Chapter 3 Coastal vegetation

A group of plants with peculiar features that are dispersed on a relief very much influenced by the coastal biosphere is known as coastal vegetation (Rao and Sastry, 1972). Coastal vegetation comprises of (a) marine algal vegetation of littoral and sub littoral, (b) phanerogamic and algal vegetation of salt and brackish marshes, (c) vegetation of sand dunes together with that of their "Slacks", (d) specialized vegetation associated with the drift-line, (e) vegetation of shingle beaches, (f) plants found on coastal cliffs and (g) mangrove (Chapman, 1976). Each of these types of vegetation grows under specific environmental gradient which subsequently leads to a distinct vegetation zonation in coastal or estuarine areas (del Moral and Watson, 1978; Disraeli and Fonda, 1979; Armstrong *et al*., 1985; Upkong, 1991). The environmental gradient includes various abiotic factors such as soil texture (Dawe and White, 1982 and 1986), soil drainage (Mendelssohn and Seneca, 1980; Wiegert *et al*., 1983), soil aeration (Burdick and Mendelssohn, 1987), inundation frequency (Disraeli and Fonda, 1979; Hutchinson, 1982), salinity (Snow and Vince, 1984; Ewing *et al*., 1989), nutrient availability (Valiela and Tela, 1974; Mendelssohn, 1979) and nutrient toxicity (Mendelssohn and McKee, 1988; Koch and Mendelssohn, 1989). Besides these, biotic factors such as interspecific and intraspecific plant competition also play an important role in demarcating a sharp spatial boundary among various plants (Snow and Vince, 1984; Dawson and Bliss, 1987; Levinton, 1995). Among all these, edaphic factors, periodic inundation and the saline water table are the primary environmental influences that determine the distribution and abundance of plants within and across coastal wetland systems (Kim and Ihm, 1988; Lee, 1989; Ihm *et al*., 2001). Salinity is governed to a large extent by tidal inundation. The coast is divided in to three zones namely sub tidal zone (mostly covered with tidal water), inter tidal zone (under daily influence of tidal inundation) and high tidal zone (where tidal waters inundate generally during the spring and neap tide) based on this tidal inundation. This is generally followed by a dune system which acts as an ecological niche between terrestrial and marine realms and form important nature conservation sites (Saye and Pye, 2007).

In coastal areas there is a distinct vegetation growth pattern and zonation e.g. sea grass and macroalgae mostly grow in the sub tidal areas which are mostly covered with water (rarely getting completely exposed). Macroalgae also proliferate well on rocky shores or on coral reefs. The next zone is the intertidal zone which is continuously influenced by daily tidal cycle. This is the zone where salinity of soil and water limit growth of other plant species. On muddy intertidal coasts this facilitates the growth of mangroves. This is followed by high tidal mud flat, an area where salinity is relatively high and is not under the continuous influence of tidal cycles. Salt marsh vegetation and mangrove associates thrive in such areas. Finally towards the land ward side is the dune or cliff vegetation which comprises mostly of herbs, shrubs, creepers and runner and is relatively more biodiverse (Zalba and Nebbia, 1999; Nebbia and Zalba, 2002; Monserrat *et. al.*, 2012). At end of one zone and beginning of next zone there is generally an ecotone which can be narrow or broad based on the steepness of the environmental gradient. Thus, in the coastal area plant communities have distinct pattern of zonation.

Coastal areas contain many species of specific flora on account of their complex environmental conditions. The word specific flora is used to emphasis specialized group of plants which can grow only in coastal or estuarine area. Among different types of coastal vegetation mangrove, mangrove associates and salt marsh vegetation are considered in present study as they are generally found in muddy coasts to which the current study area belongs to. These plants have developed special adaptations or features which allow them to grow and sustain in unique coastal environment (Compiled from various sources including Tomlinson, 1986; Kathiresan, 2010 etc.). A few of these features or adaptations are,

1. Development of specialized root system such as stilt roots, knee roots, aerial roots, plank roots and pneumatophores (in mangroves) and other plants (eg. Pandanus) for various purposes like anchorachment and respiration.
2. The specialized mechanism of seed germination i.e. vivipary restricted to mangroves.
3. An increase in thickness of the leaves to protect plant from dehydration, exposure to the sun and salt spray.
4. The ability to roll leaves in response to heat, salt and lack of water.
5. Occurrence of hairs on the leaves, which helps to avoid heat stress.
6. Wiry stiff leaves and stem which enable the plants to tolerate abrasion by salt-laden winds and sand.
7. Ability to produce large seeds to increase viability and vigour of seedlings and dependence on the sea for dispersal of their seeds.

The presence of a few to all of the above mentioned characters allows mangrove, mangrove associates and salt marsh vegetation to survive in high saline conditions. This group of plants is also known as "Halophytes".

In the present study land vegetation present adjacent to the coast (i. e. within 500m area from high water line) was also considered in addition to the vegetation types mentioned above.

3.1 IMPORTANCE OF COASTAL VEGETATION

Coastal vegetation provides considerable goods and services to billions of people. It acts as an ecological storehouse which is rich in biodiversity and of high ecological and economical values (Untawale, 1994; Banerjee, 1994). To emphasis the important role played by coastal vegetation, its functions are divided into two broad categories namely ecological and economical functions.

