Chapter 13
Coastal Ecosystem Services of Gujarat, India: Current Challenges and Conservation Needs

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Abstract Gujarat is the only state in India with the longest coastline of 1663 km (20% of the country) and the widest shelf zone covering about 184,000 km^2. The main feature includes two gulfs, the Gulf of Khambhat and the Gulf of Kachchh, and the open coast of Saurashtra facing the Arabian Sea. Further, Gujarat is the only state on the west coast of India with coral reefs. The other ecosystems present in the coastline are the seagrass, seaweeds, mangroves, beaches, and coastal dunes.

Ecosystem services are defined as the many and varied benefits to humans provided by the natural environment and from any ecosystems. All ecosystem services can be grouped into four broad categories: provisioning (production of food), regulating (control of climate and diseases), supporting (nutrient cycling), and cultural (recreational benefits). The services provided by different ecosystems are immense and described in length in the paper (Millennium Assessment 2000). The paper describes the ecosystem services provided by corals, mangroves, seagrass, seaweeds, coastal dunes, and others. For example, the corals not only protect the shoreline from erosion but also act as carbon sinks. Likewise, the seagrass meadows provide habitat for threatened *Dugong dugon*. Seaweeds have an important provisional role as raw materials in the pharmaceutical and cosmetics industry. Mangroves are considered as one of the most valuable coastal vegetation providing economic, social, and environmental benefits to the local communities. These mangroves also act as a major carbon sink and provide stability to coastal erosion. The mangroves of the Kori Creek support unique breed of Kharai camels. Large intertidal zone of the Gulfs provide regulatory services, as they act as major sinks of pollutants released into the coastal waters. The sandy beaches not only provide habitat for the green sea and olive ridley turtles but also sustain coastal tourism. The service provided by these coastal ecosystems is enormous, and this article discusses the components of each ecosystem with important services it provides.

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S. Madhav et al. (eds.), *Coastal Ecosystems*, Coastal Research Library 38,
https://doi.org/10.1007/978-3-030-84255-0_13

Industrial development combined with coastal developmental activities has increased stress on the various ecosystems along the coast, and the paper brings out the facts. The effluent discharges into the coastal region and its impact on the sensitive mangrove system and coastal fishery need to be discussed as the country is to implement the Sustainable Development Goals (SDGs). There is need to mitigate the growing pressures on the ecosystem through policy interventions and need to conserve or enhance the ecosystem services in a way that reduces the negative trade-off with other ecosystem services. There is need to create more conservation areas in the coastal line for the various threatened ecosystems similar to that of the terrestrial system where protected area for threatened species is emphasized. Examples could include seagrass conservation centers or areas with high diversity of seaweeds.

Keywords Gujarat · Salt marshes · Mangroves · Ecosystem services

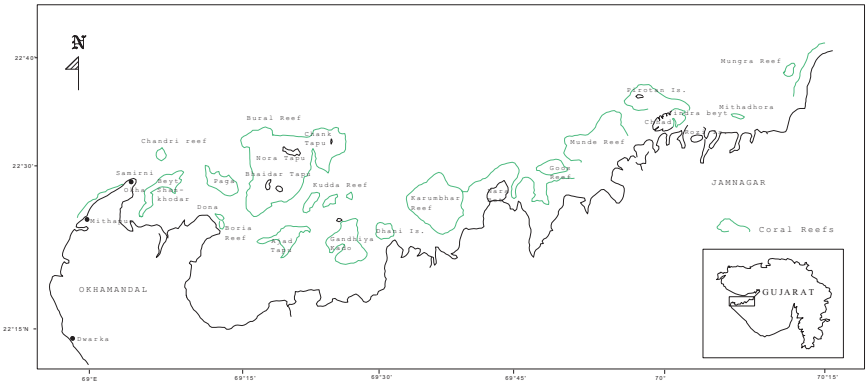
1 Introduction

The oceans and coastal areas provide both human (fisheries, energy, tourism, and transport/shipping) and environmental (climate regulation, carbon sequestration, habitat for biodiversity) benefits. This is the reason for the presence of human settlements within 100 km of the coastline, and it is estimated that more than 40% of the world's population (>2.8 billion people) live in the coastal region. In Asia, the coastal megacities like Chennai (2011: population 8.65 million), Dhaka (21.00 million), Karachi (11.62 million), Kolkata (14.05 million), and Mumbai (18.4 million) are located only a few meters above sea level (United Nations 2019). India has a long coastline of about 5422.6 km starting from the Gulf of Kachchh in the west and extending up to the Indo-Gangetic delta in the east. Among the various states, Gujarat has the longest coastline of 1663 km and the largest continental shelf of about 184,000 km^2 in the country. Also, the state owns 214,000 km^2 of exclusive economic zone (EEZ) which extends up to 20 nautical miles from the coast as defined by the United Nations Conference on the Law of Sea (Balan et al. 1987).

