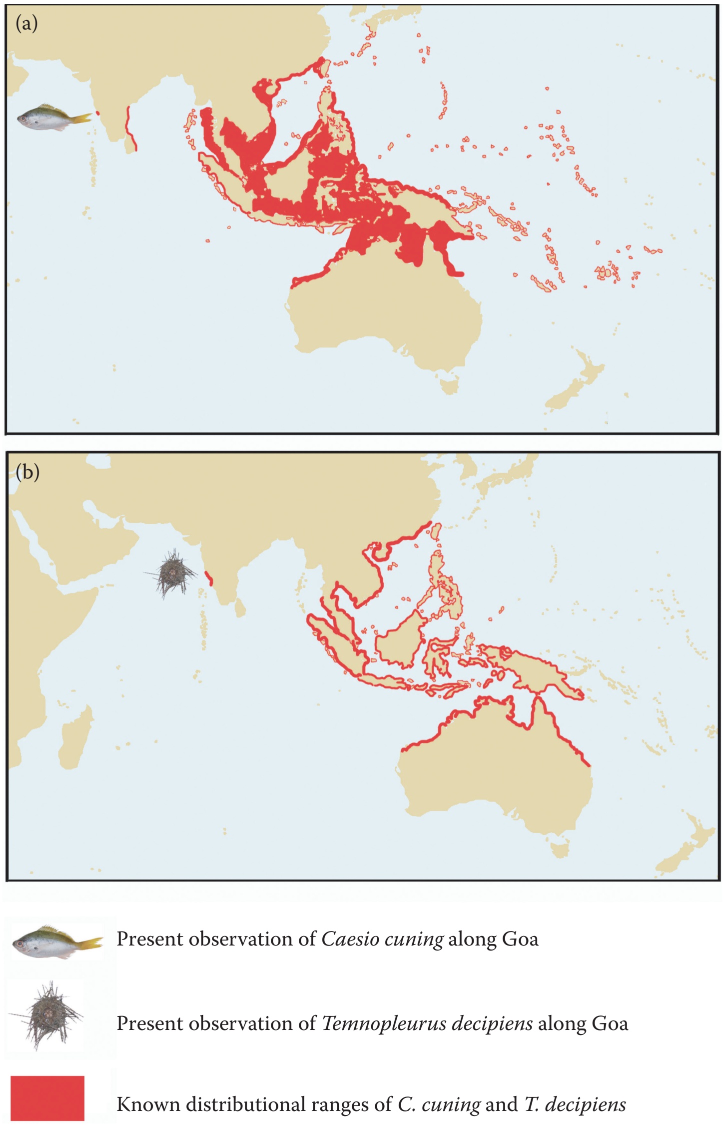

FIGURE 10.2
Range distribution maps of (a) *Caesio cuning* and (b) *Temnopleurus decipiens*, along with their respective photographs, indicating their occurrences outside these ranges.

The relationship of calcification to zooxanthellae was thought to be indirect since large apical polyps of some corals have very few zooxanthellae, yet calcification proceeds most rapidly at the tips of their branches. To gain a better understanding of these aspects, Pearse and Muscatine (1971) carried out ^{45}Ca experiments with staghorn coral (*Acropora cervicornis*) and hypothesized that zooxanthellae provided organic material for the construction of a skeleton matrix. Other studies demonstrating the role of zooxanthellae suggested that they provided glycolate, subsequently converted to glyoxylate, and then combined with urea to form allantoic acid. They proposed that allantoins served as the medium by which Ca and CO_2 were transported to sites of calcification.

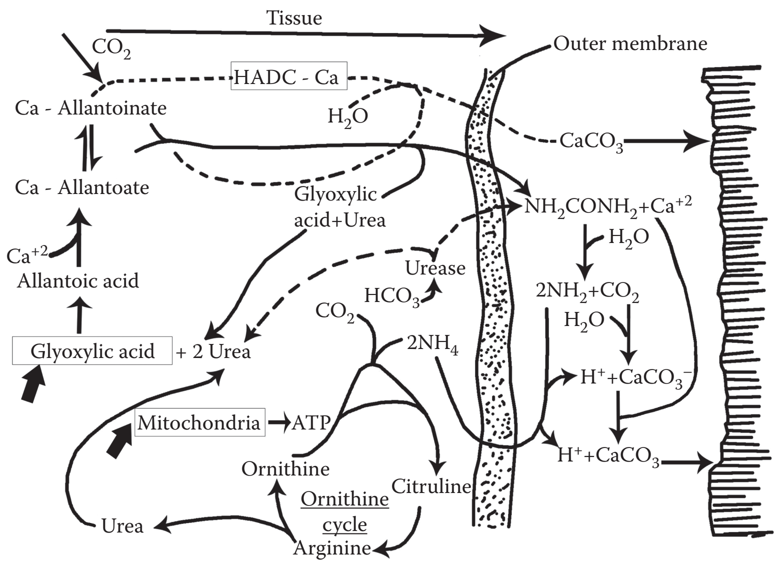

FIGURE 10.3
Diagrammatic representation of calcification mechanism in corals.

The mechanism of calcification (Figure 10.3 illustrates the calcification mechanism in corals) involves glyoxylic acid and mitochondria, both associated with zooxanthellae, as probable sites for the stimulation of the calcification process. Glyoxylic acid combines with urea to form allantoic acid, which under the influence of calcium from seawater forms calcium allantoate. This, in combination with CO_2, forms calcium salts of hydroxyl-acetylene diureide carboxylic acid, which serves as a medium for the deposition of $CaCO_3$ on the skeleton. On the other hand, the nitrogenous (excretory) products released by corals under the influence of CO_2 and urease enter the ornithine cycle, initially forming citruline, then arginine and ornithine. The propagation of the ornithine cycle is mainly mediated through energy supply as ATP by mitochondria. This is then converted to urea, which then combines with glyoxylic acid.

10.2.1.3 Nutrition

Corals meet their nutritional requirements from several sources, namely through extracellular products of zooxanthellae; by capturing particles in the water, especially zooplankton, bacteria, phytoplankton and particulate matter scavenged from the substrate and possibly dissolved organic matter. The mechanism of capture among these species includes raptorial use of tentacles bearing nematocysts, the use of mucus as a trap, ciliary currents to carry the trapped particles to their mouth and the extrusion of mesenterial filaments through the mouth. However, coral reef ecosystems are highly transparent clear waters that support zooplankton and other particles. To assess the role of zooplankton in coral nutrition, Johannes and Tepley (1974), using time-lapse photography, concluded that no more than 10% of a coral reef's energy requirements are derived from this source, suggesting that zooxanthellae are the primary source of carbon for corals. On the other hand, zooplankton communities in coral reefs are mainly represented by a damsel population that hides within the reef during the day and emerges at night. Hence, random collections of zooplankton from such ecosystems may greatly underestimate their true abundance. Q3

From the foregoing discussion, it appears that zooplankton may be a major source of diet of highly voracious carnivorous corals. However, it is very unlikely that they provide more than a fraction of the metabolic needs of the whole community.

10.2.1.4 Ecosystem Function

Coral reefs primarily act as sinks for CO_2, which is accumulated as $CaCO_3$ that forms colossal substrates over millions of years and serve as a substrate for the settlement of myriad varieties of marine flora and fauna. Moreover, these structures act as a buffer for other coastal ecosystems and entire shorelines as they drastically reduce (by up to 95%) the insidious effects of waves and surges. Corals are filter feeders that enhance the water quality of near-shore waters by consuming large quantities of suspended particulate matter. Coral-associated symbiotic bacteria convert molecular nitrogen in water to nitrogenous products that are taken up by reef-associated plants, which are grazed upon by herbivores, thereby allowing N_2 to enter the food web (Figure 10.4 illustrates key components of a coral reef ecosystem). Corals themselves serve as food for invertebrates and fishes, whose calcareous faecal pellets either settle at the bottom or are carried off by waves and currents to adjacent ecosystems, where they contribute to the beach sands. Coral reefs are havens for commercially important fish and invertebrates and thus support large-scale artisanal as well as mechanized fisheries. Moreover, corals are exploited for limestone, jewellery and medicinal purposes. Coral reefs are tourist attractions and thus make it possible to generate valuable foreign exchange.