3.1.1 ECOLOGICAL FUNCTIONS

Coastal vegetation is involved in multifarious ecological functions and provides a large range of ecological services. These services though very important are generally not appreciated by common people. But its remarkable role as a "Barrier" or "Bioshield" at time of Indian Ocean Tsunami on 26th December, 2004 has increased awareness among the public on its importance (Feagin *et al*., 2010). Some of the important ecological services provided by coastal vegetation have been described below.

As a strom barrier: Coastal vegetation acts as a natural barrier against extreme natural and anthropogenic activities, protecting infrastructure and human lives. Several incidents have proved the importance of coastal vegetation as a speed breaker against the waves of tsunami and reduced intensity of calamities (Selvum *et al*., 2005; Dahdouh-Guebas *et al*., 2005; Tanaka *et al*., 2007; Mascarenhas and Jayakumar, 2008; Mukherjee, *et al*., 2009a; Thuy *et al*., 2012).

As a sediment binder: Mangrove, salt marsh and dune vegetation can trap sediments and thereby accelerate accretion (Chapman, 1976; Wolanski *et al*., 1992; Furukawa *et al*., 1997; Boorman, 1999; Kathiresan, 2003; Bhatt *et al*., 2009). Aerial roots and plant form increases effective roughness of the substratum and humus derived from dead vegetation increases cohesive and water retentive properties of surface. This impedes the movement of sediment and thus traps them at same time (Melton, 1940; Cooper, 1958; Ash and Wasson, 1983; Sarre, 1989; Carter and Wilson, 1990; Thomas and Tsoar, 1990; Wolfe and Nickling, 1993).

As a preventer of the coastal erosion: Salt marsh, mangrove and dune vegetation minimizes action of waves and thus prevents the coast from erosion (Mazda *et al.*, 1997; Kathiresan, 2010; Shepard *et al.*, 2011). Harada *et al.*, (2002) proved that mangrove in the form of "Live Seawall" to be very cost effective compared to concrete seawall and other such structures.

As a sink of organic carbon and nutrient: Among different types of vegetation, mangrove and salt marsh vegetation are considered to be rich in nutrients and organic carbon content. They are considered as sink for organic carbon and mineral nutrient (Hazelden and Boorman, 1999; Kathiresan, 2003; Donato *et al.*, 2011). According to the concept of outwelling given by Odum (1968 and 1980), mangroves and salt marsh vegetation produce more organic matter than can be stored within system and this excess material is exported to coastal waters where it supports marine productivity. Hence, they are considered to be among the most productive and biodiverse wetland ecosystem on earth (Odum *et al.*, 1982; Mitsch and Gosselink 1993).

As a sink of pollutant: Mangrove and salt marsh vegetation act as filters where in they trap organic pollutant and heavy metals (Scrimshaw *et al.*, 1994; Boorman, 1999). Sediments have a high capacity for absorbing and holding heavy metals and thereby preventing spread of metal pollution in the coastal area (Kathiresan, 2010).

As a habitat: Coastal vegetation starting from algae to dune vegetation supports various life forms. Mangrove ecosystem serves as nursery, feeding and breeding grounds for many fishes and shellfishes (Deshmukh, 2007). According to Kjerfve and Macintosh (1997) nearly 80% of the fish catches directly or indirectly depends on this ecosystem. This mangrove and salt marsh nurture variety of crabs, prawn, mollusks and fishes. Besides fish, they also support a variety of wild lives such as fox, deer, Bengal tiger, crocodiles, snakes, fishing cats, insects and variety of birds. This system is also rich in microorganisms which play an important role in cycling of nutrients through the detritus food chain.

Collectively the coastal vegetation act as green wall, sediment trapper, binder and filter for nutrients as well as pollutants.

3.1.2 ECONOMICAL FUNCTIONS

Coastal vegetation is also a source of several economic benefits in addition to the several tangible and intangible benefits that have been mentioned in the previous section. These includes them,

As a source of food: Different plant parts belonging to a variety of coastal vegetation types such as algae, mangrove, salt marsh or dune vegetation are used as source of food by the coastal communities (Bandaranayake, 1999; Kathiresan, 2010; Rameshkumar and Eswaran, 2013).

As a source of fish: Coastal vegetation especially mangroves provides excellent nursery ground for fishery products such as fish, prawn, crab and mollusks. The nutrient rich soil of mangrove and salt marsh vegetation provides fish and prawn seeds for aquaculture industries (Chaudhuri and Choudhury, 1994).

As a source of fuel: Branches of mangroves have considerable high calorific value. Due to which they are used in production of charcoal which produces high heat energy without any smoke (Kathiresan, 2010). Energy produced by burning of this charcoal is much higher than that of coal. Therefore mangroves are used mainly for making of charcoal and firewood. In addition to this stem and branches of mangrove, mangrove associates and dune vegetations are also directly used as fuelwood.

As a source of tannin: Wood of mangrove contains high amount of tannin. Hence, it is used as a source of Tannin (Kathiresan, 2010). High content of tannin in the wood increases its durability and hence is used as timber for various construction purposes.

As a source of honey: Mangroves attract honey bees and promote the apiculture activities in areas such as Sunderban and some part of Bangladesh (Krishnamurthy, 1990; Siddiqi, 1997).