Geologically and geomorphologically, the coastline of Gujarat is differentiated into four distinct coastal zones, viz. (1) Gulf of Kachchh, (2) Saurashtra coast, (3) Gulf of Khambhat, and (4) South Gujarat coast (GES 1998). The presence of two gulfs, a large continental shelf, very high tidal amplitude (highest in India) (Mitra et al. 2020), a large area under mangroves (Forest Survey of India 2019), and corals are some of the unique features of the state (Dixit et al. 2010). Because of this geomorphological character, the intertidal region of the state is highly diverse and sustaining rich biodiversity. All of these components add together to provide ecosystem services, and the present research article describes the ecosystem services with the conservation needs.

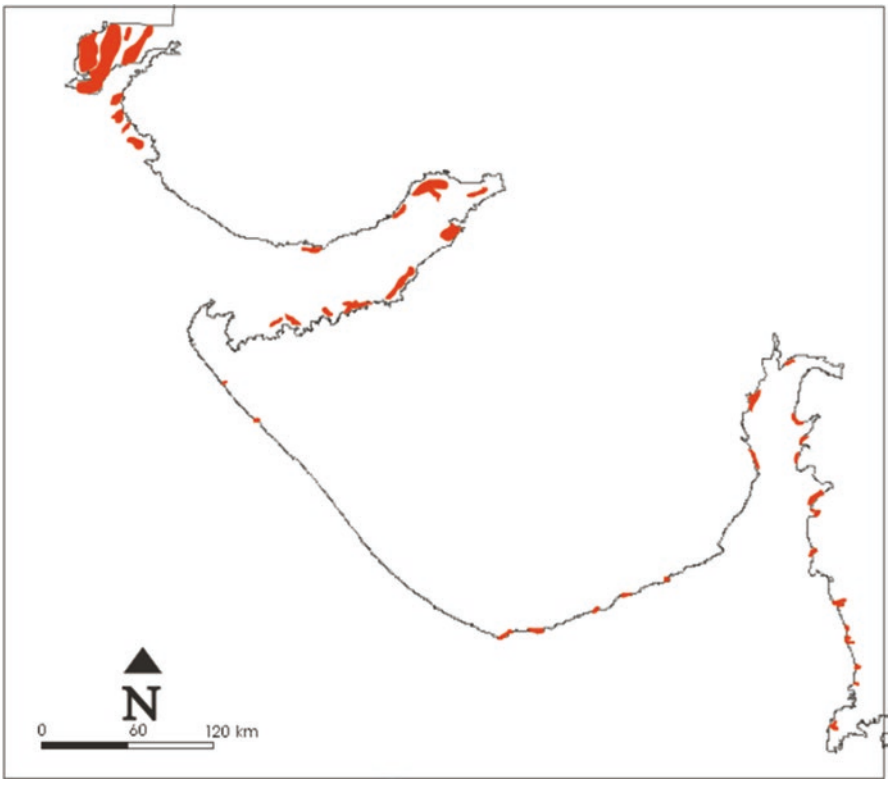
2 Coral Reefs

The coral reef is a unique bio-geological structure formed by a group of coral polyps held together by calcium carbonate. The coral reefs in the Gulf of Kachchh are found between 22°20′ N and 22°40′ N latitudes and 69° and 70° E longitudes.



(Source: Deshmuke et al 2000)

Source: Deshmukhe et al. (2000)



Source: Based on GEC (2010)

The Gulf of Kachchh region has 42 islands on its southern side, 34 of which have corals on one or the other shores (Satyanarayana and Ramakrishna 2009; Lakhmapurkar and Gavali 2018).

2.1 Corals

Various authors have worked on the coral diversity in the Gulf at different time scales. Patel (1978) reported 44 species of scleractinian corals and 12 species of soft corals from the Gulf. The monograph on Biological Diversity of Gujarat (Gujarat Ecology Commission 1996) lists 40 species of stony corals and 3 species of soft corals from the gulf. Gujarat Ecology Society (GES) in a pioneering effort carried out surveys of the subtidal reefs in 13 coral reef islands in the Gulf of Kachchh by scuba divers in 1999 and 2002. The study reported 75–80% subtidal live corals represented by 21 species of stony corals and 12 species of soft corals (Deshmukhe et al. 2000; Sen Gupta et al. 2003). Corals are reported outside the Marine National Park from Shivrajpur located between Okha and Dwarka (Lakhmapurkar and Gavali 2018), and it was declared as a Blue Flag beach in 2020.

The ecosystem services provided by corals reefs include coral fish diversity, coastal protection, fisheries, pharmaceutical, and others. Coral reefs are one of the highly biologically productive ecosystems with estimated productivity at 4200 (g C/m^2/year) (https://apescoralreefs.weebly.com). The corals have symbiotic relation with microalgae wherein the corals provide shelter to the algae and algae give color to the reefs with exchange of nutrients between both the organisms. The various life forms present to enhance the bio-resource of the region and assist to sustain the fishery or pharmaceutical industry; concerning economic significance globally, around 500 million people depend directly or indirectly on the reef ecosystem (Miththapala 2008). About 30 million worldwide depend exclusively on reefs for their food (Wilkinson 2008). Many coral species and species associated with coral reefs possess significant medicinal value (Hunt and Vincent 2006; Demers et al. 2002; Chivian 2006). Some hard corals are also utilized in bone grafts (Demers et al. 2002).