10.2.2 Estuaries

Pritchard (1967) defined an estuary as ‘a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage’. Estuaries are one of the most complex and dynamic ecosystems, with high variability leading to stressful environments. These environments acts as buffer zones between freshwater and seawater, subjected to the dilution of seawater depending upon the density gradient and basin morphology. Estuaries form an excellent area for nutrient traps and are highly productive. These are enriched by sewage effluents and agricultural runoff.

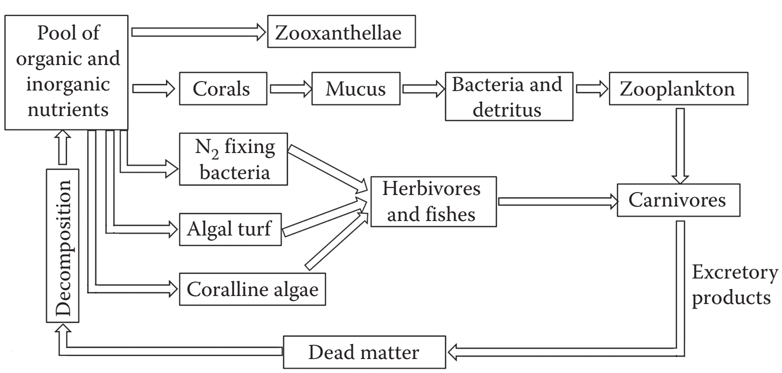

FIGURE 10.4
Schematic diagram of various abiotic and biotic constituents of a coral reef ecosystem.

Biotic communities in estuarine ecosystems are mainly euryhaline and are referred to as transitional/opportunistic species. The number of species living in estuarine environments/ecosystems is significantly less than in marine or freshwater habitats. Further, most truly estuarine organisms are derived from marine regimes owing to fluctuating salinity, which requires a certain kind of physiological specialization to survive; however, most estuaries do not have a sufficiently long geological history to permit the development of completely estuarine fauna.

10.2.2.1 Types

10.2.2.1.1 Mixed Estuaries

In mixed estuaries, the tidal flow is moderate (partially mixed) to strong (well mixed), and salinity generally decreases away from the mouth. Based on tidal amplitude, Goan estuaries exhibit partially mixed behaviour during the non-monsoonal period (Unnikrishnan and Manoj, 2007).

10.2.2.1.2 Stratified Estuaries

Stratified estuaries are formed when riverine flow is stronger than the incoming tide. Goan estuaries exhibit this behaviour at the mouth during the Southwest monsoon season, when freshwater input greatly exceeds tidal flow, resulting in the formation of sand banks at estuarine mouths (Qasim, 2003).

10.2.2.2 Salinity Adaptations (Osmosis)

Estuarine fauna exhibit two different approaches, namely osmoconformation (isoosmotic body fluids) and osmoregulation (use of specialized organs), to overcoming salinity fluctuations in their ambient environment. In lower animal phyla such as Cnidaria, Ctenophora and Echinodermata, the internal osmolarity of body fluids is almost equal to the surrounding seawater. In contrast, other invertebrates, such as annelids, crustaceans and molluscs, possess specialized organs that regulate the internal salt concentration. In shelled molluscs, the mantle cavity is hermetized (waterproofed), while at the same time changes occur in protein and RNA synthesis, and osmotic and volume regulation is carried out by intracellular amino acids and inorganic ions. Moreover, exposure to extreme salinity triggers the closure of shells and burrowing in the substratum (Berger and Kharazova, 1997). In crustaceans, osmoregulation is triggered by neuro-endocrinal secretions that control filtration by specialized organs such as metanephridia. Moreover, their embryos develop in pouches and cyst envelopes, and eggs are exposed to the external environment to become acclimatized to ambient salinity (Charmantier and Charmantier-Daures, 2001). Several sharks employ both osmoconformation and ion regulation through their rectal gland. Marine teleostean fishes possess hypotonic internal fluids; hence ion concentration is regulated through the removal of salt ions by mitochondria-rich chloride cells located in gills. Their kidneys produce concentrated urine, and the gastrointestinal tract compensates for salt loss through continuous uptake by drinking seawater and feeding. Estuarine gobies and mudskippers possess well-vascularized skin that undertakes active ion transport (Marshall and Grosell, 2006). Moreover, they are highly mobile and undertake three types of migration to overcome salinity fluctuations in estuaries, namely offshore release of eggs, larval migrations to inshore nursery areas and regular non-reproductive migrations (shelter and foraging) between freshwater and seawater (Pittman and McAlpine, 2001).

10.2.2.3 Biotic Structure

Most of the estuarine fauna is mainly derived from the seawater regime and categorized as euryhaline, i.e. they tolerate salinity down to 5 parts per thousand (ppt). Truly estuarine species are found in a salinity range of 15–18 ppt and are not found either in marine or freshwater. Estuarine fauna are dominated by polychaetes, oysters, clams, crabs and shrimps. Goan estuaries are known to harbour diverse assemblages of benthic, epibenthic and pelagic fauna (Parulekar et al., 1980; Ansari et al., 1995), including several rare species (Padate et al., 2010b; Hegde et al., 2013). A recent study by Padate (2010) reported 134 taxa of epibenthic and pelagic fauna, including 5 elasmobranchs, 100 teleosts, 2 gastropods, 24 crustaceans, 2 sea snakes and 1 cnidarian from the mouth regions of the Mandovi and Zuari estuaries. Among these, some of the estuarine genera may be limited to the seaward side not by physiological tolerances but by biological interactions such as competition and predation. Therefore, the species composition of any given estuary may not be easily defined. Much of these species have their origin in freshwater and cannot tolerate salinity above 5 ppt, thereby limiting themselves to the upper stretch of the estuary. These include the freshwater puffer *Tetraodon fluviatilis fluviatilis* (Padate et al., 2013a) and the shrimps of the palaemonid genus *Macrobrachium* (Padate, 2010). Transitional opportunistic species include migratory species those crossed over in an estuary either for breeding or nursery purposes (e.g. elasmobranchs, eels, ariid catfishes, snappers, sciaenids) (Padate, 2010). This also includes a few organisms that spend part of their life in the estuary, particularly crabs of the genus *Scylla* (Padate et al., 2013b).

Much of the estuarine productivity in recent times has been strongly influenced by eutrophication, mainly caused by increased use of artificial nitrogen fertilizers and anthropogenic activities associated with shoreline development. Goan estuaries are prone to ore spillage originating from iron ore mining in the hinterland and barge traffic along estuarine channels. These activities generate excessive amounts of human waste, leading to water-quality deterioration, whereas the activities pertaining to shoreline development, particularly removing natural vegetation, lead to the replacement of natural vegetation by weedy algae.

10.2.3 Mangrove Wetlands

Mangroves are morphologically and physiologically diversified, highly evolved plant communities that cover 60%–75% of Earth's coastlines. The unique features of a mangrove community are shallow root systems, thick leaves and aerial biomass. Overall, 53 true species of mangroves have been reported worldwide, and the criteria adopted to distinguish these communities are complete fidelity to a mangrove environment, possession of morphological specializations such as aerial roots and viviparity, ability to establish in a wide range of substrates and synchronization with the local hydrological regime. These communities are distributed in tropical and subtropical ecosystems where the water temperature exceeds 24°C. The best luxuriant growth of these species occurs in the Asian region, particularly along the Indo-Malaysian range. Besides these, Sunderbans in India and part of Bangladesh also form ideal sites for the establishment of these species.