As a source of medicine: Each type of coastal vegetation from algae to dune vegetation has high medicinal value. Considerable work has been done by a large number of scientists to explore the medicinal value of mangroves, salt marsh and dune vegetation. The extract of several mangroves have astringent, antidiarrhoea and antemetic activities (Kathiresan, 2010). They have been used as an indigenous medicine for reducing blood pressure, for the treatment of leprosy and epilepsy, rheumatic disorders etc. In the same way different salt marsh and dune vegetation is also used as medicine by ethnic group living in their vicinity (Muthukumar and Samuel, 2010; Padmavathy and Anbarashan, 2011; Chakraborty *et al*., 2012).

As a source of fodder: The young leaves of mangrove especially *Avicennia* sp. are very nutritive fodder for buffaloes, sheep, goat and camels (Qasim, 1998; Vannucci, 2002; Vishwanathan *et al*., 2011). Apart from this salt marsh and dune vegetation is also used as fodder for cattle.

3.2 CLASSIFICATION OF COASTAL VEGETATION

The process of classification includes sorting or grouping of vegetation in to a particular class or group based on its similarities and dissimilarities with other plants. The classification varies based on the objective of the study, geography of the area, geomorphology of the area, pedological conditions, phenology, physiognomy, ecology, dominance and type of dataset used to study the coastal vegetation (Vesey-Fitzgerald (1955-1957); Hemming, 1961; Udvardy, 1975; Peet and Allard, 1993; Reid *et al*., 1995; Newell *et al*., 1997; Simon *et al*., 2006).

The vegetation of entire India was first classified by Champion in 1936. He had classified the vegetation of India and Burma based on climatic conditions. The main drawback of this classification is that it did not recognize actions and interactions of vegetation with biota, soil, geology and geomorphology. It was mainly physiognomic with major emphasis on dominant plants. In 1968 Champion and Seth classified Indian vegetation into 16 groups under 6 major groups based on climate, geomorphology, physiognomy with cognizance to edaphic and biotic factors. Rao and Sastry during 1972-1973 developed an ecological classification of Indian coastal vegetation based on field data (Rao and Sastry, 1974a). A comparative assessment of all the three classification systems with regards to coastal vegetation is given in the Table 3.1. Among these three the one developed by Champion and Seth is most frequently followed in our country (Rao and Sastry, 1974b; Pullaiah, 2000; Joshi *et al*., 2006; Pattanaik *et al*., 2008a; Muthulingam and Parthasarathy, 2010; Finlayson and Valk, 2012; Panda *et al*., 2013). A brief description of the different categories under the classification is given in Table 3.2 while Plate 3.1 shows some characteristic plants of the different categories.

Preliminary Survey (Champion 1936)		Revised Survey (Champion and Seth 1968)		Rao and Sastry (Rao and Sastry 1972-73)	
Major group 1.		**Moist Tropical Forests**			
Group 4. Moist Tropical seral types (Part)		Littoral and Swamp Forests		Coastal vegetation	
Sub-group 4A.		**Littoral Forests**		**Strand vegetation**	
Type M. Tr/ 1S/1	Beach forest	Type 4A/L1	Littoral Forest	Type 4A/SS.	Strand sand
				Type 4A/SR.	Strand Rock
				Type 4A/SC.	Strand coral
Sub-group 4B		**Tidal swamp forests**		**Estuarine vegetation**	
Type. M.Tr/1S/2	**Tidal forests**	**Type 4B/**	**Tidal swamp forests**	**Type 4B/PE.**	**Proestuarine**
Type		Type		Sub-Types	
M.Tr/1S/2(a)	Low mangrove forest	4B/TS1. scrub	Mangrove	4B/PE/TM.	Tidal mangrove
M.Tr/1S/2(b)	Tree mangrove forest	4B/TS2.	Mangrove forest		
M.Tr/1S/2(c)	Salt water Heritiera forest	4B/TS3.	Salt water mixed forest *(Heritiera)*	4B/PE/E.	Euhyline
M.Tr/1S/2(d)	Fresh water Heritiera forest	4B/TS4.	Brackish water mixed forest *(Heritiera)*	4B/PE/P.	Prohyline
		4B/TS4/EI.	Palm swamp	**Type 4B/EE.**	**Euestuarine**
					Source: Rao and Sastry (1974a)

Table 3.1 Comparison of different classification systems for coastal vegetation

Coastal vegetation	**Strand vegetation**	Characterized by open mat forming pioneers in varying proportions closely followed by scattered herbs, shrubs and trees dispersed on a relied beyond the high tide limit.		
		Strand Sand		A vegetation type along a sandy relief beyond the mean high tide limit. Indicator plants: *Ipomoea pes-caprae* (L.) Sw.
		Strand rock		A vegetational type along rocky relief. Indicator plants: *Tephrosia purpurea* (L.) Pers.
		Strand coral		A vegetational type along a coral relief beyond the mean high tide limit
	Estuarine Vegetation	Characterized by dense woody plants, shrubs and succulent herbs in varying proportions dispersed on a relief under the constant influence of tidal and fresh water resources.		
		Euestuarine		Plants grow on a muddy relief which is under constant influence of tides and fresh water. Indicator plants: *Porteresia coarctata* (Roxb.) Tateoka (on fresh silt).
		Proestuarine	The plants follow a distinct pattern depends on the nature of the relief and tidal influence.	
			Tidal mangrove	Characterized by abundantly and luxuriantly growing scrubs and tree species of mangroves. Indicator plants: *Rhizophora mucronata* Lamk., *Avicennia officinalis* L., *Avicennia marina* Vierh., *Aegiceras corniculatum* Blanco.
			Prohyline	There is a mixing of salt water from the sea and fresh water from the rivers resulting in a condition favorable for growth of salt tolerant fresh water plants. Indicator plants: *Bruguiera gymnorrhiza* (L.) Lamk., *Lumnitzera racemosa* Wild., *Caesalpinia crista* L.
			Euhyline	Characterized by the presence of highly salt tolerant plants which grow under conditions of apparent wetness and dryness. Indicator plants: *Acanthus ilicifolius* L., *Arthrocnemum indicum* (Willd.) Moq., *Aeluropus lagopoides* (L.) Trin. ex Thw., *Suaeda maritima* (L.)Dum., *Suaeda nudiflora* Moq.

