

An evaluation of flora from coastal sand dunes of India: Rationale for conservation and management

Rouchelle S. Rodrigues, Antonio Mascarenhas, Tanaji G. Jagtap *

National Institute of Oceanography (CSIR), Dona Paula, Goa 403004, India

* Corresponding author, Tel. No. 91(0) 832 – 2450390, Fax. 91(0) 832 – 2450606,

e-mail: tanaji@nio.org

ABSTRACT

A key component that guarantees stability of coastal sand dunes (CSDs) is vegetation. In this study, the floristic composition and distribution from CSDs of India is reviewed. Analysis revealed a total 338 species of CSD flora, of which 92 species are found to be common to the west and east coasts. The west coast showed a greater diversity than the east coast, accounting for 267 and 163 species respectively. Fabaceae members dominated the flora and 62% of dune species exhibited an herbaceous habit. The non-metric multi-dimensional scaling (nMDS) resulted in three groups at 20% similarity. The CSD vegetation appeared to be more influenced by the geological setting and climatology of the region. The higher number of coastal dune species along the west coast is attributed to larger and extensive sandy areas. The CSD flora of India is under constant anthropogenic pressure due to rapid elimination of sand dunes and its associated vegetation. The prevailing Coastal Regulation Zone (CRZ) notification does not guarantee the health of sand dune flora. A coastal vegetation conservation policy that ensures a succession of species in the form of a three layered biozone is proposed as a long term sustainable option to maintain biodiversity of coastal flora.

1. Introduction

Coastal sand dune (CSD) habitats serve as an ecological niche between terrestrial and marine realms, and form important nature conservation sites [1]. However, these habitats have been severely affected by natural and anthropogenic activities resulting in loss of habitat and dependent flora and fauna [2]. Consequently, CSD flora has gained global attention for their protection, conservation and rehabilitation. Therefore, adequate information (extent, biotic and abiotic constituents, climate, coastal dynamics, sediment type) pertaining to such habitats forms the basis for developing effective strategies for management.

Sand dune vegetation or psammophytes comprise vital components of coastal sand dune habitats owing to their bioengineering role in sediment accumulation, sand binding and land building processes. Beach ecosystems in India have been studied for their physical, geological and restoration aspects [3-8]. Although CSD ecosystems are categorized as ecologically sensitive [9], their floral composition is poorly understood [10-14]. As such, a gap exists in the understanding of diversity, ecology and functioning of dune vegetation from the Indian coasts [10].

In 1991, the Government of India (CRZ) declared coastal stretches influenced by tidal action as Coastal Regulation Zone [9]. Of the four categories, CRZ I comprises ecologically sensitive areas, such as sand dunes, mangroves and areas rich in genetic diversity. Accordingly, human interference along these critical strips is forbidden. However, this instrument neither proposes strategies for restoration of landforms nor does it guarantee the conservation of dune vegetation.

This communication addresses the composition and distribution of CSD flora based on surveys and scrutiny of published literature, and an analytical perspective of field observations supported by relevant measurements. The paper enumerates the existing flora on the coast and affirms how the presence of sand dune belts and associated vegetation are potential agents of natural defense. Problems that ail coastal management are projected.

2. Description of the study area

Coastal regions of Indian lie between 7° to 24° N latitude and 70° to 94 ° E longitude, and are bounded by the Arabian Sea on the west and by the Bay of Bengal on the east. The west coast is characterized by sandy beaches backed by dunes, cliffs, promontories, and drowned estuaries, whereas the east coast exhibits a sequence of delta formations [3]. The littoral areas of India constitute the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal. In addition, the group of Islands of Lakshadweep (Arabian Sea) and Andaman and Nicobar (Bay of Bengal) are also included (Fig. 1).

India experiences a tropical climate marked by three seasons: the pre monsoon (February - May), monsoon (June to September) and post monsoon (October- January). The west coast of India receives southerly winds that drive high waves during the monsoon (June-September), while along the east coast, wave activity is generally prominent during the north east monsoon.

3. Methods

3.1. Data Collection

An assessment of CSD flora was conducted along the Goa coast in 2001 and 2003 as a preliminary study to determine relatively undisturbed CSD areas. During these surveys, species were recorded and photographed. Monthly sampling was carried out at Mandrem (north Goa) from October 2003 to November 2004. Sampling was carried out along a fixed belt transects laid perpendicular to the shore. Within each transect, quadrates of (0.25m², 1 m² and 100 m²) were used depending on the growth forms (herbs, shrubs and trees). For the present study, only the species richness of sand dune flora was used. The species were identified using published literature [11]. Similarly, in Andhra Pradesh (Kakinada) qualitative data on the CSD floral species was recorded. Field data for Goa and Kakinada was collected as a part of the Indo-European Union Project “Measuring, monitoring and managing sustainability: the coastal dimension” (2000-2005). Along Tamil Nadu coast, post tsunami field work was conducted at 24 locations. The surveys consisted of measuring beach profiles, tsunami run-up heights and inundation limits at each location, from north to south, of the state [8]. During the field studies, the type of vegetation and the impacts of the tsunami on the flora were assessed up to the tsunami inundation limits. In all, 24 transects and an equal number of secondary sites are considered for studies of dune vegetation. In Gujarat (Pirotan, Mithapur, and Narara), Maharashtra (Malvan) and Lakshadweep (Kadmat), data on richness of floral species was collected at selected locations during field programmes of the Institute [12, 13].

In addition to field work, a comprehensive literature survey was attempted to document the biodiversity of CSD flora using published data in journals, reports and books [11-28]. This exercise helped in augmenting species richness data collected in the field. A list of the species was thus compiled for each Indian state (Table 1).

3.2. Data Analysis

A structured table of CSD flora was produced in MS excel from the assembled data. Species common to the states were deleted and a final list of CSD for the Indian coast was produced. The species were then grouped based on their respective families and habit type (herb, shrub, tree,

creeper and climber). Families which contributed to less than 5 species were pooled together and represented as “others”. The final CSD flora list was subjected to statistical analysis.

In order to obtain the similarities and differences in the vegetation of the study area, inter-state heterogeneity was evaluated by Jaccard’s index of similarity [29]. The Jaccard’s index is one of the most useful and widely used similarity indices for binary data [30, 31]. A presence/absence data matrix was developed using a binary system (presence=1; absence=0). The resemblance matrix between coastal states was calculated and a non-metric multi-dimensional scaling (nMDS) plot was generated. Species which contributed to the groups in the nMDS were analyzed using Similarity Percentage (SIMPER). Pearson’s correlation between CSD species number and environmental variables was tested using STATISTICA 6. The environmental data which showed a correlation with CSD species number was superimposed as bubbles on the nMDS plot.