In India, mangroves occupy an area of about 6740 km^2 representing about 7% of global mangrove cover. The east coast of India, including Sunderbans, Bhitarkanika wildlife sanctuary, Andaman and Nicobar Islands and the estuarine belts of Mahanadi, Godavari, Krishna and Kaveri, account for about 80% of India's total mangrove cover. In contrast, the west coast of India from Kachchh to Kerala contributes only 20%. The limited distribution of mangroves along the west coast is mainly due to the peculiar coastal structure and the nature of estuaries formed by non-perennial rivers (except Narmada and Tapti). The aforementioned conditions do not support the establishment of these communities.

Mangrove vegetation occurs from the highest level of spring tide to mean tide level. These are protected areas or sheltered shores formed by reduced wave action. Additionally, mangroves occur in fully saline conditions as well as banks of estuaries. Crabs, molluscs and other invertebrates are permanent inhabitants, whereas migratory shrimp and fishes move in and out with the tides. The upper canopy of mangroves supports a rich diversity of insects, insectivorous fauna and piscivorous birds.

10.2.3.1 Primary Production

High incident solar radiation and the ability of mangroves to take up freshwater from seawater are the major factors that enable primary production in mangrove areas. The role of phytoplankton biomass in such aquatic ecosystems is believed to be of lesser significance. In mangrove ecosystems, the gross primary productivity is approximately 8 g C m^{-2} day^{-1}. However, total respiration is almost of a similar level. It has been estimated that the export of particulate matter from such ecosystems is around 1.1 g C m^{-2} day^{-1}. Miller (1972) prepared a detailed model of leaf production in terms of solar radiation, associated temperature, transpiration, respiration and gross and net photosynthesis in illuminated and shaded zones and found that leaf water stress induced stomatal closure at the top of the canopy on a bright clear sunny day such that maximum production occurred in the middle of the canopy, and they further emphasized that mangroves are of great importance compared to phytoplankton biomass in some nutrient-deficient tropical waters.

10.2.3.2 Heterotrophic Production

In a mangrove ecosystem, about 5% of the mangrove leaf is directly consumed by potential grazers, and the remaining 95% enters the aquatic environment as debris (Figure 10.5 depicts pathways of energy flow through the mangrove trophic web). An estimation of the biochemical composition of a leaf on a tree suggests that it contains 6.1% protein on a dry weight basis, whereas a fallen leaf has 3.1% protein on a dry weight basis. This leaf that has fallen in seawater, over a period of time, is subject to decomposition, and the detrital particles get enriched with organic matter, and after a period of about 12 months, the protein content increases to about 22%. This forms a nutritious food source for the majority of inhabitants mediated through bacterial protoplasm (Heald, 1969). Further, to explain the importance of detritus in fish and invertebrate diets, Heald analyzed the stomach contents of 10,000 individuals and defined a detritus consumer as a species whose digestive tract contains on average 20% of vascular plant detritus by volume on an annual basis. Using these criteria, he reported that about 33% of the species represented mainly by fishes, polychaete worms, crabs, chironomid worms and crustaceans such as cumaceans, copepods and mysids were detritus consumers.

10.2.3.3 Life Cycle

Mangroves exhibit a unique reproductive strategy wherein seeds germinate on trees and drop into the water. Seedlings are dispersed by water, and the embryo continuously develops, grows with the parent tree and may even fall after 3–4 years. The floats on the seed act as a buoy, and therefore the seed floats upright when water levels are high due to tidal inundation. As the tide recedes, the upright seed, owing to the decrease in water level,

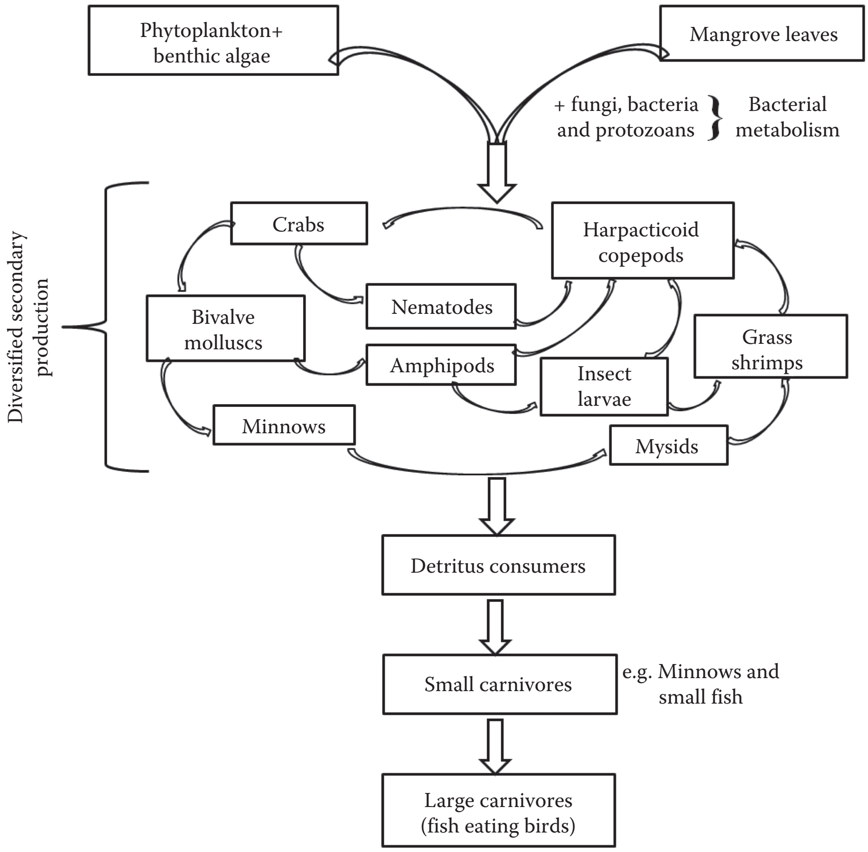

FIGURE 10.5
Schematic diagram of heterotrophic production in a mangrove ecosystem.

touches the bottom and, over a period of time, develops roots and leaves and continues to grow (Figure 10.6 illustrates different stages in the life cycle of a mangrove species).

10.2.3.4 Adaptations

10.2.3.4.1 Salinity

Mangroves are facultative halophytes, which means that salt is not essential for their growth. However, growth in seawater is advantageous owing to a lack of competition. It is pertinent that only a limited number of vascular plants have invested evolutionary energy to adapt to intertidal areas. Although an adaptation, it is noteworthy that these species of vascular plants might be expending some energy to overcome stress in these areas such that they derive an advantage of 'no competition' in such environments. These species exhibit various approaches to and methods of withstanding these environmental anomalies. Mangrove genera such as *Rhizophora* and *Bruguiera* prevent much of the salt from entering body tissue through filtration at the root level. About 90% of the salt is excluded through roots, as evidenced by the high concentration (up to 97%) of salts near the roots. In *Sonneratia*, the plants prevent water loss through the closure of stomatal openings. This is noticed in areas with reduced availability of freshwater coupled with a changing portion