Table 3.2 Characteristics of vegetation type as per Rao and Sastry (1974a)

Ipomoea pes-caprae **(L.) R. Br.**
Strand sand vegetation

Porteresia coarctata **(Roxb.) Tateoka**
Euestuarine vegetation

Rhizophora mucronata **Lamk.**
Proestuarine (tidal mangrove vegetation)

Lumnitzera racemosa **Wild.**
Proestuarine (prohyline vegetation)

Acanthus ilicifolius **L.**

Arthrocnemum indicum **(Willd.) Moq.**

Proestuarine (euhyline vegetation)

Plate 3.1 Photos of coastal and estuarine vegetation

3.3 METHODS USED TO STUDY COASTAL VEGETATION

There are several methods to study coastal vegetation. The most common and time tested method to study the vegetation is extensive field work. In the past few decades remote sensing has been extensively used to study vegetation.

In the past, when tools and techniques such as remote sensing were not available, coastal vegetation was studied purely based on field surveys. The main constraint in such a study was the soft muddy substratum due to daily tidal inundation. Hence, in an area where the approach was very difficult or inaccessible, the alternate method is to study it through remote sensing techniques (Rao *et al.*, 1996). Coastal vegetation is well studied by many researchers using remote sensing technique and different data sets. Cameron in 1950, O'Neill in 1953, Nicholson and VanDeusen, (1953), and Olson in 1964 had studied coastal vegetation using aerial photographs. Hardisky *et al.*, 1986; Hinson *et al.*, 1994; Ramsey and Laine, 1997; Kunte and Wagle, 1997; Hurd *et al.*, 2005 and Zhang *et al.*, 2011 studied coastal tidal marsh using remotely sensed satellite data. They studied coastal vegetation with optical multispectral data such as SPOT, Landsat (MSS), Landsat TM and IRS-LISS II images. Nayak, 1994; Nayak *et al.*, 2003; Shah *et al.*, 2005; Ajai *et al.*, 2013b had used remote sensing technique for community zonation of mangrove communities. Later, hyperspectral data (with enhanced spectral resolution) was utilized by Schmidt *et al.*, 2004 and Pengra *et al.*, 2007 to study coastal vegetation. Lange *et al.*, 2004 and Hurd *et al.*, 2005 used field spectroradiometer to collect spectral signature of coastal plants in order to identify a particular species from the hyperspectral image. But, the application of optical and hyperspectral data become limited in an area with high cloud cover. In such cases, radar data became an important data source for wetland studies (Augusteijn and Warrender, 1998; Baghdadi *et al.*, 2001; Hess *et al.*, 2003; Martinez and Toan, 2007). Use of multitemporal radar data (Hess *et al.*, 2003; Martinez and Toan, 2007) or the combination of radar and Landsat or SPOT (Toyra and Pietroniro, 2005) had improved accuracy in the classification of wetland systems. Thus, with advancement in spectral, spatial, temporal resolutions of sensors and development of sensors for hyperspectral and microwave data, studies on newer aspects such as biomass, lignin content and species identification from space borne sensors became possible.

The study of coastal vegetation using field surveys involves the collection of data from either a quantitative or a qualitative perspective. The quantitative method is used to collect numerical data on number of individuals, plant size, area occupied by plant, for estimation of biomass etc. On the other hand qualitative methods are used to quickly define a plant community based on the observation. Clarke (1993) used transects to study species composition, distribution and abundance of vascular plants of Jervis bay. Min and Kim (1999) conducted quadrate study and soil analysis (moisture content, pH, conductivity and content of Sodium, Chloride, Calcium and magnesium were measured) in order to bring relation between properties of soil and plant distribution along the west coast of Korea. Shah (2004), Rodrigues *et al.*, (2011) and Monserrat *et al.*, (2012) had carried out phytosociology in order to study mangrove and coastal dune vegetation of India and Argentina.

Qualitative data can be collected by observation, conducting interviews and group discussion. This method of study is generally used when a quick or general overview of an area is required or at the time of studying ethnobotanical aspects of vegetation. Thaman (1992) described the ethnobotany of coastal plants of Pacific Island based on their observation for 20 years. Similarly, Pattanaik *et al.*, (2008a) studied phytomedicinal properties of sand dune species of Orissa using interviews. In the same way Muthukumar and Samuel (2010) and Padmavathy and Anbarashan (2011) had studied medicinal properties of coastal vegetation for Tuticorin coast of Tamil Nadu and Puducherry part of India.