General metrological data for temperature (mean maximum and mean minimum) and rainfall for the study area were taken from Indian Metrological Department (IMD) [32]. Similarly, data on various categories of coastal land forms (sandy beach, rocky coast and muddy coast) and erosion of coastal areas are calculated using published data [33].

4. Results

4.1. Distribution of flora

The coastal dune ecosystem was found to support diverse flora with a total of 338 species (Table 1) belonging to 69 families. The west coast was found to be more diverse as compared to the east coast, accounting for 267 and 163 numbers of species respectively. Maximum number of species from the west and east coasts were recorded from Karnataka (145) and Tamil Nadu (89) respectively.

Fabaceae were found to be dominant, followed by poaceae, cyperaceae and asteraceae (Fig. 2). A large number of species fall in the herbaceous habit (62%) of the vegetation, followed by shrubs (21%), while trees, climbers and creepers contributed 17% (Fig. 3). The fore dunes mostly sustain plant species of *Cyperus arenarius* Retz., *Ipomoea pescaprae* (L.) R. Br. and *Spinifex littoreus* (Burm.f.) Merr., while *Calotropis gigantea* (L.) R. Br., *Vitex* spp., *Casuarina equisetifolia* Forst. and *Cocos nucifera* L. occupy frontal and hind dunes thus showing a mixed disposition particularly along the East coast of India. *Pandanus* spp. occurs exclusively along beach areas influenced by fresh water.

The nMDS analysis resulted in three groups at 20% similarity (Fig. 4a). Group I constituted flora from the regions of Maharashtra, Goa and Karnataka with a group average of 22%. Major species contributing to group I, exhibited a cumulative percentage of 59% (Table 2). Group II comprised

flora from Tamil Nadu, Andhra Pradesh, Orissa and West Bengal, with a group average of 27%. Some of the species which resulted in this group similarity were *Ammannia baccifera* L., *Borreria articularis* (L. f.) F. N. Will and *C. gigantea*. Species contributing to group II showed a cumulative percentage of 66% (Table 2). Group III included flora from Kerala and Andaman and Nicobar group of Islands with a group average of 29%. Few of the species contributing to this similarity are *Anacardium occidentale* L., *Calophyllum inophyllum* L. and *C. gigantea*. Species listed in Table 2 are those which were found to be the major contributors leading to the groups. The flora from Gujarat and Lakshadweep were separate and did not form a part of the major cluster at 20% similarity.

4.2. Climate and sediment type

In general, the annual rainfall along the west and east coasts varies from 1117.2 mm to 3796.9 mm and 1102.7 mm to 3034.8 mm respectively. The temperatures along the west coast range from 21.7°C to 33.4°C while that of the east coast range from 21.7°C to 32.9°C [32].

The west coast of India comprised extensive sandy beaches and rocky coasts compared to the east coast (Fig. 5), except for the state of Gujarat where 51% of the coast was muddy. The eastern states of India are dominated by muddy coast. Maximum erosion (75-80%) along the Indian coast was observed on the Karnataka-Kerala coastal stretch [33].

Pearson's correlation between CSD species number and environmental variables showed a weak correlation. However, species number showed a positive correlation with rainfall ($r= 0.33$) (Fig. 4b) and sandy beach ($r= 0.46$) and negative with muddy coast ($r= -0.49$).

5. Discussion

5.1. Coastal Dune flora – beach morphology relationships

Results from the data matrix revealed 338 spp. of CSD flora from the Indian coast (Table I). Of these, 88 genera and 92 species were found to be common to the west and east coasts. A wide variety of plant species have adapted to the CSDs of the tropics [10]. The species richness of CSD flora was higher along the west (267 spp.) compared to the east coast. This could be attributed to the large sandy areas along the west coast (Fig. 5), as sediment texture is one of the important factors which govern vegetation. Correlation analysis between CSD flora and environmental factors showed a positive correlation with sand. Further, the east coast is more prone to recurring cyclones and storm surges [34, 35], another likely reason for the relatively low number of CSD flora. Mechanical disturbances due to wave action have been reported to damage CSD flora [36].

Extensive sand dune belts are found along the west coast from Goa to Kerala (Fig. 1). However, this entire coastal stretch being dynamic in nature is subjected to erosion, intense at places along the Kerala and Karnataka coasts (Fig. 5). The erosion is more prominent towards the southern coasts of Karnataka [37] and Kerala. Although an erosive coast, Karnataka represents relatively more number of sand dune species, which could be attributed to the larger beach widths, compared to the other littoral states, along the west coast. In comparison, Kerala coast is represented by a low number of sand dune flora as over 60% of the shoreline is threatened by erosion [38]. Also, human interventions such as erection of seawalls are rampant and nearly 73% of the Kerala coast is protected by hard structures [39]. These embankments affect the dune vegetation and micro flora, besides disrupting the normal biogeochemical cycle [10].

The dominance of floral families from the Indian coasts was found to be similar to earlier reports from tropical regions [16, 40-43]. Our study revealed that members of fabaceae dominate the flora (Fig. 2), whereas, in temperate countries / shorelines, poaceae members are found to be prevailing [10]. The dominance of fabaceae family is due to the ability of these plants to harbor a variety of arbuscular mycorrhizal fungi [17, 41, 43]. Plants belonging to the fabaceae family are also known to fix nitrogen [42] in order to cope with the nutrient deficit in the sand [44], besides making it available to the plants and enhancing the fertility of the soil.

The nMDS revealed three groups at 20% similarity indicating low floral similarity from different geographical regions of the Indian coast (Fig. 4). Low similarity in flora can be attributed to the dynamic coasts, which have different degrees of stabilization. Earlier studies on coastal dunes have reported that the stabilization of the coast is closely related to the topography of the area [45, 46]. The similarity of flora along the central west coast (Maharashtra, Goa and Karnataka) could be attributed to the similar climatology and geomorphologic setup (Fig. 4). The flora of Gujarat did not cluster in group I (central west coast) flora, attributed to scanty rainfall in this region (Fig. 4b) and sediment composition (Fig. 5). However, the flora from Gujarat expresses affinity to the east coast flora at <20% similarity, which could be due to similar sediment composition (Fig. 5). Similarly, the flora from Lakshadweep did not form a part of the three major groups, but showed affinity for group I at < 20% similarity, due to its proximity to the South West coast (Fig. 1). Group II which comprised the east coast (Orissa, Tamil Nadu, West Bengal and Andhra Pradesh) (Fig. 4), is also subjected to an identical environmental and geomorphologic set up, and hence exhibited similar kind of flora (Table 2). Comparatively, Group III could have resulted due to the poor record of sandy flora from Kerala and Andaman and Nicobar group of islands (Tables 1 and 2) with a consequent loss of habitat [47].