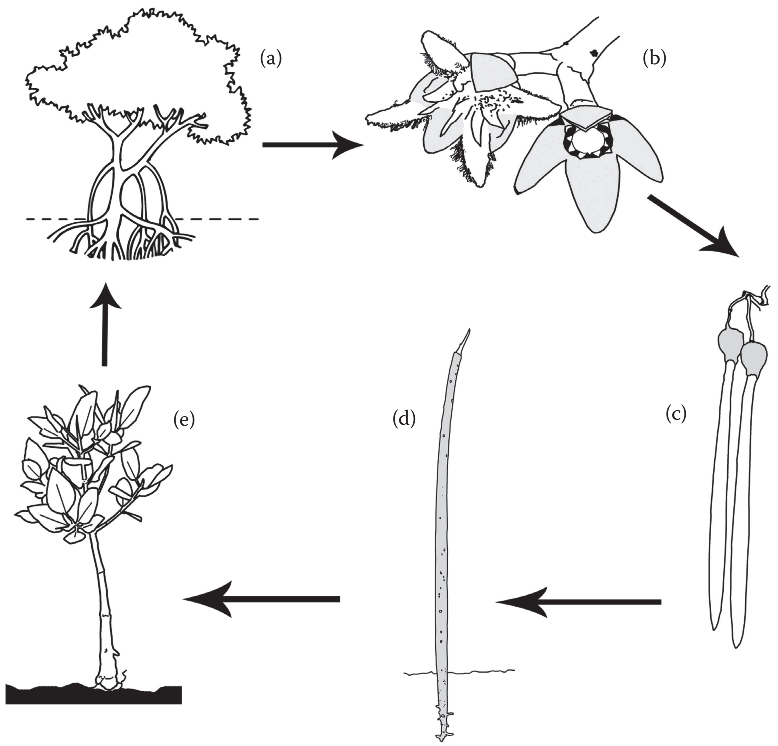

FIGURE 10.6
Life cycle of mangrove species *Rhizophora mucronata*: (a) tree; (b) flowers; (c) fruits and seedlings; (d) germination; (e) young plant.

of the leaf with respect to solar radiation. In *Acanthus*, the plants concentrate salt in the old leaf or bark by forming crystals on the leaf, which are carried and then dropped.

10.2.3.4.2 Water-logged Conditions

In the normal tidal rhythm, the partial pressure of oxygen (O_2) falls when air roots are submerged in the water. The lenticels are hydrophobic under submergence and are effectively closed, preventing entry of air and water. On the other hand, respiration takes up oxygen from air spaces and releases carbon dioxide (CO_2). CO_2 thus released is readily soluble in water and is not effective at replacing the volume of O_2 removed; in this way, the gas pressure within the roots is reduced. This was confirmed by direct measurement of the gas composition in submerged *Avicennia* spp. Consequently, once the roots are covered by the tide, the O_2 level therein falls and the CO_2 level does not increase to compensate for the pressure fall because it is readily soluble in water. For this reason, a negative pressure develops in the air spaces during submergence. Therefore, when the tide recedes and the lenticels are reopened, there is a relatively rapid inhalation of air as gaseous pressure is equalized through lenticels.

10.2.4 Sandy Shores

Sandy shores, intertidal sand flats and protected sand flats are common along the world's coastlines and are better known to human population as sites for recreation. Exposed sandy beaches are devoid of macroscopic life because the environmental conditions are adverse and do not support such species. On the other hand, protected sand flats are densely populated with large numbers of macro-organisms.

10.2.4.1 Grain Size and Beach Profile

Grain size on a sandy beach is affected by wave action and varies with the beach and the season. In tropical environments, the profile of a beach depends on the season. During light wave action particles are fine, whereas heavy wave action leads to coarser particles or gravel beds. The importance of particle size to organism abundance and distribution depends on water retention capacity and suitability for burrowing. The finer particle size through capillary action retains water in the interstitial spaces when the tide recedes, whereas coarser particles allow the water to drain quickly. Protected sand flats are seasonally variable and consist of fine grain sand. In such ecosystems, wind is a function of the size of the water body, and therefore the effect of wind and wave action is less important.

Sand and gravel particles are small and unstable. As a wave strikes the shore, it picks up certain particles, keeps them in suspension and redeposits them elsewhere. Hence, the particles are constantly removed and redeposited, causing wave-induced substrate movement. During high wave action, coarser particles dominate because most of the finer particles are kept in suspension and carried away, allowing coarser particles to settle. Most beaches at the high-water mark support coarser particles, whereas the low-water mark is dominated by finer particles. This suggests that the wave energy on a beach is closer to the high-water mark where waves break and is farther from the low-water mark where the increasing depth reduces the impact of wave action. Hence the substrate itself is in the motion regulated by wave action, so any change in the wave intensity would change not only the grain size but also the profile of the beach.

10.2.4.2 Adaptations

Biological communities occurring in such unstable environments are bestowed with a variety of adaptations categorized under two major types:

1. Burrowing deep in the substrate such that the depth of the sediment is not affected by passing waves (e.g. clam, *Tiavela sturdoran*). Deep-burrowing organisms possess heavy shells that help them to retain in sediments and possess long siphon tubes that enable feeding.
2. Ability to burrow very quickly such that a passing wave does not remove the animal from the substrate (e.g. annelid worms, sand crabs). Among these organisms, the limbs are highly modified to dig wet sand quickly. They burrow quickly before wave motion carries them offshore.

Other adaptations among sandy shore organisms are smooth shells (clams) that reduce resistance to burrowing in sand. A few gastropod shells (e.g. *Trochus* spp.) possess special ridges that make it possible to grip in the sediments, whereas in some onshore echinoderms the spines are reduced. A special adaptation noticed in the sand dollar (*Dendraster excentricus*) is an iron compound that accumulates in a special area of the digestive tract referred to as a 'weight belt' that enables the organism to stay down during wave action.

10.2.4.3 Biotic Communities

Much of the biota present along sandy shores is mainly composed of algae (e.g. *Ulva, Enteromorpha, Sargassum*), which are seasonally abundant and form clumps. Benthic diatoms of different forms are found attached to sand particles, whereas in protected sand flats diverse microflora, benthic diatoms, dinoflagellates and blue green algae form brownish or greyish film on sediments.

Sessile organisms like mussels, barnacles or oysters do not inhabit exposed sandy shores because there is no firm substrate for attachment. Moreover, they do not have access to food sources, as evidenced by the fact that there is little or no primary productivity generated in this ecosystem. Hence, most of the animal communities in this zone depend for food on phytoplankton brought by seawater, organic debris brought by waves and the consumption of other beach animals.

However, intertidal sand flats support a variety of polychaete worms, nematodes, bivalves, molluscs and crustaceans. Primary productivity is confined to microfilms and epiphytes. However, 90%–95% of epiphytes add to the detritus. The distribution of carnivores is relatively smaller and is mainly dominated by suspension or detritus feeders (e.g. crabs, bivalves). The sandy shores of Goa harbour only a few brachyura such as *Ocypoda* and *Dotilla* and Anomura such as *Emerita*.

10.2.5 Rock Patches

The rocky intertidal zone, with its hard substratum, is densely populated by microbes and shows a great diversity of plants and animals, in contrast to sandy and muddy shores, which appear to be barren.

10.2.5.1 Physical and Biological Factors

Zonation along the rocky shore is mainly determined by physical and biological factors.