There are, thus different ways in which coastal vegetation can be studied but method to be choosen is mainly dependent on the objective of study.

3.4 LITERATURE REVIEW

There have been a large number of studies by both global and Indian scientists on the coastal vegetation in different parts of the world. This coastal vegetation is sometimes studied separately under different heads such as mangroves, salt marsh, coastal dune vegetation, strand vegetation, algal vegetation and seaweeds and sometimes in a combined form as a coastal flora.

3.4.1 GLOBAL SCENARIO

The past work on coastal vegetation has been carried out by many researchers who had different perspectives. Schimper (1891) had carried out his work on the littoral flora of Indo-malayan coasts. The flora of the coastal plain of North Carolina, United States was studied by Wells (1928). Wells and Shunk (1931) had carried out ecological study on vegetation and habitat factors of the coarser sands of the North Carolina coastal plain. Olson (1964) studied salt marsh vegetation of Merrymeeting Bay with help of aerial photographs. Tabata (1986) studied native coastal plants of Hawaii. Crane (1989) studied estuarine vegetation and geomorphology of Minnamurra estuary. Clarke (1993) studied mangrove, salt marsh and peripheral vegetation of Jervis Bay. He studied vascular plant species composition, distribution and abundance and reported 140 species of vascular plants of which mangrove and salt marsh vascular flora consists of 38 species. Talbot and Talbot (1994) carried out phytosociological study of vegetation present along beaches, dunes and associated lower mountain slopes of Attu Island, Aleutin Islands of Alaska. Smith *et al.* (1998) assessed seasonal changes in the vegetation in the coastal wetland area of Scolt Head Island, England with help of airborne remote sensing. Gul and Khan (1999) studied effects of intraspecific competition and inundation on growth of *Arthrocnemum macrostachyum* in coastal swamp of Karachi, Pakistan. Min and Kim (1999) studied the plant distribution along the west coast of Korea in relation to soil properties. Jagtap and Untawale (1999) had studied atoll mangroves and associated flora from republic of Maldives of Indian Ocean. Coulter *et al.*, (2000) studied vegetation types in Marine Corps Air Station (MCAS) Miramar, California with high spatial resolution imageries from the ADAR 5500 airborne digital multispectral system and USGS CIR DOQQ. Kost and Penskar, (2000) studied the flora of coastal plain marshes along Atlantic and Gulf coastal plains. Ihm *et al.*, (2001) studied coastal vegetation along the western, southern and eastern coasts of south Korea with Braun-Blanquet method. Ehrlich *et al.*, (2002) studied land cover types and ecological conditions of the Estonian coast. Their study involved compilation of CORINE land cover database, Estonian administrative division database and Estonian nature protection areas database in GIS. Jayatissa *et al.*, (2002) studied floral composition and distribution of mangroves in Sri Lanka. They reported 20 mangroves species and 18 mangrove associates. Abuodha *et al.*, (2003) described floristic composition and vegetation ecology of Malindi Bay coastal dune field, Kenya. They identified total 174 plant species during the study. Agrawal *et al.*, (2003) used SPOT- vegetation data for vegetation mapping of south central Asia. Araujo and Pereira, (2004) reviewed the vegetation present on a sandy coastal plain in Brazil and the effect of environmental factors and substratum on vegetation physiognomy and structure. Lange *et al*., (2004) used hyperspectral data as well as field data for monitoring and studying vegetation in the coastal zone of Netherlands. Schmidt *et al*., (2004) mapped coastal vegetation of Schiermonnikoog (Netherland) using hyperspectral imagery. Provoost *et al*., (2005) explored methods of vegetation mapping with particular attention to automated classification of remotely sensed images and investigated past, present and future of vegetation mapping in coastal dunes and salt marshes along the Dutch and Belgian coast. Hurd *et al*., (2005) studied the coastal marsh vegetation of Long Island Sound, United states using satellite remote sensing and *in situ* radiometry data. Alfarhan (2005) studied the coastal vegetation along the coastal area of Al-Muwassam in north Saudi Arabia and prepared the flora of Jizan region of Saudi Arabia. McKerrow (2007) mapped and monitored plant communities in the coastal plains of North Carolina using Landsat TM satellite imageries. Woldewahid *et al*., (2007) described the plant communities on the Red sea coastal plain of Sudan. Khatoon and Akbar (2008) studied the floral diversity of Keti Bundar, Pakistan. They had reported 117 species from inland area and creeks of Keti Bundar. Horton *et al*., (2008) monitored coastal vegetation in the Tasmanian Wilderness World Heritage area using aerial photographs. Gedan and Bertness (2010) studied effect of warming on *Spartina patens* (a common salt marsh vegetation species) by conducting field experiments at Prudence Island and Rhode Island of the United States. Payne *et al*., (2010) studied coastal sand plain vegetation at Brisban Water and Broken Bay area of Australia. Zhang *et al*., (2011) classified the coastal wetland vegetation of the coastal region of Jiangsu Province, China with Landsat TM images. Cakan *et al*., (2011) studied the coastal sand dune vegetation of the Seyhan Delta in southern Turkey. They had reported 96 vascular plants belonging to 85 genera and 34 families. Monserrat *et al*., (2012) studied the coastal dune vegetation of the southern Pampas (Argentina) wherein 51 vascular plants were recorded during the survery. Watson and Byrne (2012) surveyed vegetation changes in the San Francisco Estuary, California and compared the vegetation survey of 2004 with that of 1975. Perera *et al*., (2013) studied the vegetation structure and species distribution of mangroves along the north-western coast of Sri Lanka using belt transects. Rahman (2013) studied changes in vegetation cover in Patuakhali coastal area of Bangladesh using remotely sensed satellite images such as Landsat TM and ETM+ and GIS technique. Bosire *et al*., (2014) studied the structural attributes and species composition of mangroves in periurban areas of Kenya. Perera and Amarasinghe (2014) studied mangrove vegetation structure at Batticaloa and Uppar/Panichchankeni lagoon sites along east coast of Sri Lanka. Sciandrello *et al*., (2015) investigated temporal and spatial changes in the floristic composition and abundance in sand dunes along the coast of Sicily (Italy).