The dune flora from India is subjected to various natural and anthropogenic pressures leading to a loss of habitat [47]. The east coast is more vulnerable to natural hazards such as cyclones, storms and occasional tsunamis. The likely effect of an eventual sea level rise is predicted [34]. In comparison, most of the rich CSD habitats are located along the central west coast. The major threats arise from anthropogenic pressures, particularly tourism related activities (Goa) and sand mining (Karnataka and Kerala). Goa being a tourist destination of international repute, accounts for almost 11% of tourist arrivals in the country [48]. The CSD vegetation from Goa which accounts for 26% of the west coast CSD vegetation is facing major threat from intense tourism and related human activities.

5.2. Conservation and management perspectives

So as to highlight the need for maintaining biodiversity of coastal flora, the coasts of Goa and Tamil Nadu are considered here. The shorefront of Goa is under the onslaught from tourism and related activities. As a result, coastal dunes and its vegetation have borne the maximum impact of human actions [49]. In Tamil Nadu, the manner in which coastal vegetation species reacted during and after the tsunami of December 2004 is noteworthy. The profusely vegetated stretches of Tamil Nadu coast displayed an exceptional resilience by dissipating high waves. Field measurements confirmed that only the frontal Casuarina woodland strip, ranging from 0 to 25 m, was stripped of leaf cover [8]. Villages behind coastal forests remained intact and sea water intrusion was negligible. Casuarina plantations helped dissipate violent waves as coastal vegetation played an essential role as efficient biological buffers.

Nevertheless, coastal experts are confronted with a dilemma: whereas casuarinas performed exceptionally as natural wave breakers in the wake of the tsunami (9), the same cannot be applied to storm surges events. Also, the wind driven wave run up during the monsoons supports this observation. Though the tsunami was an instantaneous episode, storm surges last for several hours, and even days. Erosion of sand is observed wherever high waves recurrently lash the base of casuarinas trees [50]. This phenomenon is observed in Goa during monsoons, and along the East coast of India during storm surge events.

Therefore, the levels of natural protection that coastal plantations can offer are being debated. Extensive casuarina plantations established in the 1990's and earlier as a cyclone protection measure along the Orissa coast were ineffective in preventing damage; rather, these plantations have caused destruction to native flora [51, 52, 53]. These plants are known to bear a shallow root system and easily uproot with strong wind and beach erosion [50].

The CRZ guidelines have been found deficient as far as the significance, role and conservation of sea front vegetation is concerned [49]. India relies on a National Forest Policy of 1988, one of the objectives being the conservation of the vast variety of flora and fauna. However, this document does not offer any scheme to enhance coastal biodiversity. A question thus arises whether the plantation programs should be undertaken and, if so, the manner in which these projects should be accomplished, by taking the coastal morphology into account. Guidelines on the conservation and management of coastal vegetation are lacking [35].

In the present scenario, if transects across a dune coast of Goa or Tamil Nadu is considered, a mixed disposition of floral species is noticed (Figure 6 a). Although herbs cover the dune in most places, tall hinterland trees such as *C. nucifera* and *C. equisetifolia* are routinely seen along the frontal dune. The main reason could be attributed to lack of management initiatives and haphazard plantation programs. Improper selection of plant species in different areas of the beach / dune, and inadequate planning generates a potentially high environmental stress on the coast [54]. Such unscientific methods of plantations cannot guarantee the health of sea front vegetation.

A succession of CSD species landward from the dune [2] that is expected to form a functional buffer zone (Figure 6 b) is proposed:

- Zone 1 would comprise of pioneer shallow rooted herbs such as *S. portulacastrum*, *I. pescaprae* and *C. arenarius* on the frontal dune (Figure 6b). These species can withstand burial by sand and salt stress, as the foredune areas receive maximum salt spray owing to their proximity to the sea. *Ipomoea pescaprae* would be ideal in the foreshore due to its occurrence and rapid vegetative propagation. The plant is estimated to generate about 446,000 plants per annum, through tissue culture, from a single nodal segment of *I. pescaprae* [55].
- Zone 2 would consist of a mid-shore zone of herbs and medium-rooted shrubs. *Cyperus arenarius*, *Launea* spp. and *Vitex* spp. are some of the species which could be used. Species from Zone 1 could also be used along with the shrubs so that a natural succession of vegetation is achieved. The use of *C. equisetifolia* would not be recommended in the foredune and mid-shore areas as they are known to pose a threat to marine fauna [50] and may obstruct the natural succession patterns of vegetation.
- Zone 3 could be represented by deep rooted CSD species of taller shrubs and trees such as *A. occidentale*, *Ziziphus* spp. and *C. nucifera* (Figure 6b). Although some of the plants (*A. occidentale* and *C. nucifera*) proposed in Zone 3 are not native to the country, these species

have been introduced centuries ago and have got naturalized in the area. Also, these trees provide socioeconomic benefits to the local inhabitants and, their influence on the native flora is insignificant.

The concept of coastal biozones, if implemented effectively, is bound to contribute towards conservation efforts in several ways: (a) The proposed biozone (Fig. 6b) would help to preserve the native flora, and thereby maintain the natural biodiversity of the region; (b) The preference in selection of vegetation from different habit types (herbs, shrubs, trees) allows a natural gradation in vegetation and would permit colonization of species from nearby areas which would otherwise be blocked if tall trees were planted in the fore dunes (Fig. 6a); (c) The proposed biozone would enhance the sediment dynamics of the area and help in sand accretion process thus contributing to dune stabilization and protection of the coasts; (d) Plants selection in the biozone (Fig. 6b) has taken into account the salinity tolerance, nutrient regime, wind and wave tolerance of the species proposed, as each of the species proposed have adaptations to cope with the beach conditions [10, 56, 57]. Species which are more salinity tolerant are placed towards the fore dune area; (e) Artificial concrete structures disrupt natural sediment processes thereby preventing colonization of plant species and dune restoration; (f) Inhabited hazard prone coasts would benefit from green belts in terms of security, access to food, materials for shelter and income.

In summary, the answer to the effective management of ecologically sensitive coastal habitats is the formulation of a new coastal vegetation conservation policy, implementation of the existing laws, continuous monitoring and public awareness. Therefore, a scientifically designed shelter belt with natural landforms covered with vegetation (Fig. 6b), and the encouragement of appropriate plantation programs, is the most sustainable management option to ensure the conservation of CSD habitats of India.