1. *Physical factors*:
    a. *Tidal exposure/amplitude*: This is exclusively determined by the tide, reflecting the tolerance of organisms to increasing exposure, the resultant desiccation and temperature extremes. However, the disadvantage is that the rise and fall of a tide follows a smooth pattern with no sudden breaks, and therefore it is the tide level that determines the extent of occurrence of an organism near the high-water mark. The critical tide level is defined as the maximum change in exposure time with very short vertical movement. However, this hypothesis does not apply at low tide levels, owing mainly to the diverse topography and variations in exposure time. This suggests that the upper limit for an organism to occur in a particular location is set by physical factors such as temperature and desiccation. The temperature is found to act as a synergist along with desiccation, causing mortality of the biological community. The role of solar radiation, although not very clearly understood, suggests that ultraviolet radiation has deleterious effects on living cells. Light, on the other hand, also regulates the distribution of intertidal algae because the absorption spectra of light vary with depth. However, under natural conditions, a mixture of intertidal algae is exported, suggesting that their distribution is mainly regulated by the interaction of other factors and by the physiology of algae. Q4

2. *Biological factors*: The role of biological factors in regulating the biological communities along rocky shores tends to be more complex, and those factors are closely related to each other.

   a. *Competition*: Intertidal rocky shores constitute only 0.003% of the world's total marine ecosystems, suggesting that one of the limited resources in this ecosystem is a restricted area, and therefore, there is increased competition for space, causing densely populated habitats. Along intertidal rocky shores, primarily based on the time of the spawning season, the recruitment of a particular species is likely to occur. Among these, the small barnacle *Chthalamus stellatus* is known to be recruited first and occupy the highest zone, followed by *Balanus balanoides*, which occupies the mid-intertidal zone. The reason for the disappearance of *C. stellatus* from mid-littoral region is mainly due to competition from *B. balanoides*, which either overgrows or uplifts or crushes the young *Chthalamus* species. In the higher zone, however, *B. balanoides* cannot evict *Chthalamus* outright because it cannot tolerate the high temperatures in the upper zone – a case of partial function of biological competition. A complex case of competition is seen among mussels and several species of barnacles – a dominant competitor for space. Given enough time and freedom from potential predators, these species overgrow and outcompete all other organisms and take over the complete substrate throughout the intertidal zone. However, this is a slow process. The availability of empty space facilitates rapid colonization by barnacles, which persist until mussels enter. Once the mussels enter, they outcompete and destroy barnacles by settling on top of them because they are competitively superior. As long as they remain in the intertidal zone, they control the space. However, because these species are filter feeders/suspension feeders, they survive and grow well in subtidal environments. But these species do not occur in subtidal ecosystems, and this fact is explained by another biological factor.

   b. *Predation*: The dominant species in the intertidal zone are mussels followed by barnacles. Barnacles, despite being competitively inferior to mussels, occur mainly because of predatory sea stars, *Pisaster ochraceus*, which prefer preying upon mussels, thereby preventing them from completely outgrowing barnacles and preventing mussels from occupying the entire space. Simultaneously, barnacles occur as individuals or in clumps in the intertidal zone owing to predation by predatory gastropods (*Nucella* spp.), which regulate the population in the narrow bend of the upper subtidal zone. However, they do not proceed towards higher water mark because their movement is restricted by excessive desiccation. Regulation of *Nucella* (and mussels) is also carried out by *P. ochraceus*, which acts as the top predator, controlling and regulating the structure of the entire community; hence, they are often referred to as the keystone species.Along the upper intertidal zone, no predation is seen mainly because both *P. ochraceus* and *Nucella* feed only during high tide and need long periods of submergence to attack their prey. Moreover, they cannot withstand the high temperatures and desiccation problems in the upper intertidal zone. The main theme of intertidal ecology is that wherever predation is absent, competition is greater.

   c. *Grazing*: The animal communities comprised of gastropods, molluscs, crustaceans, sea urchins and fishes exclusively graze upon intertidal algae and affect algal zonation, species diversity, patchiness and succession through recolonization creates open space and altered physical conditions.

Q5

d. *Larval settlement*: The recruitment of invertebrate communities in these ecosystems is a function of algal film and favourable environmental conditions, and therefore the zonation pattern is structured by larval choice. Larval recruitment and settlement in such environments vary with space and time. Under favourable conditions, heavy recruitment leads to increased competition, predation and probably changes in adult population and community structure. Therefore, the same area may harbour communities that not only differ in composition over time but also change in relative numbers of individuals. Hence, these factors play an important role in determining community structure in such ecosystems.

10.2.5.2 Zonation Pattern

Zonation along rocky shores is mainly characterized by colour, morphology or a combination of both. The vertical extent of zonation is mainly regulated by the slope of the shore, tidal range and exposure to wave action. However, zonation reported from different places mainly depends upon region and local topography.

10.2.5.3 Adaptation

Algal populations subject to increased grazing intensity have developed a few defence mechanisms. A few algae have developed an ability to deposit $CaCO_3$ in their tissues (*Halimeda* spp.), whereas others develop woody tissue (*Egregia* spp.) upon maturity that reduces palatability. Further, a few species have also developed an ability to defend themselves by chemical means, accumulating toxic compounds. *Desmarestia* species from Pacific coast accumulates sulfuric acid that is sufficient to erode the $CaCO_3$ teeth of a potential grazer, *Strongylocentrotus franciscanus*. A few other algal species have developed an ability to produce alkaloids, phenolic compounds and halogenated metabolites. A few species have also developed the ability to overcome grazing pressure through natural history. A few species (*Microcystis* spp.) are known to have a low crust with a slow growth rate and high grazing resistance, whereas a few species have an upright frondose form with a high growth rate and low grazing resistance (seagrasses).

Rocky-shore organisms are intermittently exposed and therefore have developed strategies to avoid desiccation. This includes shell closure by shelled molluscs and barnacles during low tide, burrowing by crabs and other invertebrates in the soft substratum and hiding beneath rocks, between crevices or within rock cavities. These strategies also protect these organisms from predation and secondarily from wave action that causes them physical damage by dislodging them from the substratum and even harming essential vital organs.

10.2.5.4 Species Diversity

Rocky shores are among the most complex ecosystems and have diverse floral and faunal assemblages. Thin microalgal films support diverse microbial flora, which serve as food for a wide array of larval invertebrates. Primary consumers include filter feeding sedentary invertebrates (barnacles) and grazers (sea urchins). Predators such as brachyuran crabs (families Eriphiidae, Pilumnidae, Xanthidae, Grapsidae and Portunidae) and birds constitute the higher tier of the rocky-shore food web, whereas scavengers such as holothurians enable recycling of decomposed matter into the food web.

TABLE 10.1

Q6 New Records of Coastal Macrofaunal Species along with Their Habitats from Goa, West Coast of India