This review of literature from global perspective suggested that coastal vegetation has been studied by number of researchers from different perspectives. Field surveys as well as the use of remote sensing data and GIS have both been used commonly throughout the world. Among the different remotely sensed satellite images, Landsat TM was the most frequently used. With the improvement in the different resolutions, the utility of the remote sensing for mapping and monitoring the coastal vegetation has increased in the last few decades.

3.4.2 INDIAN SCENARIO

In India, the earliest scientific record on mangroves was given by Van Rheede (1678) in his book 'Hortus Malabaris'. In the 19th century several eminent botanists Roxburgh (1814), Griffith (1836 and 1851), Heining (1893), Clarke (1896) and Prain (1903) devoted their interest to the study of the flora of Gangetic Delta and the biology of the mangrove and their seedlings (Bhagwanani, 1980). Talbot (1894) studied the trees, shrubs and woody climbers of the Bombay Presidency. Later, in 1901-1908, Cooke studied vegetation of Bombay Presidency and published three volumes on it. Blatter, in 1905 published studies on halophytic vegetation on Bombay region. Gamble (1918) carried out pioneering investigation of the mangrove flora of Krishna delta. Fyson (1919) carried out ecological studies on coastal plant communities on Tinnevelly coast. Erlanson (1936) carried out ecological investigation on phanerogamic flora for Wellingdon islands, Kochi (Kerala). Venkateshwarlu in 1944 studied the coastal vegetation of Andhra Pradesh. Bharucha (1950) and Navalkar (1953, 1956) studied the flora and analysed the geographical distribution of halophytes along the coast of Bombay and Salsette islands. Satyanarayan studied coastal vegetation of the Bombay coast (in 1958) and Elephanta (in 1959). Rao (1959) studied the flora of coastal vegetation of Andra Pradesh. Jain (1959) studied coastal plant community of the Konkon coast. Lawrence (1960) investigated the coastal plant communities of Kanyakumari district. Sidhu in 1963 described the mangroves of east Godavari region. Rao *et al*., (1963a and 1963b) studied the phanerogamic flora of Rameswaram and Krusadi group of island of Tamil Nadu district. The vegetation of Diu and Daman was studied by T. A. Rao and K. R. Aggarwal in 1964 and by R.S.

Rao in 1965. Pradhan and Satyanarayan (1965) described the vegetation of Manori and Madh islands in Bombay. Raju (1968) studied coastal vegetation of Andhra Pradesh. The Flora of the Salsette island, Bombay (Malad-Madh area) was compiled by Santapau and Shah in 1969. Eminent ecologist T. Ananda Rao undertook a major study on the vegetation of the entire Indian coastline. He published the maritime strand flora of India in 1971. Together with Sastry, (1974a) he developed a classification of the coastal vegetation of India using an ecological approach during 1972-73 which was described earlier in the chapter. Rao and Meher-Homji (1985) studied the strand plant communities of the Indian subcontinent. Jagtap (1985a) investigated the structure and composition of mangrove forest along the Goa coast. He prepared vegetation maps using aerial photographs and studied distribution, structure and composition of selected mangrove locations in Goa. Banerjee and Rao (1990) enumerated 23 species of mangrove from Orissa. Untawale and Jagtap (1991) studied the floristic composition of the deltaic region of India. Basha (1991) had studied the distribution of Mangroves in Kerala. Rao *et al.*, (1992) described the mangrove environment and sediment characters in Godavari estuary of east coast of India. Kunte and Wagle (1997) used remote sensing for delineating mangrove and its associated vegetation in Mandovi and Zuari estuarine complex of Goa. Parthasarathy and Karthikeyan (1997) made an inventory and suggested conservation measures for two tropical dry evergreen forests on the Coromandel coast, south India. Banerjee and Ghosh (1998) reported 26 mangrove species and 58 mangrove associates from Sundarbans, West Bengal. Suma (2000) described the physiological changes and distribution patterns of the mangrove flora of Cochin. Nayak and Bahuguna (2001) reviewed different methods to monitor the coastal vegetation present along the coast of India with remote sensing technique. Blasco and Aizpuru (2002) made a cartographic assessment of mangroves of west Bengal using remotely sensed satellite data such as SPOT images, RESURS satellite data. Kothari and Rao (2002) listed 16 true mangroves, 6 obligate halophytes with 67 associates from Goa. Anupama and Sivadasan (2004) had recorded 15 true mangrove species and 49 mangrove associates from mangrove area of Kerala. Rajendran and Sanjeevi (2004) described the flowering plants and ferns in mangrove ecosystem of India. Saravanan (2005) studied mangroves of Pondicherry using remote sensing. Kathiresan and Qasim (2005) had reported 71 species of mangroves under 43 genera in 28 families for India. The coastal and marine biodiversity of India was studied by Venkataraman and Wafar