Acknowledgements

Authors are grateful to the Director, National Institute of Oceanography (NIO) for permission to publish this paper. One of the authors (RSR) is grateful to the Council of Scientific and Industrial Research (CSIR), New Delhi, India, for the grant of Senior Research Fellowship during the tenure of which a part of this work was carried out.

This is NIO contribution xxxx.

References

- [1] Saye SE, Pye K. Implications of sea level rise for coastal dune habitat conservation in Wales, UK. *J Coast Conserv* 2007; 11: 31-52.
- [2] Clark JR. *Coastal Zone Management Handbook*. Florida: Lewis Publications; 1996.
- [3] Ahmad E. *Coastal geomorphology of India*. Orient Longman; 1972.
- [4] Shenoj SSC, Murty CS, Veerayya M. Monsoon induced seasonal variability of sheltered versus exposed beaches along the west coast of India. *Mar Geol* 1987; 76: 117-130.
- [5] Chandramohan P, Kumar SJ, Kumar VS, Ilangoan D. Fine particle deposition at Vainguinim tourist beach, Goa, India. *J Coast Res* 1998; 14: 1074-1081.
- [6] Kunte PD, Wagle BG, Sugimori Y. A review and re-assessment of sediment transport along the Goa Coast, India. *J Coast Res* 2002; 18: 612-621.
- [7] Mascarenhas A. Sand Fences: An environmentally – friendly technique to restore degraded coastal dunes. *J Geol Soc India* 2008; 71: 868-870.
- [8] Mascarenhas A, Jayakumar S. An environmental perspective of the post-tsunami scenario along the coast of Tamil Nadu, India: Role of sand dunes and forests. *J Environ Manage* 2008; 89: 24-34.
- [9] MoEF. Declaration of Coastal Stretches as Coastal Regulation Zone (CRZ), Notification, S.O. no. 114(E), 19 February. New Delhi: Ministry of Environment and Forests; 1991. p. 14.
- [10] Sridhar KR. Bioresources of coastal sand dunes- are they neglected? In: *Coastal Environments: problems and perspectives*. New Delhi: International Publishing House; 2009. K.S. Jayappa, A.C. Narayana (eds) p. 53-76.
- [11] Rao RS. *Flora of Goa, Diu, Daman, Dadra and Nagarhaveli*. Botanical Survey of India Publications; 1985.
- [12] Desai VV, Komarpant DS, Jagtap TG. Distribution and diversity of marine flora in coral reef ecosystems of Kadmat Island in Lakshadweep Archipelago, Arabian Sea, India. *Atoll Res Bull* 2003; 506: 1-23.
- [13] NIO. Status report on Pirotan Islands (Gulf of Kutch) for starting a conservation plan. Wildlife Fund, India National Appeal (Western Region). Goa: National Institute of Oceanography; 1978. p. 16.
- [14] Jagtap b TG, Desai K, Rodrigues R. Coastal vegetation: patterns in a tourist region. In: *Coastal tourism, environment, and sustainable local development*. New Delhi: Tata Energy Research Institute; 2003. L. Noronha, N. Lourenco, J.P. Lobo-Ferreira, A. Lleopart, E. Feoli, K. Sawkar, A. Chachadi (eds). p. 131-150.
- [15] Banerjee LK, Rao TA, Sastry ARK, Ghosh D. Diversity of coastal plant communities in India. Kolkata: ENVIS- EM CBTAP Publication, Botanical Survey of India, Ministry of Environment and Forests; 2002.

- [16] Kulkarni SS, Raviraja NS, Sridhar KR. Arbuscular mycorrhizal fungi of tropical sand dunes of west coast of India. *J Coast Res* 1997; 13: 931–936.
- [17] Arun AB, Sridhar KR. Arbuscular mycorrhizal association with CSD legumes of south west coast of India. *Mycorrhiza News* 2006; 18: 13-17.
- [18] Arun AB, Beena KR, Raviraja NS, Sridhar KR. Coastal sand dune- A neglected ecosystem. *Curr Sci* 1999; 77: 19-21.
- [19] Beena KR, Raviraja NS, Arun AB, Sridhar KR. Diversity of arbuscular mycorrhizal fungi on the coastal sand dunes of the west coast of India. *Curr Sci* 2000; 79: 1459- 1466.
- [20] Environmental Information System (ENVIS) Newsletter. Botanical Survey of India, Vol. 8, Kolkata: Ministry of Environment and Forest; 2002.
- [21] Ingole BS. Indian Ocean coasts, coastal ecology. In: Encyclopedia of coastal science. Dordrecht: Springer; 2005. M.L. Schwartz (ed).p. 546-554.
- [22] Jaiswal V, Rodrigues BF. Occurrence and distribution of arbuscular mycorrhizal fungi in CSD vegetation of Goa. *Curr Sci* 2001; 80: 826-827.
- [23] KSCSTE. State of environment report for Kerala. Kerala: Kerala State Council for Science, Technology and Environment; 2005.
- [24] Kumaran KPN, Limaye RB, Nair KM, Padmalal D. Palaeological and paleoclimate potential of subsurface palynological data from the data quaternary sediments of South Kerala sedimentary basin, South West India. *Curr Sci* 2008; 95: 515-526.
- [25] NIO. Development of GIS based information system for selected marine critical habitat: Data collection around Kadmat Island (Lakshadweep), Arabian Sea, India. Goa: National Institute of Oceanography (Report no. NIO/TR-4/2000); 2000.
- [26] Pattanaik C, Reddy CS, Dhal NK. Phytomedical study of coastal sand dune species of Orissa. *Indian Journal of Traditional Knowledge* 2008; 7: 263-268.
- [27] Sivadas P, Narayanan B, Sivaprasad K. An Account of the vegetation of Kavaratti Island, Laccadives. *Atoll Res Bull* 1983; 266: 1-9.
- [28] Desai KN. The structure and function of sand dune vegetation along the coast of Goa. Ph.D. thesis, Goa University, Goa, IN; 1995.
- [29] Jaccard P. Nouvelles recherches sur la distribution florale. *Bull Soc Vaudoise Sci Nat* 1908; 44: 223-270.
- [30] Izsak C, Price ARG. Measuring β -diversity using a taxonomic similarity index, and its relation to spatial scale. *Mar Ecol Prog Ser* 2001; 215: 69-77.
- [31] Zintzen V, Anderson MJ, Roberts CD, Diebel CE. Increasing variation in taxonomic distinctness reveals clusters of specialists in the deep sea. *Ecography* 2010; Doi:10.1111/j.1600-0587. 2010.06546.x.
- [32] IMD (Indian Metrological Department); 2009. <http://www. Imd.gov.in>.