The latest the coral reefs play a major role as net sinks for C, principally as $CaCO_3$ accretion. Oceanic algae absorb carbon dioxide from the atmosphere for photosynthesis. The polyps build exoskeletons of calcium carbonate ($CaCO_3$) consuming these algae rich in carbon. This serves as a long-lasting store of carbon, making coral reefs as carbon sinks. However, several recent studies believe corals release carbon dioxide as a result of alteration of pH of seawater. However, on a global scale, the magnitude of the reef-generated CO_2 is small compared to current human-induced perturbations. Further it is found that deep coral reef lagoons act better sink of carbon compared to intertidal corals (Philben 2016).

Apart from these, coral reef plays a crucial role in protecting the shoreline. It acts as a physical barrier against the tides and helps in protecting coastal erosion, flooding, and loss of infrastructure. The best example of corals assisting in shoreline protection was witnessed in the 2004 tsunami in Tamil Nadu. In absence of coral

reefs, extensive damages to the shoreline and human life and property were seen along the Kanyakumari and Nagapattinam coast, whereas the coastal region of Tuticorin and Tirunelveli in the Gulf of Mannar was least affected due to presence of coral reefs in 21 islands of Gulf of Mannar which dissipated the energy of strong tsunami waves, thereby reducing the damages (Kumaraguru et al. 2005).

It has been estimated that coral reefs of the Gulf of Kachchh provide an annual benefit of approximately Rs. 2200 million (Dixit et al. 2010). The coastline of the Gulf of Kachchh is well protected from shoreline erosion due to the presence of corals against the coastline of the South Gujarat coast which is muddy in nature. However, coral reefs are fragile ecosystems and very sensitive to water quality and temperature variation. Water quality parameters like pH, total suspended solids, and nutrient load have very strong impacts on coral survival (Kelmo et al. 2014; Lapointe et al. 2008).

Coral reefs worldwide are under threat from a rise in sea surface water temperature as a result of global warming. In the process of the temperature rise, the sensitive photosynthetic algae die leading to large-scale bleaching events (Hoegh-Guldberg 1999; Done et al. 2003; Great Barrier Reef Marine Park Authority 2017). There are incidences of coral bleaching from the region in 1999 and 2010 (Adhavan et al. 2014). Another important threat to the survival of corals in the region is the presence of an industrial cluster adjoining the coastal areas that release treated effluents into the Gulf of Kachchh (Gujarat Ecology Commission 2017; Panseriya et al. 2020).

The presence of ports and their increased activity in the Gulf of Kachchh have to lead to sedimentation along the southern coast largely due to high dredging activity. Gujarat Ecology Society (2018) has reported the occurrence of petroleum hydrocarbons (PHCs) in the sediments along the coast that bears a direct relationship to the transport activity of crude oil by various ports. This could be detrimental to the growth of benthic diversity. High sediment load reduces light penetration, and this results in reduced photosynthetic activity of zooxanthellae (Anthony and Fabricius 2000). A thin layer of sediments over the coral reef can be cleaned by the coral itself, but such a cleaning process by the corals cannot overcome the high rate of sedimentation (Stafford-Smith 1993; Erftemeijer et al. 2012). This can lead to deposition of thick sediment cover on the coral reefs. The Gulf of Kachchh is highly turbid, and the suspended sediment concentration during the post-monsoon season varies from 0.5 to 674 mg/l (Vethamony and Babu 2010). Studies have reported (Bahuguna and Nayak 1998) a reduction in total coral cover because of the high sediment influx. Sharma et al. (2008) have reported loss in coral area and coral bleaching in Pirotan islands blaming on the high sedimentation rate, loss of mangrove cover, and sand mining.

With the increase in urbanization and expansion of the existing urban zones, disposal of solid waste has become an important issue. Urban centers like Jamnagar, Lalpur, Dwarka, Khambhaliya, Gandhidham, Anjar, and Mandvi located close to the Gulf of Kachchh discharge sewage of 369 tons/day (estimation for 2012) directly or indirectly into the Gulf. Studies carried out by GES have reported the discharge of high nutrient loads from various urban and industrial centers into the Gulf. These discharges lead to algal bloom which hinders coral growth (Sen Gupta and Deshmukhe 2000).

The unregulated tourism in the coral supporting reef area especially the Pirotan islands is posing a threat to the corals. A detailed study (Sharma et al. 2008) on the Pirotan reef indicated that increase in sediment (due to dreding activity) and release of untreated sewage have resluted in increase of algal growth and sandy/muddy deterimental for the occurence of corals and sea grass.