Sr. No.	Species	Habitat
1	*Charybdis (Charybdis) goaensis* (Padate et al., 2010)[a,f]	Sandy
2	*Callionymus sublaevis* (McCulloch, 1926)[b,g]	Rocky/coral reef
3	*Thysanophrys armata* (Fowler, 1938)[b,g]	Sandy/silt
4	*Hydatina velum* (Gmelin, 1791)[b,h]	Sandy/rocky
5	*Raphidopus indicus* (Henderson, 1893)[b,h]	Soft muddy/sandy
6	*Scylla olivacea* (Herbst, 1796)[c,h]	Mangrove/muddy
7	*Charybdis (Charybdis) variegata* (Fabricius, 1798)[b,h]	Sandy
8	*Hexapus estuarinus* (Sankarankutty, 1975)[b,i]	Sandy bottom
9	*Caesio cuning* (Bloch, 1791)[d,h]	Coral reef
10	*Stomopneustes variolaris* (Lamarck, 1816)[b,h]	Rocky
11	*Haustellum* (*Vokesimurex*) *malabaricus* (Smith, 1894)[b,i]	Sandy bottom
12	*Morula anaxeres* (Kiener, 1835)[e,i]	Sandy/rocky
13	*Trigonostoma scalarifomis* (Lamarck, 1822)[b,i]	Sandy bottom
14	*Cistopus indicus* (Orbigny, 1840)[b,i]	Muddy bottom
15	*Parapenaeopsis maxillipedo* (Alcock, 1905)[b,i]	Muddy/mangrove
16	*Macrobrachium equidens* (Dana, 1852)[b,i]	Sandy/estuary
17	*Thalassina anomala* (Herbst, 1804)[b,i]	Muddy/mangrove
18	*Diogenes miles* (Fabricius, 1787)[b,i]	Muddy bottom
19	*Clibanarius infraspinatus* (Hilgendorf, 1869)[b,i]	Sandy/soft silt
20	*Diogenes alias* (McLaughlin and Holthuis, 2001)[b,i]	Sandy/muddy/coral reef
21	*Albunea symmysta* (Linnaeus, 1758)[b,i]	Sandy bottom
22	*Harpiosquilla raphidea* (Fabricius, 1798)[b,i]	Sandy/soft clay
23	*Philyra globus* (Fabricius, 1775)[b,i]	Sand/silt
24	*Schizophrys aspera* (H. Milne Edwards, 1834)[b,i]	Rocky
25	*Himantura walga* (Müller and Henle, 1841)[b,i]	Sandy bottom
26	*Himantura gerrardi* (Gmelin, 1789)[b,i]	Sandy/rocky/coral reef
27	*Himantura marginata* (Blyth, 1860)[b,i]	Sandy reef
28	*Neotrygon kuhlii* (Müller and Henle, 1841)[b,i]	Sandy/rocky/coral
29	*Aetobatus flagellum* (Bloch and Schneider, 1801)[b,i]	Sandy/rocky
30	*Rhinobatos obtusus* Müller and Henle, 1841)[b,i]	Sandy/muddy
31	*Ilisha sirishai* (Rao, 1975)[b,i]	Pelagic/euryhaline
32	*Thryssa setirostris* (Broussonet, 1782)[b,i]	Sandy/rocky/seagrass
33	*Thryssa mystax* (Bloch and Schneider, 1801)[b,i]	Sandy/rocky/coral
34	*Hyporhampus limbatus* (Valenciennes, 1847)[b,i]	Muddy/mangrove/estuary
35	*Hippocampus kuda* (Bleeker, 1852)[b,i]	Mangrove/rocky/estuary
36	*Apogon fasciatus* (White, 1870)[b,i]	Sandy/muddy bottom
37	*Archamia bleekeri* (Günther, 1859)[b,i]	Muddy/clay
38	*Scomberoides commersonnianus* (Lacepede, 1801)[b,i]	Pelagic coral
39	*Trachinotus mookalee* (Cuvier, 1832)[b,i]	Coral reef
40	*Heniochus acuminatus* (Linnaeus, 1758)[b,i]	Rocky/coral
41	*Drepane longimana* (Linnaeus, 1758)[b,i]	Sandy/rocky/coral
42	*Platax teira* (Forsskål, 1775)[b,i]	Coral reef
43	*Gerres erythrourus* (Bloch, 1791)[b,i]	Sandy
44	*Gerres longirostris* (Lacepede, 1801)[b,i]	Estuary/mangrove
45	*Gazza minuta* (Bloch, 1795)[b,i]	Sandy/silt
46	*Leiognathus brevirostris* (Valenciennes, 1835)[b,i]	Sandy/rocky

(*Continued*)

TABLE 10.1 (*Continued*)

New Records of Coastal Macrofaunal Species along with their Habitats from Goa, West Coast of India

Sr. No.	Species	Habitat
47	*Monodactylus argenteus* (Linnaeus, 1758)[b,i]	Estuary/mangrove
48	*Upeneus tragula* (Richardson, 1846)[b,i]	Coral reef
49	*Nemipterus bipunctatus* (Valenciennes, 1830)[b,i]	Rocky/coral reef
50	*Parascolopsis townsendi* (Boulenger, 1901)[b,i]	Sandy/soft bottom
51	*Pempheris molucca* (Cuvier, 1829)[b,i]	Coral reef/rocky
52	*Dendrophysa russelii* (Cuvier, 1829)[b,i]	Rocky
53	*Johnius amblycephalus* (Bleeker, 1855)[b,i]	Muddy soft bottom
54	*Johnius carutta* (Bloch, 1793)[b,i]	Muddy/estuary
55	*Johnius coitor* (Hamilton, 1822)[b,i]	Muddy/estuary
56	*Epinephelus coioides* (Hamilton, 1822)[b,i]	Coral/sandy/mangrove
57	*Epinephelus erythrurus* (Valenciennes, 1828)[b,i]	Rocky/coral reef
58	*Sparidentex hasta* (Valenciennes, 1830)[b,i]	Rocky/coral reef
59	*Pomadasys furcatus* (Bloch and Schneider, 1801)[b,i]	Soft bottom/coral reef
60	*Plectorhinchus gibbosus* (Lacepede, 1802)[b,i]	Rocky/coral reef
61	*Plectorhinchus schotaf* (Forsskal, 1775)[b,i]	Rocky/coral reef
62	*Yongeichthys criniger* (Valenciennes, 1837)[b,i]	Muddy/coral reef
63	*Parachaeturichthys polynema* (Bleeker, 1853)[b,i]	Muddy/coral reef
64	*Oxyurichthys paulae* (Pezold, 1998)[b,i]	Muddy/coral reef
65	*Callionymus japonicus* (Houttuyn, 1782)[b,i]	Sandy/coral reef
66	*Callionymus sagitta* (Pallas, 1770)[b,i]	Muddy/mangrove/estuary
67	*Eurycephalus carbunculus* (Valenciennes, 1833)[b,i]	Muddy bottom
68	*Cynoglossus dispar* (Day, 1877)[b,i]	Muddy bottom
69	*Synaptura albomaculata* (Kaup, 1858)[b,i]	Muddy bottom
70	*Brachirus orientalis* (Bloch and Schneider, 1801)[b,i]	Coral reef/sandy bottom
71	*Acreichthys hajam* (Bleeker, 1851)[b,i]	Coral reef
72	*Odonus niger* (Rüppell, 1836)[b,i]	Coral reef
73	*Diodon hystrix* (Linnaeus, 1758)[b,i]	Coral reef
74	*Lactoria cornuta* (Linnaeus, 1758)[b,i]	Rocky/coral/seagrass
75	*Triacanthus nieuhofii* (Bleeker, 1852)[b,i]	Sandy bottom
76	*Takifugu oblongus* (Bloch, 1786)[b,i]	Estuary/coral reef
77	*Arothron immaculatus* (Bloch and Schneider, 1801)[b,i]	Seagrass
78	*Tetraodon fluviatilis* fluviatilis (Hamilton, 1822)[b,i]	Estuary/muddy bottom
79	*Arius subrostratus* (Valenciennes, 1840)[b,i]	Muddy bottom
80	*Nemapteryx caelata* (Valenciennes, 1840)[b,i]	Muddy bottom
81	*Netuma bilineata* (Valenciennes, 1840)[b,i]	Muddy bottom
82	*Muraenesox bagio* (Hamilton, 1822)[b,i]	Estuary/mangrove
83	*Gymnothorax pseudothyrsoideus* (Bleeker, 1853)[b,i]	Coral reef/muddy bottom
84	*Trachinocephalus myops* (Forster, 1801)[b,i]	Sandy bottom/coral reef

Source: Hegde, M. R. et al. *Indian Journal of Geo-marine Sciences*, 42, 900–901, 2013. With permission.

[a] Padate et al. 2010a.
[b] Present study.
[c] Padate et al. 2012. Q7
[d] Padate et al. 2010b.
[e] Kumbhar and Rivonker, 2012. Q8
[f] New to science.
[g] New to Indian waters.
[h] New to west coast of India.
[i] New to Goa coast

10.3 Management of Coastal Resources

10.3.1 Need for Management

Goa, with a coastline of 105 km, is marked by varied habitats including reefs (Rodrigues et al., 1998), mangroves, mudflats, estuaries (Shetye et al., 2007) and sandy and rocky shores that support rich, diversified demersal assemblages (Rivonker et al., 2008). The importance of the Goa region with respect to demersal fishery potential has been emphasized by Rao and Dorairaj (1968).