- [33] Kumar SV. Coastal processes along the Indian coastline. *Curr Sci* 2006; 91: 530-536.
- [34] Shetye SR, Gouveia AD, Pathak MC. Vulnerability of the Indian coastal region to damage from sea level rise. *Curr Sci* 1990; 59: 152-156.
- [35] Mascarenhas A. Oceanographic validity of buffer zones for the east coast of India: A hydro meteorological perspective. *Curr Sci* 2004; 86: 399-406.
- [36] Maun MA. Colonizing ability of *Ammophila breviligulata* through vegetative regeneration. *J Ecol* 1984; 72: 565-574.
- [37] NIO. Integrated studies to identify vulnerable areas and adaptive measures for sea level rise along the coast of India. Goa: National Institute of Oceanography Publication (Report no. NIO/TR/ 91); 2003.
- [38] Mallik, TK. Coastal zone management programme in Kerala, India. *Environ Geol Water Sci* 1987; 10: 95-102.
- [39] Nayak GN. Indian Ocean coasts, coastal geomorphology. In: *Encyclopedia of Coastal Science*. Dordrecht: Springer; 2005. M.L Schwartz (ed). p. 554-557.
- [40] Moreno-Casasola P. Patterns of plant species distribution on coastal dunes along the Gulf of Mexico. *J Biogeogr* 1998; 15: 787–806.
- [41] Beena KR, Arun AB, Raviraja NS, Sridhar KR. Association of arbuscular mycorrhizal fungi with plants of coastal sand dunes of west coast of India. *Trop Ecol* 2001; 42: 213–222.
- [42] Arun AB. Studies on CSD legumes of Karnataka (India). Ph.D. thesis, Mangalore University, Karnataka, IN; 2002.
- [43] Arun AB, Sridhar KR. Symbiotic performance of fast-growing rhizobia isolated from the CSD legumes of west coast of India. *Biol and Fert Soils* 2004; 40: 435-439.
- [44] Zhang J. Interactive effects of soil nutrients, moisture and sand burial on the development, physiology, biomass and fitness of *Cakile edentula*. *Ann Bot* 1996; 78: 591-598.
- [45] Barbour MG, De Jong TM, Pavlik BM. Marine beach and dune plant communities. In: *Physiological ecology of North American plant communities*. New York: Chapman and Hall; 1985. B.F. Chabot & H.A. Mooney (eds). p. 296-322.
- [46] Moreno-Casasola P, Espejel I. Classification and ordination of coastal sand dune vegetation along the Gula and Caribbean Sea of Mexico. *Vegetatio* 1986; 66: 147-182.
- [47] IPCC. The regional impacts of climate change: An assessment of vulnerability. In: *Intergovernmental Panel on Climate Change Special Report*. Cambridge: Cambridge University Press; 1997. R.T. Watson, M.C. Zinyowera, R.H. Moss & D.J. Dokken (eds). p.1.
- [48] Sawkar K, Noronha L, Mascarenhas A, Chauhan OS. Tourism and the environment issues of concern in the coastal zone of Goa. In: *Tourism and the environment: Case studies on Goa, India, and the Maldives*. Washington: The Economic Development Institute of the World Bank Publication; 1996. K. Sawkar, L. Noronha, A. Mascarenhas, O.S. Chauhan, S. Saeed (eds). p. 1-19.

- [49] Mascarenhas A. The coastal regulation zone of Goa: Oceanographic, environmental and societal perspectives. *Curr Sci* 1999; 77: 598-1605.
- [50] Schmid JL, Addison DS, Donnelly MA, Shirley MA, Wibbels T. The effect of Australian pine (*Casuarina equisetifolia*) removal on loggerheads turtle (*Caretta caretta*) incubation temperatures on Keewaydin Island, Florida. *J Coast Res* 1993; 55: 214–220.
- [51] Craighead FC. The trees of South Florida: The natural environments and their succession. Florida: University of Miami Press; 1971.
- [52] Johnson AF, Barbour MG. Dunes and maritime forest. In: *Ecosystems of Florida*. Florida: University of Central Florida; 1990. R.L. Myers, J.J. Ewel (eds). p. 429-480.
- [53] Nelson G. The trees of Florida: A reference and field guide. Pine apple Press; 1994.
- [54] Martinez ML, Gallego- Fernandez JB, Garcia- Franco JG, Moctezuma C, Jimenez CD. Assessment of coastal dune vulnerability to natural and anthropogenic disturbances along the Gulf of Mexico. *Environ Conserv* 2006; 33: 109-117.
- [55] Kane ME, Bird KT, Lee TM. In vitro propagation of *Ipomoea pes- caprae* (rail road- vine). *J Coast Res* 1993; 9: 356–362.
- [56] Devall MV. The biological flora of coastal dunes and wetlands. 2. *Ipomoea pes caprae* (L.) Roth. *J Coast Res* 1992; 8(2): 442-456.
- [57] Valverde T, Pisaty I, Rincon E. Growth response of six tropical dune plants species to different nutrient regimes. *J Coast Res* 1997; 13(2): 497-505.

Legends

Fig. 1. Location of the maritime states of India (Refer to Table 1 for abbreviations).

Fig. 2. Contribution of plant species from families of CSD.

Fig. 3. Percentage of CSD species representing different habit types.

Fig. 4. The non-metric multi-dimensional scaling (nMDS) plot: (a) Based on presence/ absence data of CSD flora from the coastal states, (b) Bubble plot of rainfall data superimposed on nMDS (Refer to Table 1 for abbreviations).

Fig. 5. Percentage composition of sandy, rocky and muddy coastline affected by erosion (Refer to Table 1 for abbreviation; Source data [32]).

Fig. 6. A schematic diagram representing CSD flora: (a) Present scenario depicting a mixed disposition of vegetation; note that *C. equisetifolia* and to some extent *C. nucifera* occupy frontal dunes almost all along the East coast of India, (b) A succession/ zonation of species proposed as structured biozone so as to streamline plantation program and enhance conservation efforts.

Table 1

Distribution of sand dune flora from the coastal areas of India.