2.2 Restoration of Corals

Coral restoration is a very slow process and requires a lot of scientific interventions. The critical part of coral transplantation is the adaptation by the coral polyps introduced from a donor site to the Gulf of Kachchh. Reported presence of ample quantity of Acropora coral fragment on beach and intertidal in several studies indicated presence of live Acropora corals in the subtidal region (Satyanarayana and Ramakrishna 2009; Dixit et al. 2010). Pillai and Patel (1988) have reported local extinction of *Acropora* from the region because of temperature fluctuations and high sedimentation rate. Considering the loss of *Acropora*, Zoological Survey of India undertook the initiative of improving the population of *Acropora* in the Gulf of Kachchh region, during December 2013 to January 2015 in three different reefs, i.e., Pirotan Island, Narara Reef, and Mithapur reef (Kumar et al. 2017). Three hundred and twelve nubbins of *Acropora* sp. and *Montipora* sp. were transplanted from the Gulf of Mannar. The preliminary results (Kumar et al. 2017) indicated successful rate of survival of transplanted nubbins as the transplanted coral could adopt the high sedimentation load, temperature variation, and strong tidal currents of the restoration site.

Looking at the cost-effectiveness of coral transplants, it would be advisable to conserve the existing coral reefs through conservation measures. Some initiative like pollution control, sustainable tourism (Diedrich 2007), and declaration of certain areas as no human intervention zone can help to protect the corals for a longer run (Ali et al. 2011, Anu et al. 2007, Allers et al. 2013; Larsson et al. 2013). Pollutants like heavy metals reduce abundance of live hard corals as hard coral colonies are susceptible to contaminants dissolved in seawater (Ali et al. 2011). Similarly, many times it has been reported that unplanned tourism leads to activities like human trampling which leads to destruction in coral reef ecosystems (Sarmento and Santos 2012).

2.3 Seagrass

Seagrass belongs to angiosperms group capable of surviving under submerged conditions. Seagrass prefers shallow, sheltered coastal water and in Gujarat is found in the intertidal region of the Gulf of Kachchh. *Halophila beccarii*, *Halodule uninervis*, *Halophila ovalis*, and *Thalassia hemprichii* are the commonly observed species. Maximum seagrass extent is observed in Kalubhar Island, Bhural reef, and Pirotan Island (GeeVarghese et al. 2017).

The presence of seagrass can be seen as an indicator of the overall environmental quality of the coastal zone (Martínez-Crego et al. 2008; Syukur et al. 2017). The ecological services provided by seagrasses are immense. Seagrass serves as food for marine herbivores (Valentine and Heck 1999) and carnivore species like dugongs, manatees, sharks, turtles, tiny seahorses, shrimps, and octopus. Seagrass is known to filter and clean the water. The deep root structures associated with seagrass help in stabilizing the sediment (Ondiviela et al. 2014).

Seagrass meadows produce a variety of goods (finfish and shellfish, sediment) and provide ecological services (maintenance of biodiversity, water quality control, shoreline protection) that are directly used or beneficial to humans. The presence and abundance of seagrass can be considered an indicator of the overall environmental quality of the coastal zone (Mishra and Apte 2020). Hence, their long-term maintenance could be a surrogate target of coastal management strategies aiming at preserving or improving the environmental quality of the coastal zone. There is a need to undertake studies on the ecological significance of seagrass in Gujarat and evaluate the economic value.

Worldwide, the areas of seagrass have been disappearing at a rate of 110 km^2/year since 1980, about 30% since initial records in 1879 (Waycott et al. 2009). Like coral reefs, the seagrasses are threatened by sewage effluent and coastal development projects. Seagrass is sensitive to pollution, and therefore it becomes vital to protect the habitat from sewage and industrial waste pollution. The restoration of seagrass is very tedious and not easy as it prefers serene water conditions and long-term conservation of the areas with seagrass is the best solution.

3 Seaweeds

Seaweeds are macro algae belonging to the groups green algae, red algae, and brown algae. Based on the substratum, the seaweed distribution in Gujarat differs from the Gulf of Kachchh to Saurashtra coast. The Gulf of Kachchh region has records of 89 algal species (Nair 2002), whereas the open Saurashtra coast has higher diversity of seaweeds (198 species; Jha et al. 2009).

Seaweeds are rich in minerals and essential trace elements and used as raw materials in the pharmaceutical and cosmetics industry (Ahmed et al. 2014; Pereira 2018). Important commercially available agar is extracted from red seaweeds and algin from brown seaweeds, and green seaweeds are mostly directly consumed as salads. The economic importance of seaweeds is shown below:

Use	Reference
Production of agar, alginates, and carrageenan	Abraham et al. (2018)
Bio-fertilizer in agriculture	Zodape (2001)
As feed supplement in animal and fish feeds	Ismail (2019)
Rich sources of macro- and micronutrients, trace minerals, alginic acid, vitamins, and amino acids	McHugh (2003)

Apart from the economic value, seaweeds have an ecological role as they provide habitat for invertebrates, fish, mammals, and birds. Seaweeds serve as a source of food for many grazing vertebrates and invertebrates. However, the seaweed distribution is under threat largely from pollution, strong waves, habitat, and overexploitation, viz., collection for commercial purpose. The coastal development projects like ports and jetties are damaging the coastal habitat and thereby affecting the area of seaweed distribution.