10.3.1.1 Natural Factors

During the Southwest monsoon, the upwelled subsurface off the west coast of India brings hypoxic and even anoxic water over the shelf. But this water is generally prevented from surfacing owing to the presence of a thin (<10 m), warm, fresher layer that forms as a result of intense rainfall in the coastal zone. Off Goa, near-bottom oxygen concentrations reach suboxic levels in August, and complete denitrification is followed by the sulphate reduction in September. The quality and quantity of primary production are affected when suboxic waters ascend to the euphotic zone (Naqvi et al., 2009). The emigration of demersalfish from the shallow suboxic zone and frequent episodes of fish mortality, presumably caused by the surfacing of O_2-depleted water, affect fishery resources (Naqvi et al., 2009).

Moreover, enhanced productivity during the Southwest monsoon season often triggers blooms of phytoplankton, including several harmful algal species. The proliferation, development and subsequent senescence of these blooms result in water-quality deterioration with hazardous implications for the coastal and estuarine biota. Moreover, violent storms during this season also threaten some of the fragile coastal ecosystems.

10.3.1.2 Anthropogenic Interference

However, these coastal ecosystems are under constantly increasing threats from various anthropogenic inputs. The near-shore fishing grounds are subjected to intensive exploitation by mechanized and traditional fishing throughout the year, except a brief period during the Southwest monsoon. Discharge of untreated domestic sewage, synthetic fertilizers and industrial effluents, as well as incidental spillage of mineral ore through barge accidents into the bay-estuarine waters, has led to water-quality deterioration, resulting in an increased frequency of harmful algal blooms. Accidental oil spills and sinking of cargo vessels also cause widespread pollution of coastal habitats and interfere with ecosystem functioning. Recent development activities such as the expansion of existing port and jetty facilities, as well as rampant sand mining along estuarine channels, directly threaten the structural integrity of the estuarine habitats.

10.3.2 Approach

Modifications of the natural ecosystems, particularly those of anthropogenic origin, are deleterious for the health and functioning of these fragile ecosystems. This situation requires a holistic approach to acquiring deeper insight into the role of ecological processes that govern demersal species populations and, ultimately, regulate species distributions. This necessitates the creation of baseline data to understand the composition and nature of biological assemblages (animals, plants and microbes) within an ecosystem. Such an enterprise would involve long-term and intensive field surveys incorporating the collection of biological (primary production, species richness and abundance) and physico-chemical parameters (temperature, salinity, pH, dissolved oxygen, nutrient concentration). Analyses of these data and their comparison with existing published literature or global (and regional) databases would make it possible to make inferences about the variations in geochemical and biological processes regulating and, therefore, influencing the health of the concerned ecosystems. There is a need to study coastal processes that overcome the deterioration effect of changing land-use patterns and monsoonal sequences, thereby diluting their deleterious impacts on the diverse faunal assemblages. However, these constitute only the preliminary stages of a holistic strategy in the management of coastal resources and serve as guidelines to spread awareness among both the general public and government agencies to sensitize people to certain complex environmental issues as well impart specialized training in framing and implementing environmentally friendly regulations.

10.3.2.1 Public Awareness and Training

General awareness among the general public, particularly coastal human communities, regarding the complexity of coastal ecosystems and the resultant ecosystem function is vital. This will not only sensitize people to the fragility of the impacted coastal environments but also educate them about the benefits of environmentally friendly development for their means of earning a livelihood.

Awareness programmes conducted by local government departments and non-governmental organizations (NGOs) are the most common and effective means of imparting information (particularly NGOs) to the public from far-flung rural areas. These include thematic training workshops, seminars, group discussions and street exhibitions, as well as through print and television media. Among these, print and television media may be used to educate the general public about the perils of environmental deterioration on their livelihoods. Training workshops, seminars and group discussions take things a step further towards capacity-building measures aimed at the direct involvement of the general public in the conservation and sustainable management of environmental resources.

10.3.2.2 Legal Regulations and Implementation

Numerous legal regulations, such as the Wildlife (Protection) Act of 1972, the Forest (Conservation) Act of 1980, the Environmental (Protection) Act of 1986 and the Biological Diversity Act of 2002 have been promulgated to forward the cause of conservation of endangered natural habitats. Furthermore, the Ministry of Environment and Forests, Government of India, issued special Coastal Regulation Zone notifications in 1991 to impose restrictions on changes in land-use patterns, including urbanization, industrialization and mining in ecologically sensitive coastal regions, as well as prohibit any activities endangering coastal ecosystems. To protect larger areas of natural marine and coastal habitats inclusive of human communities, the government has declared three ecologically sensitive areas – the Gulf of Mannar, Sundarbans and the Nicobar Islands – to be Marine Biosphere Reserves that fall under Category V protected areas of the International Union for Conservation of Nature (IUCN). In addition, there are four marine national parks (two on Andaman and Nicobar Islands and one each in Gujarat and West Bengal) that fall under Category II of the IUCN.

Implementation of the aforementioned legislation is achieved through various central and state government agencies such as the Ministry of Environment and Forests, the respective state forest departments and biodiversity boards that strive not only to conserve coastal living resources but also protect indigenous knowledge of these resources. The state biodiversity boards operate at regional and local levels for the regulation and conservation of local resources with the aim of attaining sustainable utilization. The state biodiversity boards are mainly governed by national guidelines imposed from time to time.

Acknowledgements

The authors are grateful to the Ballast Water Management Programme, India, carried out by the National Institute of Oceanography (CSIR), India, for the Directorate General of Shipping, Ministry of Shipping, Government of India. MRH and DTV acknowledge the University Grants Commission and Council of Scientific and Industrial Research (CSIR) respectively for funding their research. Thanks are also due to the registrar, Goa University, for providing the necessary facilities.

References

Agren, G. I. and Bosatta, E. 1996. *Theoretical Ecosystem Ecology: Understanding Element Cycles*. New York: Cambridge University Press.

Ansari, Z. A., Chatterji, A., Ingole, B. S., Sreepada, R. A., Rivonkar, C. U. and Parulekar, A. H. 1995. Community structure and seasonal variation of an inshore demersal fish community at Goa, west coast of India. *Estuarine, Coastal and Shelf Science* 41:593–610.

Berger, V. J. and Kharazova, A. D. 1997. Mechanisms of salinity adaptations in marine molluscs. *Hydrobiologia* 355:115–126.

Charmantier, G. and Charmantier-Daures, M. 2001. Ontogeny of osmoregulation in crustaceans: The embryonic phase. *American Zoologist* 45:1078–1089.

Golley, F. B. 1993. *A History of the Ecosystem Concept in Ecology: More Than the Sum of the Parts*. New Haven/London: Yale University Press.

Goreau, T. F. and Goreau, N. I. 1959. The physiology of skeleton formation in corals. II. Calcium deposition by hermatypic corals under various conditions in the reef. *The Biological Bulletin* 117:239–250.

Heald, E. J. 1969. The production of organic detritus in a South Florida estuary. *PhD Diss*., University of Miami, Florida.

Hegde, M. R. and Rivonker, C. U. 2013. A new record of *Temnopleurus decipiens* (de Meijere, 1904) (Echinoidea, Temnopleuroida, Temnopleuridae) from Indian waters. *Zoosystema* 35:97–111.

Hegde, M. R., Padate, V. P., Velip, D. T., and Rivonker, C. U. 2013. An updated inventory of new records of coastal macrofauna along Goa, west coast of India. *Indian Journal of Geo-marine Sciences* 42:898–902.