Coast	Genera (n)	Species (n)
West Coast (WC)		
Gujarat (GJ)	57	66
Maharashtra (MH)	40	46
Goa (GA)	91	106
Karnataka (KL)	113	145
Kerala (KA)	34	37
Lakshadweep (LD)	60	67
Total WC	176	267
East Coast (EC)		
Tamil Nadu (TN)	79	89
Andhra Pradesh (AP)	51	57
Orissa (OR)	62	73
West Bengal (WB)	40	43
Andaman and Nicobar (A & N)	23	29
Total EC	120	163
Total (WC & EC)	208	338

Source data: [11-28].

Table 2

Plant species contributing to the similarity in the group clusters.

Group I	Group II	Group III
<i>Acrocephalus indicus</i> (N. Burman) Kuntze	<i>Ammannia baccifera</i> L.	<i>Anacardium occidentale</i> L.
<i>Calophyllum inophyllum</i> L.	<i>Borreria articularis</i> (L.f.) F. N. Will	<i>Calophyllum inophyllum</i> L.
<i>Calotropis gigantea</i> (L.) R. Br.	<i>Calotropis gigantea</i> (L.) R. Br.	<i>Calotropis gigantea</i> (L.) R. Br.
<i>Cassia tora</i> L.	<i>Casuarina equisetifolia</i> Forst.	<i>Canavalia maritima</i> (Aubl.) Thou.
<i>Chromolaena odorata</i> (L.) R.King & H.Robi.	<i>Chromolaena odorata</i> (L.)R.King & H.Robi.	<i>Casuarina equisetifolia</i> Forst.
<i>Clerodendron inerme</i> Gaertn.	<i>Clerodendron inerme</i> Gaertn.	<i>Cocos nucifera</i> L.
<i>Cocos nucifera</i> L.	<i>Cyperus arenarius</i> Retz.	<i>Dodonaea viscosa</i> (L.) Jacq.
<i>Cyperus arenarius</i> Retz.	<i>Hydrophylax maritima</i> L. f.	<i>Ipomoea pescaprae</i> (L.) R. Br.
<i>C. rotundus</i> L.	<i>Ipomoea pescaprae</i> (L.) R. Br.	<i>Pandanus odoratissimus</i> L.f.
<i>Hybanthus enneaspermus</i> (L) F.V. Muell.	<i>Ixora arborea</i> Roxb. Ex. Sm.	<i>Pongamia pinnata</i> (L.) Pierre
<i>Ipomoea pescaprae</i> (L.) R. Br.	<i>Launea sarmentosa</i> (Willd.) Alston	<i>Scaevola sericea</i> Vahl.
<i>Launea sarmentosa</i> (Willd.) Alston	<i>Mollugo disticha</i> (L.) Ser.	<i>S. taccada</i> (Gaertn.) Roxb.
<i>Murdannia nudiflora</i> (L.) Brenan	<i>Oldenlandia biflora</i> L.	<i>Terminalia catappa</i> L.
<i>Pedaliium murex</i> L.	<i>Pandanus odoratissimus</i> L.f.	<i>Thespesia populnea</i> (L.) Sol.ex Corr.
<i>Physalis minima</i> L.	<i>Rothia indica</i> (L.) Druce	
<i>Sesuvium portulacastrum</i> L.	<i>Spinifex littoreus</i> (Burm. f.) Merr.	
<i>Sida cordifolia</i> L.	<i>Thespesia populnea</i> (L.) Sol. ex Corr.	
<i>Spinifex littoreus</i> (Burm. f.) Merr.	<i>Waltheria indica</i> L.	
<i>Tephrosia pupurea</i> (L.) Person.	<i>Ziziphus jujuba</i> Mill.	
<i>Triumfetta rhomboidea</i> Jacq.		
<i>Vitex trifolia</i> L.		
<i>Ziziphus jujuba</i> Mill.		

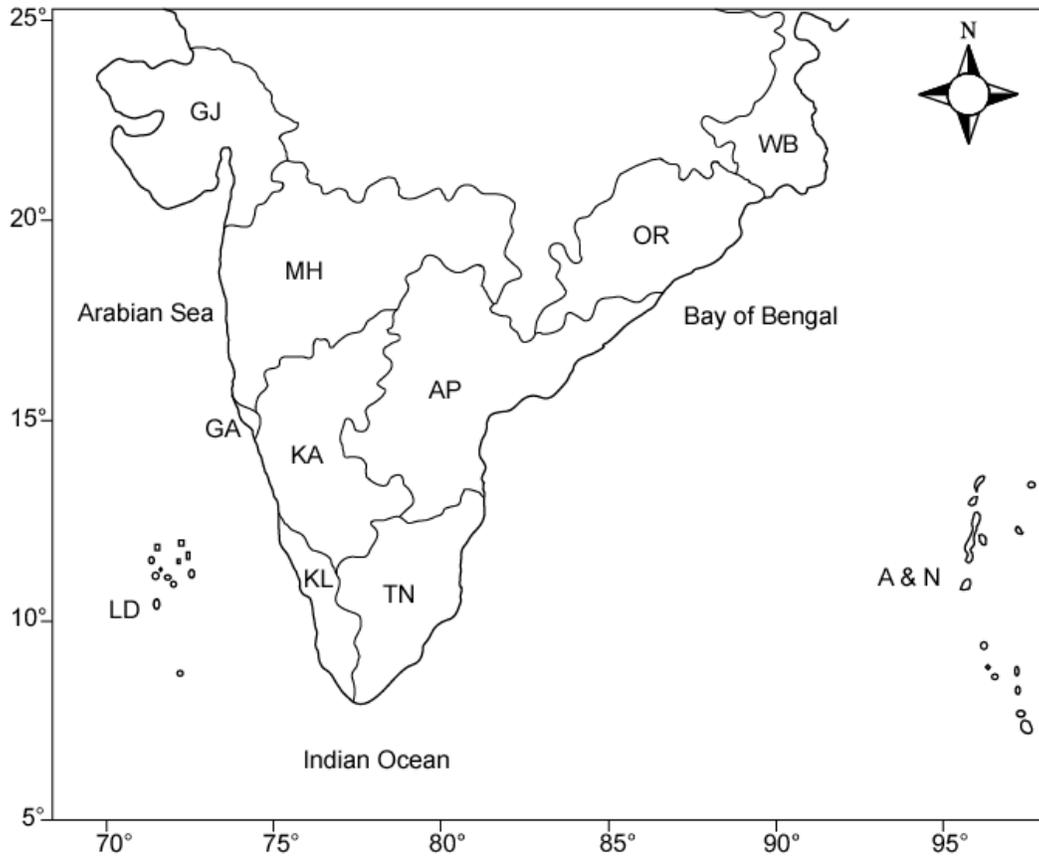


Fig. 1.