One of the effective conservations includes their farming in natural habitat to reduce pressure in the wild (Anon 2019). Seaweed farming of red seaweed (*Gracilaria dura*) is being initiated in two villages of the coastal region of Saurashtra coast by the Central Salt and Marine Chemicals Research Institute (CSMCRI). There is a need to escalate these efforts in other coastal villages as well not only for economic gains but also for ecological purposes. Gujarat Livelihood Promotion Company (GLPC) is engaged in the promotion of seaweed farming for small farmers living near the coast. Other benefits of open ocean seaweed farms include improving the water quality and reducing ocean acidification as the seaweeds are known to absorb five times more carbon than terrestrial plants.

4 Salt Marsh Ecosystem

4.1 Mangroves

The mangrove ecosystem is one of the productive ecosystems and sustains diverse marine forms. The mangroves provide the nursery grounds for fish, crab, shrimps, and molluscs. Mangroves are considered as one of the most valuable coastal vegetation providing economic, social, and environmental benefits to the local communities. They provide a valuable biological resource like fodder and firewood to the coastal community.

In Gujarat mangrove distribution is the second largest in the country covering 1177 km^2, published by Forest Survey of India (2019). There are 15 mangroves and associated species present in Gujarat.

1	*Acanthus ilicifolius* L.
2	*Aegiceras corniculatum* (L.) Blanco
3	*Avicennia alba* Bl.
4	*Avicennia marina* (Forsk.) Vierh
5	*Avicennia officinalis* L.
6	*Bruguiera cylindrica* (L.) Bl.
7	*Bruguiera gymnorhiza* (L.) Savigny
8	*C. decandra* (Griff.) Ding Hou.
9	*Ceriops tagal* (Perr.) Robinson
10	*Excoecaria agallocha* L.

11	*Kandelia candel* (L.) Druce
12	*Lumnitzera racemosa* Willd
13	*Rhizophora mucronata* Lamk.
14	*Rhizophora mucronata* Lam.
15	*Sonneratia apetala* Buch.-Ham.

The Purna estuary has the highest representation, while the Gulf of Kachchh has seven mangrove species. The important ones include *Avicennia* spp., *Rhizophora mucronata*, and saline grasses in the intertidal region (*Aeluropus lagopoides*, *Sporobolus* sp.) (Singh 2000). The intertidal region of the Gulf of Khambhat is muddy in nature and supports small- to medium-size *Avicenna marina*.

The ecological service provided by mangroves is enormous. The root systems of mangroves help form a natural barrier against heavy storms and floods. River sediment trapped by the roots protects coastline areas and slows erosion. In the case of the Gulf of Kachchh, filtering process by mangroves prevents a large amount of sediment from reaching coral reefs and seagrass beds. Mangroves are considered as nature's best solution for carbon sequestration. It has been estimated that mangroves of Gujarat sequestrated 8.116 million tons of carbon, with an average of 88.95 tons sequestration per ha (Pandey and Pandey 2013). The carbon sequestration rate is high in South Gujarat (180.24 tons/ha) because of good mangrove cover and density (Pandey and Pandey 2013). The rate of carbon sequestration is high in the dense mangrove patches (95.3 tons/ha), followed by moderate dense mangroves (39.1 tons/ha) and least in the sparse mangrove patches (19.3 tons/ha).

The foliage of many mangrove species is used as fodder for cattle, camels, and goats and sustains them during incidences of drought. Kharai breed of camel, an indigenous breed of the Kachchh region, feeds on mangroves of Kori Creek. The mangroves are a reliable source for construction and fuelwood; it is hardy and resistant to both rot and insects.

Mangroves are facing threats from various natural and man-made activities like pollution, coastal land diversion, and geomorphic changes, and overexploitation. The diversion of mangrove area for port activities has led to a loss of mangrove cover in the Mundra region between 2006 and 2010. The photographic evidence shows how the removal of mangroves has resulted in the sand deposition in the same area by 2010 (Fig. 13.1). Similarly, there is a loss of mangrove area in the Gulf of Khambhat toward diversion of coastal area for ports and jetties.

Another threat to the mangroves is pollution released from the industrial setup along the coastline. Gujarat Ecology Society studied the impact of industries on the mangroves along the Jamnagar coast in seven selected stations. The study revealed high stress condition of mangroves at Rozi beyt, Salaya, and Sikka, intermediate condition at Narara beyt, and low stress condition from Dhani, Okha, and Pindara. Damages to the mangroves with respect to physiology and damaging symptoms like chlorosis and necrosis were reported from Rozi beyt and Narara beyt (Sankhwal and Gavali 2017). At Rozi beyt, dust accumulation on the leaves was high due to the unloading of coal at the nearby jetty (Fig. 13.2).

Fig. 13.1 Synoptic view of the area in 2005 (with mangroves) and 2010 (with sand layers)

Fig. 13.2 Dust accumulation at Rozi beyt on *A. marina* clicked on 12 June 2016

4.1.1 Restoration

Restoration efforts are being made by government to improve the mangrove cover through compulsory afforestation. There is success of mangrove restoration in the South Gujarat coast; however the ecological services provided by the mature mangrove stand cannot be replaced by the young patch. Mangroves have the ability to absorb heavy metals like cadmium and chromium, and this potentiality can be utilized for bioremediation in the coastal areas with heavy pollution load.