(2005). Their study included listing of diatoms, marine algae, sea grass and mangroves. Sampath Kumar (2005) listed 32 species of mangroves in the Andaman group of Islands. Mishra *et al.*, (2005) analyzed the species diversity in Bhitarkanika mangrove ecosystem and reported 43 species of mangrove and associated angiospermic plants. Reddy *et al.*, (2007) studied the extent of mangrove in Bhitarkanika Wildlife sanctuary using Landsat MSS (1973), IRS 1A LISS II (1988), IRS P6 (Resourcesat) (2004) satellite images and used visual interpretation technique. Pattanaik *et al.*, (2008b) mapped, monitored and assessed the mangrove of Orissa using Landsat MSS and IRS P6 LISS III remote sensing data and GIS techniques. Reddy and Roy (2008) used multi temporal satellite data from 1977-2005 and GIS to assess spatial changes in vegetation dynamics in mangroves of Godavari delta. Kathiresan (2008) reviewed the diversity of Indian mangroves and found 39 mangroves and 86 mangrove associates. Swanin and Rao (2008) conducted a floristic survey in nine districts of Andhra Pradesh and recorded 65 plant species. Arisdason *et al.*, (2008) however reported 20 eumangroves and 48 mangrove associates from the mangrove of Andhra Pradesh. Bhosale (2008) surveyed the diversity of mangroves in Ratnagiri and Sidhudurg districts of Maharashtra state and found 24 mangroves, 11 halophytes and 9 associates. Nayak and Andrade (2008) surveyed the Kali estuary at Karwar in Karnataka state where in they recorded 130 species. Gopikumar *et al.*, (2008) recorded 28 plant species from Puduvypu mangrove forest of Cochin, Kerala. Khaleel (2008) recorded 14 true mangrove and 40 mangrove associated from mangroves of North Malabar region. Saravanan *et al.*, (2008) recorded 7 true mangrove and 16 mangrove associates from Pondicherry. Swanin and Sultana (2009) studied the costal ecosystem of Andhra Pradesh and discussed their management issues. Padmavathy *et al.*, (2010) described the coastal dune flora of Nallavadu village, Puducherry and enumerated 41 species of coastal sand dune vegetation. Nabi (2011) studied and quantified the mangrove vegetation of Krishna, Andhra Pradesh. He carried out studies on the ecological and socio-economic aspects involved in the conservation and management of Krishna mangrove forests. Joshi (2011) published a monograph on Indian Halophytes where he had listed 35 plant species. He has given detailed information on the habit, habitat, distinguishing characters and commercial uses for different species. Gokhale *et al.*, (2011) described the results of a floral survey of wet coastal and associated ecosystem of Maharashtra. Rodrigues *et al.*, (2011) listed the coastal sand dune vegetation of India wherein they reported 338 species. Vijaya Kumar and Vijaya (2012) studied the diversity of true mangroves and their associates in the Kundapura region, Udupi district, Karnataka. Chakraborty *et al.*, (2012) reported 60 species belonging to 56 genera and 33 families from West Bengal and its adjacent Orissa coast. Nakhawa *et al.*, (2012) mapped and studied changes in the mangrove forest in Sakhartar estuary, Ratnagiri district of Maharashtra state. Behera and Nayak (2013) described the floral diversity of Bhitarkanika. They listed 71 mangroves and their associates from Bhitarkanika and its fringe area. Pawar and Kolapkar (2013) mapped the mangrove area of Curtorim village of south Goa district using remote sensing and GIS techniques. Suma and Gowda (2013) described the diversity of mangroves in Udupi district of Karnataka state. Joshi and Ghose (2014) studied the community structure, species diversity and also estimated the above ground biomass of mangrove swamps of Sundarbans. They reported 13 true mangroves and 8 mangrove associates from 40 sites of Sundarbans. Sharma and Sikarwar (2014) studied the floristic diversity of Diu island. Sasidhar and Rao in 2015 analyzed the ecological and socio-economic aspects of mangrove of Nizampatnam and Palarevu area of Andhra Pradesh. Vijaya Kumar and Vijaya (2015) reported 9 true mangroves and 10 mangrove associates from mangrove area of Kundapura, Udupi District, Karnataka, Southwest coast of India. Pradhan *et al.*, (2015) assessed the floristic diversity of mangrove vegetation in Bagagahan Heronry of the Bhitarkanika National Park, Odisha and reported 10 plant species belonging to 9 families.

The literature survey for the country suggested that field survey was the main method for studying the coastal vegetation for considerable period of time. However in the last few decades the use of remotely sensed satellite data increased in the study of coastal vegetation.