Holling, C. S. 1995. What barriers? What bridges? In: *Barriers and Bridges to the Renewal of Ecosystems and Institutions*, ed. L. H. Gunderson, C. S. Holling, and S. S. Light, 3–34. New York: Columbia University Press.

Johannes, R. E. and Tepley, L. 1974. Examination of feeding of the reef coral *Porites lobata* in situ using time lapse photography. *Proceedings of the Second International Coral Reef Symposium* 2:127–131.

Jones, C. G. and Lawton, J. H. 1995. *Linking Species and Ecosystems*. New York: Chapman and Hall.

Kulkarni, S. S., Rivonker, C. U., and Sangodkar, U. M. X. 2003. Role of meio-benthic assemblages in detritus based food chain from estuarine environment of Goa. *Indian Journal of Fisheries* 50:465–471.

Likens, G. E. 1992. *Excellence in Ecology, 3: The Ecosystem Approach: Its Use and Abuse*. Oldendorf/Luhe (Germany): Ecology Institute

Madhupratap, M., Nair, K. N. V., Gopalakrishnan, T. C., Haridas, P., Nair, K. K. C., Venugopal, C., and Gauns, M. 2001. Arabian Sea oceanography and fisheries of the west coast of India. *Current Science* 81:355–361.

Marshall, W. S. and Grosell, M. 2006. Ion-transport, osmoregulation, and acid-base balance. In: *The Physiology of Fishes Third Edition*, ed. D. H. Evans and Claiborne, J. B., 179–196. Boca Raton: CRC Press.

Miller, P. C. 1972. Bioclimate, leaf production and primary production in red mangrove canopies in South Florida. *Ecology* 53:22–45.

Modassir, Y. and Sivadas, S. 2003. Conservation and sustainable management of molluscan resources along Goa coast, Central West coast of India. In: *Recent Advances in Environmental Science*, ed. K. G. Hiremath, 399–421. New Delhi: Discovery Publishing House.

Naqvi, S. W. A., Naik, H., Jayakumar, A., Pratihary, A. K., Narvenkar, G., Kurian, S., Agnihotri, R., Shailaja, M. S., and Narvekar, P. V. 2009. Seasonal anoxia over the western Indian continental shelf. In: *Indian Ocean Biogeochemical Processes and Ecological Variability*, ed. J. D. Wigget, R. R. Hood, S. W. A. Naqvi, K. H. Bink, and S. L. Smith, 333–345. Washington, D. C. American Geophysical Union.

Odum, H. T. and Odum, E. C. 2000. *Modeling for all Scales: An Introduction to System Simulation*. San Diego, California: Academic Press.

Padate, V. P. 2010. Biodiversity of demersal fish along the estuarine–shelf regions of Goa. *Ph.D. Thesis*, Goa University.

Padate, V. P., Rivonker, C. U., and Anil, A. C. 2010a. A note on the occurrence of reef inhabiting, red-bellied yellow tail fusilier, *Caesio cuning* from outside known geographical array. *Marine Biodiversity Records* 3:1–6.

Padate, V. P., Rivonker, C. U., Anil, A. C., Sawant, S. S., and Venkat, K. 2010b. A new species of portunid crab of the genus *Charybdis* (De Haan, 1833) (Crustacea: Decapoda: Brachyura) from Goa, India. *Marine Biology Research* 6:579–590.

Padate, V. P., Rivonker, C. U., Anil, A. C., Sawant, S. S., and Venkat, K. 2013a. First record of the freshwater puffer *Tetraodon fluviatilis fluviatilis* from the coastal waters of Goa, west coast of India. *Indian Journal of Geo-marine Sciences* 42:466–469.

Padate, V. P., Rivonker, C. U., and Anil, A. C. 2013b. A new record of *Scylla olivacea* (Decapoda, Brachyura, Portunidae) from Goa, central west coast of India – A comparative diagnosis. *Indian Journal of Geo-marine Sciences* 42:82–89.

Parulekar, A. H., Dhargalkar, V. K., and Singbal, S. Y. S. 1980. Benthic studies in Goa estuaries. Part 3. Annual cycle of macrofaunal distribution, production and trophic relations. *Indian Journal of Marine Sciences* 9:189–200.

Pearse, V. B. and Muscatine, L. 1971. Role of symbiotic algae (zooxanthellae) in coral calcification. *The Biological Bulletin* 141:350–363.

Pickett, S. T. A., Burch, W. R. Jr., Foresman, T. W., Grove, J. M., and Rowntree, R. 1997. A conceptual framework for the study of human ecosystems in urban areas. *Urban Ecosystems* 1:185–199.

Pittman S. J. and McAlpine, C. A. 2001. Movements of marine fish and decapod crustaceans: Process, Theory and Application. *Advances in Marine Biology* 44:205–294.

Pritchard, D. W. 1967. What is an estuary: physical viewpoint. In: *Estuaries*, ed. G. F. Lauf, 3–5. Washington DC: American Association for the Advancement of Science Publication.

Qasim, S. Z. 2003. *Indian Estuaries*. Mumbai: Allied Publication Pvt. Ltd.

Qasim, S. Z. and Sen Gupta, R. 1981. Environmental characteristics of the Mandovi – Zuari estuarine system in Goa. *Estuarine, Coastal and Shelf Science* 13:557–578.

Rao, K. V. and Dorairaj, K. 1968. Exploratory trawling off Goa by the Government of India fisheries vessels. *Indian Journal of Fisheries* 15:1–13.

Rao, D. G. and Rao, T. C. S. 1974. Textural characteristics of sediments of Mormugao Bay, Central West coast of India. *Indian Journal of Marine Sciences* 3:99–104.

Rivonker, C. U., Padate, V. P., Sawant, S. S., Venkat, K., and Anil, A. C. 2008. Spatio-temporal variations in demersal fish community along the fishing grounds of Goa, West coast of India, *Proceedings of International Conference on Bio-fouling and Ballast Water Management*, 5–7 February, 2008 held at National Institute of Oceanography, Dona Paula, Goa India.

Rodrigues, C. L., Caeiro, S., and Raikar, S. V. 1998. Hermatypic corals of the Goa coast, west coast of India. *Indian Journal of Marine Sciences* 27:480–481.

Shetye, S. R., Shankar, D., Neetu, S., Suprit, K., Michael, G. S., and Chandramohan, P. 2007. The environment that conditions the Mandovi and Zuari estuaries. In: *The Mandovi and Zuari estuaries*, ed. S. R. Shetye, M. Dileep Kuma, and D. Shanka, 3–28. Bangalore: Lotus Printers.

Singh, I. J., Singh, S. K., Kushwaha, S. P. S., Ashutosh, S., and Singh, R. K. 2004. Assessment and Monitoring of estuarine mangrove forests of Goa using satellite remote sensing. *Photonirvachak – Journal of the Indian Society of Remote Sensing* 32:167–174.

Tansley, A. G. 1935. The use and abuse of vegetational concepts and terms. *Ecology* 16:284–307.

Ulanowicz, R. E. 1997. *Ecology, the Ascendant Perspective*. New York: Columbia University Press.

Unnikrishnan, A. S. and Manoj, N. T. 2007. Numerical models. In: *The Mandovi and Zuari estuaries*, ed. S. R. Shetye, M. Dileep Kumar, and D. Shankar, 39–48. Bangalore: Lotus Printers.

Veerayya, M. 1972. Textural characteristics of Calangute beach sediments, Goa Coast. *Indian Journal of Marine Sciences* 1:28–44.

Wagle, B. G. 1993. Geomorphology of Goa and Goa coast – A review. *Giornale di Geologia serie 3* 55:19–24.