The South Gujarat coast is lined by a large number of perennial and seasonal rivers. Some of them have expansive mudflats, while some have a large estuarine area. Purna River is an important west flowing river of South Gujarat. Extensive mudflats at the mouth and fringing mangroves along the river and islands are important features of the river. It is one of the most diverse mangrove areas in the entire South Gujarat coastal stretch. Six species of mangroves *Avicennia marina Sonneratia apetalaAcanthus ilicifolius Rhizophora mucronata Ceriops tagalBruguiera cylindrica* eleven mangrove associates and *Clerodendrum inerme Salvadora persica Aeluropus lagopoides Derris trifoliate Suaeda fruticosa Porteresia coarctata Suaeda nudiflora Sesuvium portulacastrum Salicornia brachiata Arthrocnemum indicum Cressa cretica* have been recorded in Purna.

4.2 Beaches

Beaches are associated with rocky intertidal at many places, where the rocks form upper or supra tidal zones. The beach sands are dominantly calcareous and biogenic in nature. This indicates high biological productivity along the coasts. Sandy beaches provide ecosystem services like sediment storage and transport; wave dissipation; dynamic response to sea level rise; breakdown of organic materials and pollutants; water filtration; nutrient mineralization and recycling; storage of water in dune aquifers; nursery for juvenile fishes; nesting sites for turtles, shorebirds, and pinnipeds; prey for birds and other terrestrial species; and tourism (Defeo et al. 2009). Beaches act as a buffer against the strong wind, rough seas, and powerful storms.

The coastline of Gujarat is dotted with beaches, and some of the important tourist places include Tithal, Diu, Chorwad Madhavpur, and Mandvi. The sea beach along the Chorwad Madhavpur section is known for nesting grounds of green sea turtle and olive ridley turtle.

Beach ecosystem is one of the most vulnerable coastal ecosystems of human impact. Tourism Corporation of Gujarat Limited has identified 22 beaches and 5 other coastal sites to promote tourism in the state. Absence of regulatory beach tourism is destroying the important ecosystem, and beaches of Ubhrat, Dumas, Hazira, and Mandvi (Kachchh) are already facing issues of solid waste disposal and discharges from industrial effluents.

Beach raking is the mechanized removal of seaweed and other natural materials from the beach and is proving to be a major threat. Removal of nutrient-rich organic layer deposited along the beach can seriously affect the health of the beach and dune. Excessive beach raking promotes sand being blown and deposited in the nearby coastal areas. Of late there are reports of removal of seaweeds deposited along the shore for use as fertilizers. This activity has resulted in sand being blown in into the farmlands along the Saurashtra coast, thereby affecting the farm productivity.

Seawalls created at several places result in narrower intertidal zones and reduce abundances of invertebrates and shorebirds (Dugan and Hubbard 2006). Beach grooming also results in decreased species abundance and biomass (Hubbard et al. 2013; Dugan et al. 2010). For example beach modifications has resulted in large man made structures at Porbandar coast adversely affecting biological productivity of the beach (Illustration 13.1).

Beach management and conservation plan needs to be incorporated and made compulsory for the coastal development projects. The ecological role of the beach cannot be ignored and has to be integrated in the development projects. There is need to delineate the entire coastal zone of Gujarat and mark out no development zone in the context of conservation of beach ecosystem. Likewise, beach sand mining needs to be monitored and strict rules and regulation have to be considered. Special emphasis on the sensitive and valuable natural resources and aquifer conservation needs to be inducted during the beach management projects.

Illustration 13.1 Beach modifications for tourism at Porbandar coast

5 Coastal Dunes

Coastal dunes are geological formations, aeolian in nature, and located behind the beach. Coastal dunes are present on Saurashtra and Kachchh coast.

Sand dune formation is facilitated by strong winds blowing from SW direction during late summer. The wind lifts the beach sand during low tide and transports it landward where this sand gets trapped within the coastal vegetation, leading to sand dune formation. The process of sand dune formation is strong during the dry months of summer and winter. The ecological succession stage gets initiated during the monsoon months and the sand dune gets covered with vegetation. This vegetation over the years stabilizes the dune and such stable sand dunes are observed in Jamnagar and Kachchh district.

Ecological significance is the presence of endemic species like *Cyperus dwarkensis* from Dwarka (Nayar and Sastry 1988). Dune plays critical role protecting land fertility by preventing windblown salinity from the sea. Sand dunes are important freshwater aquifers, providing waters to coastal habitations, and act as a barrier for salinity ingress. Coastal dunes play a vital role in protecting our beaches and coastline from coastal hazards such as erosion, coastal flooding, and storm damage. Sand dunes also provide a future supply of sand to maintain the beach. The wider the band of dunes, the larger is the reservoir of sand.

Overexploitation of groundwater and dune sand mining damages/disturbs this delicate balance between saline sea and terrestrial fresh water, leading to salinization of coastal aquifers and soils. At present communities along Saurashtra coast of Gujarat are facing this situation of salinity ingress in coastal aquifers.