3.4.3 SCENARIO IN GUJARAT

Gujarat has the longest coastline among all the Indian states and has a varied coastal flora. Available literature on coastal vegetation of Gujarat state suggested that Cooke and Blatter initiated work on the coastal vegetation of the state. Cooke studied the flora of the presidency of Bombay which included Gujarat where as Blatter (1908-1909) worked on the flora of Kutch. Later Borgesen (1929) prepared notes on the vegetation of Dwarka. Kapadia (1952) published ecological and statistical notes on the grasses of Kathiawar in which the complete peninsula of Kathiawar was covered. A list of halophytes of the regions was also prepared. Toor (1958) listed the coastal vegetation for the entire coast of Gujarat for the first time. Jain and Deshpande (1960) and Jain and Kanodia (1960) studied flora of Kutch and made several addition to the flora. Several workers have undertaken ecological studies on the Gulf of Kachchh and Saurashtra. Jain (1968) studied the vegetation and succession of plant communities in Kachchh region. Rao and Aggarwal carried out ecological studies on the coastal vegetation of Saurashtra coast and neighbouring islands and published it in three parts. This included Diu island (1964), Beyt island (1966) and the coast from Okhamandal point to Diu (1971). Rao and Mukaherjee (1967) conducted ecological study along the coast of Jafarabad to Bhavanagar. In the same year Rao and Shanware (1967) proposed a classification for Saurashtra coast based on a combined knowledge of geomorphology, phytosociology and edaphic features. Patel (1971) studied the flora of Bulsar wherein he had mentioned vegetation observed along the coastal area. Shah (1978) prepared the flora of Gujarat state which includes the vegetation along the sea shores and saline ground. After this, Bhagwanani (1980) studied coastal flora of Gujarat state from Khambhat to Umargam (Umargaon) where she listed, classified and described each genus in detail. Rashid (1985) described the unique flora of the Gulf of Kutch while Chavan (1985) enumerated the mangrove, mangrove associates, salt marsh vegetation, sandy strand, inland scrub and grassland vegetation found associated with the mangrove ecosystem in Gulf of Kachchh. Untawale and Wafar (1989) studied the distribution of mangrove in the gulf of Kachchh. Untawale and Ambiye (1989) studied the flora of Beyt Shankhodar in Gulf of Kachchh. Kothari and Rao analyzed the environmental impact on mangroves of Gujarat (1991a) and reported two new records for the state (1991b). Singh (2000) published a book on current status and strategy for conservation of mangroves in Gujarat. Singh (2002) studied growth pattern of mangrove of Gulf of Kachchh. Nair (2002) surveyed floral and faunal diversity of Gulf of Kachchh. Thivakaran *et al.*, (2003) had studied the vegetation structure of Kachchh mangroves. Shah (2004) studied floral diversity and ecology of few islands of marine national park of Jamanagar and listed 7 true mangrove and 7 mangrove associates and salt marsh species, 12 beach vegetation species and 45 island vegetation species. Gujarat Ecological Education and Research (GEER) foundation (2004) had reported 4 mangrove species and 299 associated plants from marine national park and sanctuary, Jamnagar. Singh (2006) studied mangrove and their environment wherein they listed mangroves species found in Gujarat state. Bhatt *et al.*, (2009) studied the mangrove diversity of Purna estuary wherein she found 7 mangrove species and 15 mangrove associates and salt marsh vegetation. Pandey and Pandey in 2009 had reported 14 species belonging to 10 genera and 7 families from Guajrat state. The Gujarat Ecological Commission (Anon, 2011c) prepared an ecological profile for coastal talukas around Gulf of Khambhat. They listed 430 species from 19 coastal talukas of Gujarat state. Patel *et al.*, (2011) studied the angiospermic flora of Kachchh district wherein they reported 987 angiosperm plant species which included several coastal species. Mehta (2011) studied the coastal vegetation of Taldhyjagiri of Talaja taluka of Bhavnagar district. Vegda and Babaria (2012) enumerated the flora of Mundra - SEZ area. They had listed total 83 plant species belonging to 45 families. Bhatt (2013) had studied diversity of mangrove and mangrove associates for South Gujarat region. She reported 10 true mangroves species and 21 mangrove associates. Sawale and Thivakaran (2013) reported the structural characteristics of mangrove forest of Kachchh, Gujarat. Pandya *et al.*, (2013) studied the agricultural weed flora of Bharuch district. Bhatt *et al.*, (2013) studied the vegetation types in South Gujarat using IRS P6 LISS III and Landsat TM satellite images and GIS. Vyas and Joshi (2013) had studied ecological characteristics of coastal flora in "Bhal" region (Bhavnagar district) and studied diversity indices. Patel *et al.*, (2014) prepared a mangrove atlas for Gujarat state covering 13 coastal districts. They mapped potential areas for mangrove plantation using IRS P6 LISS III satellite images of the years 2006 and 2007. Gohel (2014) studied the biodiversity of halophytes along the coastline of Gujarat from Kachchh to Diu area. Upadhyay *et al.*, (2015) studied the change in mangrove cover of the Gulf of Kachchh using IRS P6 LISS III and IRS RS2 LISS IV satellite data.

Thus, in Gujarat a large amount of work on the coastal diversity of the state has been concentrated on Kachchh and Saurashtra. Sporadic work has been carried out on this aspect on the main land coast (including part of Gulf of Cambay and South Gujarat coast). These works include Patel (1971), Bhagwanani (1980), Kothari and Rao (1991) and recently Pandey and Pandey (2009) and Bhatt (2013). These studies have concentrated more on the coastal areas of South Gujarat (i.e. south of Surat district or Tapi River). Little information exists on the coastal vegetation of Bharuch district. Hence, the present study was undertaken to study the diversity of coastal vegetation and to understand the structure and dynamics of the mangrove vegetation in the district.