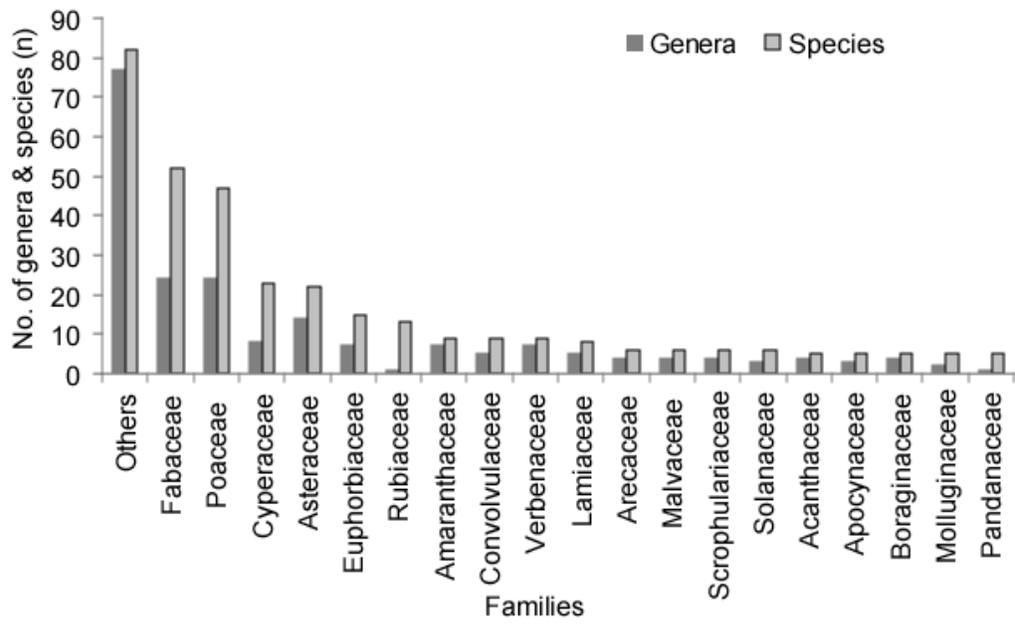


Fig. 2.

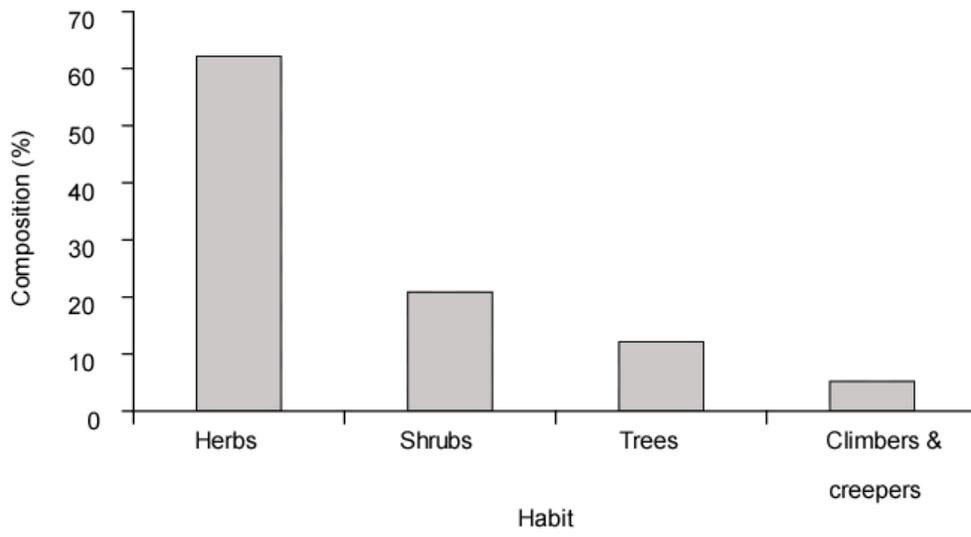


Fig. 3.