The coastal dunes are under threat as the ecological services provided are ignored. In Gujarat coast most of the dunes are stabilized and infested with *Prosopis juliflora*, which forms thick thickets damaging the native vegetation (GES MSU and GUIDE 2002). Such areas form habitat for carnivorous species like jackal and wolf, threatening the breeding of sea turtle by destroying their eggs. Therefore, control of proliferation of *Prosopis juliflora* in the sand dunes through strategic planning is required.

Conservation and restoration of sand dunes through meticulously planned efforts is required, wherein *Prosopis juliflora* is replaced with native vegetation. Prior taking up of restoration, identification of native flora through survey and historical records should be done. Restoration includes removal of exotic species like *Prosopis* sp. that has to be done manually as using heavy machinery would disturb the due morphology. *Prosopis* removal is not a onetime job, as relict tubers may again lead to their coppicing. These saplings need to be removed every year. Establishment of seral vegetation would start with grass and herbs species. Grass seed spreading during monsoon would help to restore grass species. Grass establishment would help to stabilize and prevent erosion. The grass would attract several herbivores species; though this would put pressure on the newly formed grassland, in return it will benefit the grassland through the organic manure and help in natural regeneration of other palatable species. Next step is to regenerate native shrub and tree species through plantation of saplings keeping appropriate spacing. The whole process of restoration is dependent on water and moisture availability, and it may run in to 5–10 years depending on monsoon.

The ecological role of the sand dune has to be understood and integrated in the coastal development projects. Coastal dune acts as a freshwater reservoir and barrier preventing sea salinity ingress and therefore is important system that needs conservation.

6 Salt Marsh Ecosystems

Tidal flats, along with intertidal salt marshes and mangrove forests, are important ecosystems. They usually support a large population of wildlife and are a key habitat that allows tens of millions of migratory shorebirds to migrate. Nine species of mudskippers are available in India of which seven species were reported from the Gujarat coast (Gujarat Ecology Commission 1996; Barman et al. 2000; Shukla et al. 2014).

6.1 Mudflats Fishery

Artisanal fishers doing intertidal fishery are known as Pagadiya fishers. Depending on nature of intertidal zone, they are engaged in fishery of prawn, crab, and mudskippers. The Pagadiyas of Gulf of Kachchh are doing prawn fishery from creeks, while crab fishery is common in Saurashtra. But the most dominant among this is mudskippers fishery in the gulf of Khambhat region (Fig. 13.3). Estuarine region of Narmada and Bhavnagar coast is among the most favored region for fishery of Mudskipper fishery.

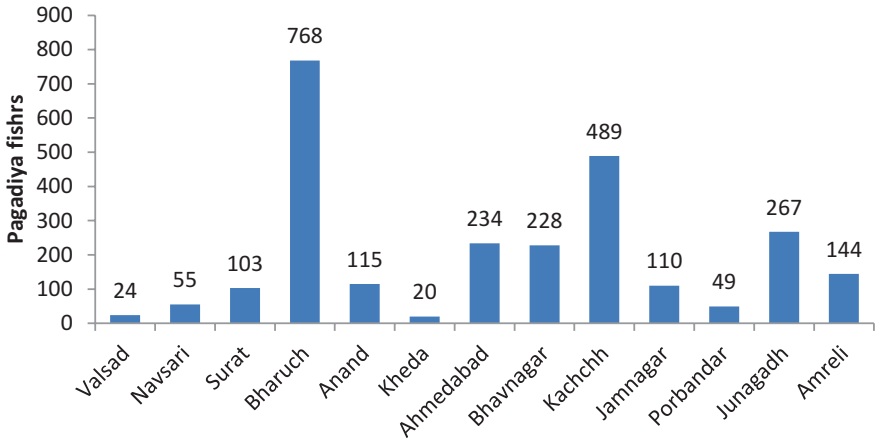


Fig. 13.3 Pagadiya fishers in Gujarat (GOG 2013)

6.2 *Paleo-Mudflats*

Paleo-mudfalts are represented inform of various landforms like palaeo-flats, salt flat and old deltaic plains. Their presence is indicative of high sea levels in the region in geological past. These paleo-mudflats form larger buffer zone in the state just above the high tide line. These mudflats are formed as a result of Khambhat and Kachchh fault line and tectonic activity (Nayak and Sahai 1983, 1985). Such landforms occur extensively in the entire Great Rann of Kachchh (including Banni plans), Little Rann of Kachchh, and northern as well western coast of the Gulf of Khambhat, also referred as *Bhal* and *Nalkantha* region. There is a small tract on east coast of Gulf of Khambhat in Bharuch region, known as *Bara* tract.

These regions play critical role in protection of human habitations from natural hazards. The raised mudflats provide habitat for unique ecosystem of salt marshes comprising of halophytic plants. The Gulf of Kachchh is represented by 27 halophytes belonging to 23 genera. Some of the important species reported from the mudflats are *Aeluropus lagopoides*, *Cressa cretica*, *Halopyrum* spp., *Ipomoea pes-caprae*, *Sesuvium portulacastrum*, and *Suaeda* spp. This vegetation provides food for a variety of herbivore species. The mudflats provide ample habitat for micro-invertebrates, gastropods, and other vertebrates. These halophytes also form food for the coastal communities and have religious value as well. For example, *Suaeda nudiflora* is consumed during fasting in the month of *Shravan*. These mudflats sustain *Pagadiya* fishery of mudskippers and crabs that is source of income for the coastal communities.

6.3 *Estuarine Fishery*

The coastal region of South Gujarat and Gulf of Khambhat is having estuaries of major rivers of Gujarat that mainly originated from eastern hilly region of Gujarat and neighboring states. Other parts of the state have seasonal rivers and creeks in

which tidal water dominates. Creeks are small tidal channel of the sea into the coast through tidal swarms. Sometimes small seasonal streams drain into the creek in the upstream region.

Estuaries include the region where there is mixing of seawater and fresh waste and therefore have the highest primary productivity in the world. This area supports mangroves and related floral and faunal species. Estuaries also provide free passage of catadromous and anadromous fishes during their breeding cycle. In Gujarat, Narmada estuary is the largest one and sustains good fishery, and important breeding species includes hilsa (*Tenualosa ilisha*) and freshwater giant prawn (*Macrobrachium rosenbergii*). The economic value of the fishery in the estuarine area is high, and it provide livelihood to thousands of fishermen in the area. Another important estuary of Gujarat is of Purna River in South Gujarat with rich mangrove diversity.

The major challenges faced by the estuaries of Gujarat are water pollution as these are the receiver points of land-based pollution activity. The addition of treated and untreated pollution destroys the aquatic life and the Sabarmati and Mahi estuaries are the examples.

Aliya Bet Case of MaldharisAliya Bet in the delta of the Narmada River had good-quality grass for camels. Fishing along the creeks and mudskipper collection do not pose any disturbance to the habitat because these activities are restricted to a certain portion of the section. Extensive mudflats with salt marsh vegetation are important habitats that support wetland birds. The utilization of mangroves by Maldharis for traditional camel rearing has additional conservation significance. The site has been designated a community reserve involving the local fishing community.

7 Ranns the Saline Deserts

The Great Rann of Kachchh forms almost half of the area of the Kachchh, covering almost 45,000 km^2 area, and comprises a flat barren landscape that occurs about 2–6 m above mean sea level (Merh 2005). In local dialect, the term *rann* means "saline wasteland." In general, the Great and Little Ranns are considered to be uplifted floors of the former gulfs (Merh 2005; Maurya et al. 2008).

The Great Rann represents a filled up Holocene basin, marking the sites of the ancient shallow gulf with river mouths. Historical studies suggest that a navigable sea existed at least up to ~2000 year BP (Oldham 1926). At present, the Ranns get submerged annually, i.e., during monsoon, under a thin sheet of water (Roy and Merh 1977). The Ranns are approachable only during the summer months when it dries out with temperatures reaching to 45 °C.

The major geomorphic component of the Great Rann is the flat areas without any gradient and isolated islands (locally called *bet*). The Arabian Sea in the west enters

and submerges about two-thirds of the Rann resulting in a thick salt crust (white desert). Inland saline flat is a zone on the east that gets inundated during monsoon by terrestrial inflow from the east and north. The bet zone comprises the flat rann surface in the northwestern part of the Great Rann and shows several bets.

The unique feature of the Great Rann is the flamingo habitat known as Kutch Desert Wildlife Sanctuary, declared as a sanctuary in February 1986. It is the largest wildlife sanctuary in India. Every year thousands of greater flamingo (*Phoenicopterus roseus*) nest in the world-famous "Flamingo City." It is the only area where flamingoes congregate to breed regularly. The Rann also sustains endemic and threatened wild ass, *Equus hemionus khur*, and some part of the area is declared as Indian Wild Ass Sanctuary. Apart from wild ass (*Equus hemionus khur*), the Wild Ass Sanctuary is also a habitat of many migratory birds, like sarus crane, ducks, the Dalmatian pelican, and flamingoes, sand grouse, the francolin, and the Indian bustard.

The climatic condition of the Rann supports the salt formation and is one of the largest salt-producing centers of the State of Gujarat. Marine chemicals like potassium sulfate and liquid bromide are also produced in the Great Rann of Kachchh. Thus, the economic services provided by the Rann are enormous in terms of foreign exchange earned from the export of raw salts to the western countries. Apart from salt works, Little Rann supports a unique seasonal fishery of ginger prawn (*Metapenaeus kutchensis*) done by Pagadiya fisherman. During the monsoon season, the Little Rann gets connected to the Gulf through flood water which allows passage of ginger prawn juveniles into the Rann.

Recently activities like tourism and White Rann and the solar farm have picked up bringing alteration in the socioeconomic conditions of the locals. However, there is need to assess the long-term consequences of these activities on ecosystems of the Rann.

Acknowledgments The authors are grateful to Gujarat Ecology Society for providing the facilities to work on the paper.

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