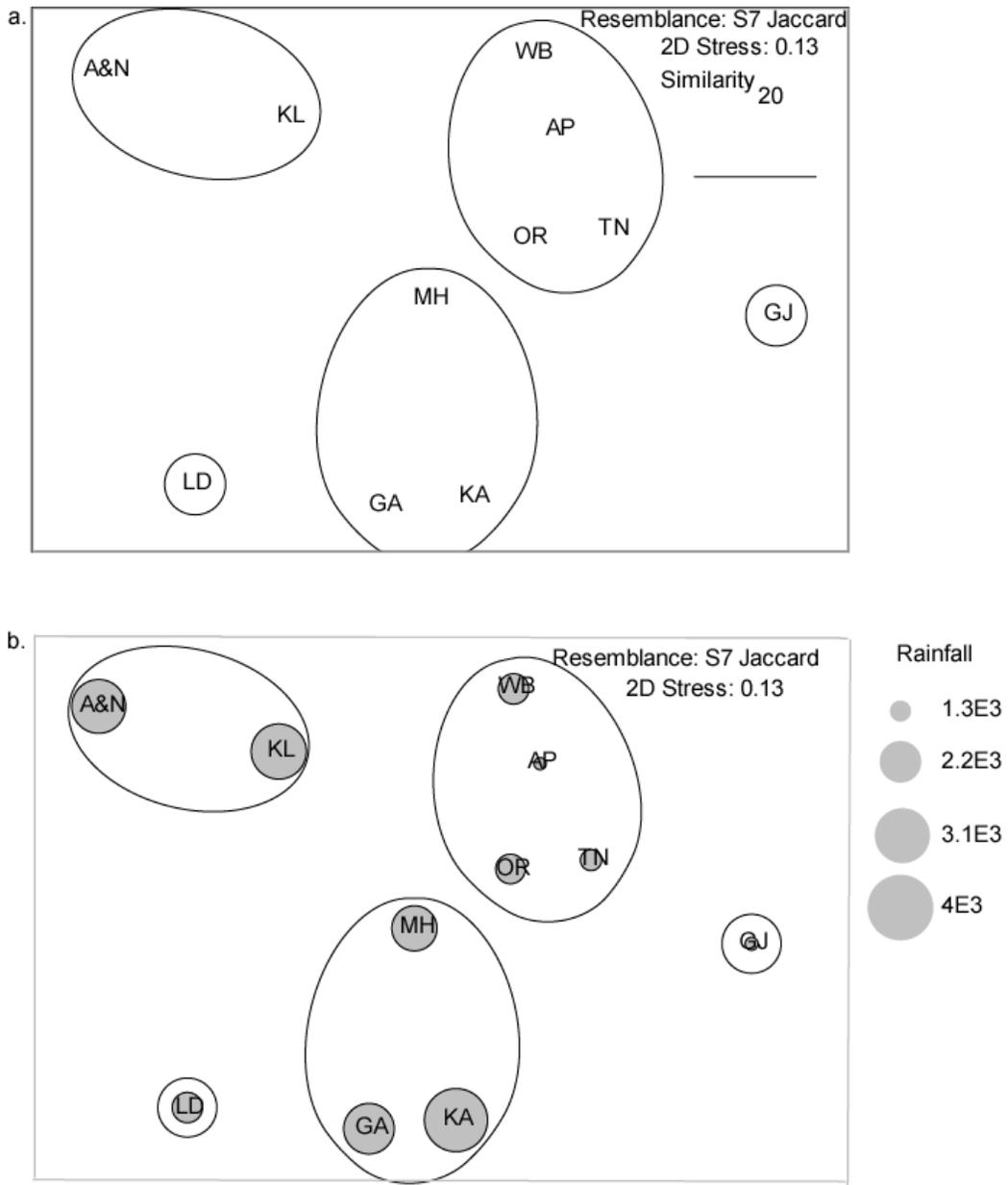


Fig. 4.

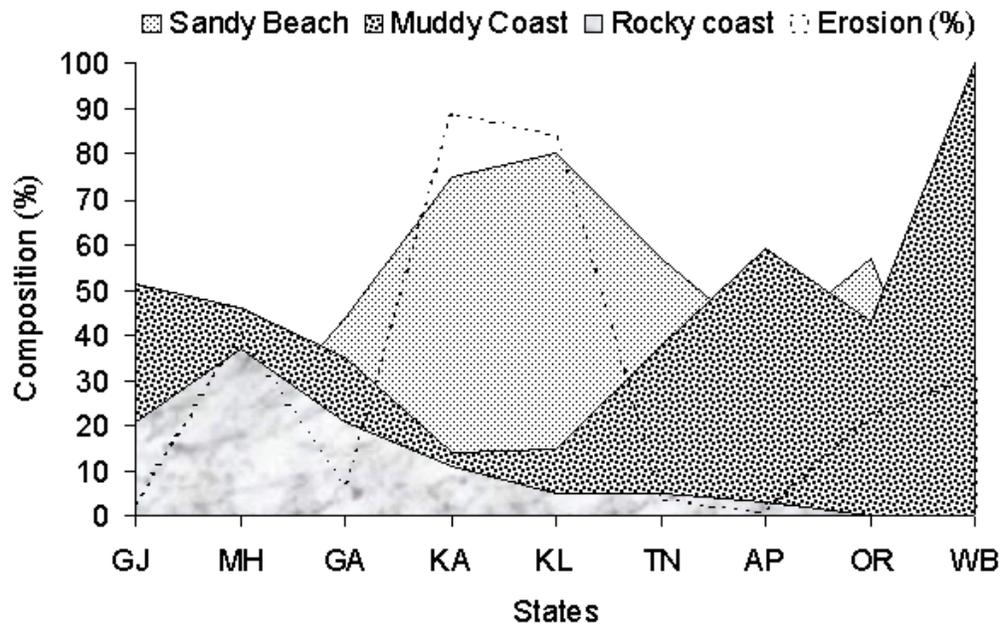
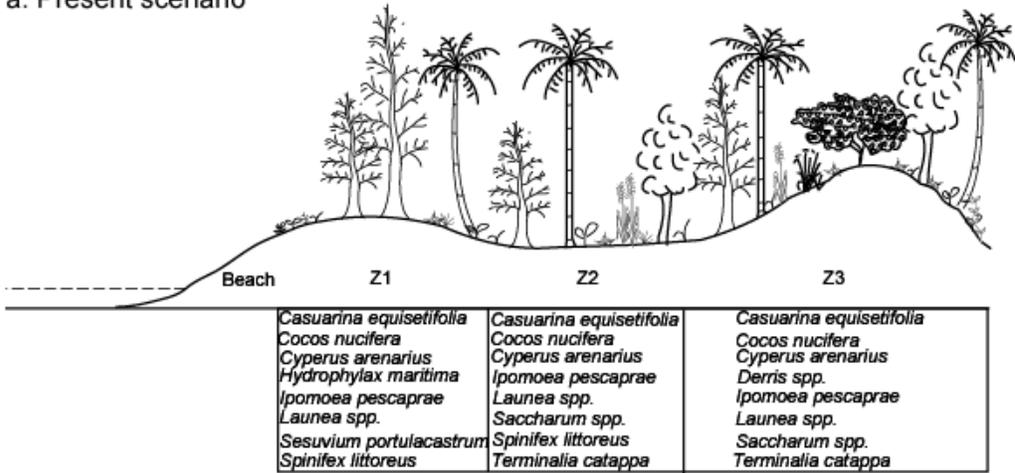


Fig. 5.

a. Present scenario



b. Proposed biozones

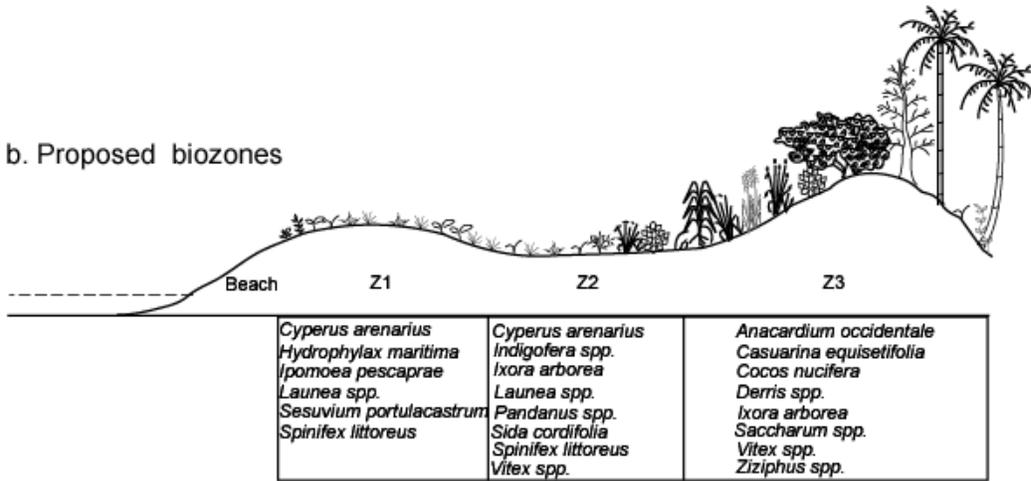


Fig. 6.