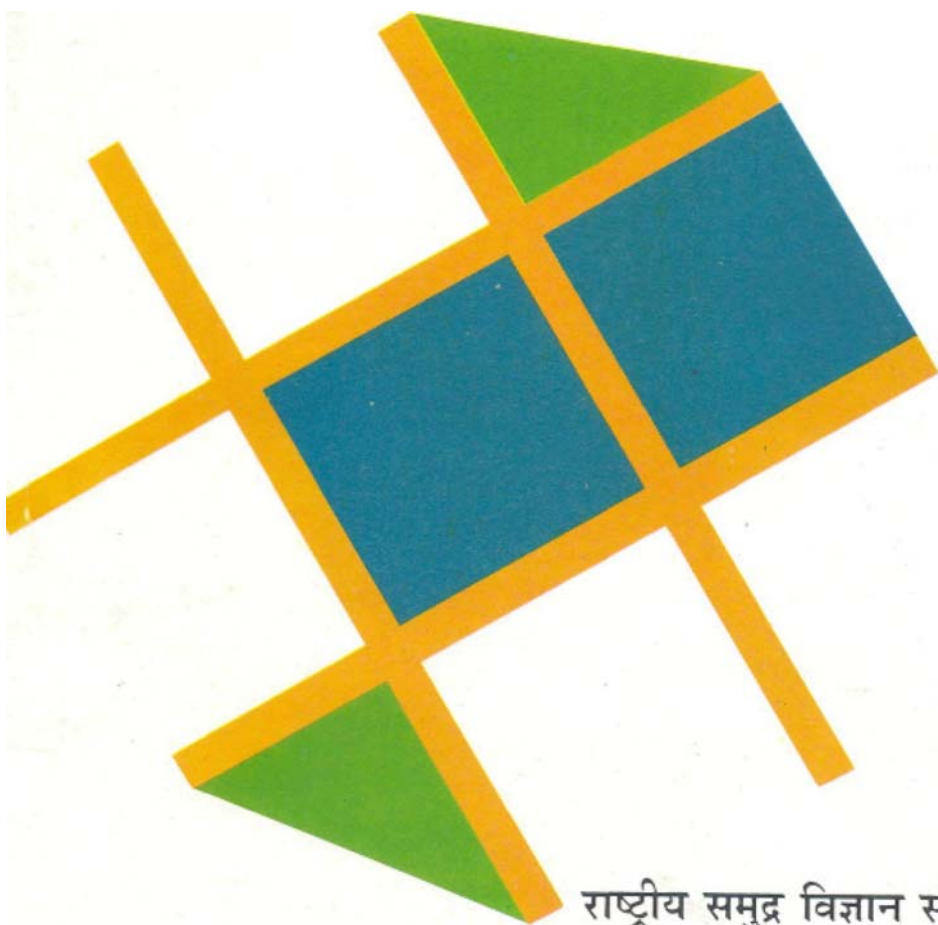


Study of Goa and its Environment from Space

A Report on

Coastal Sand Dune Ecosystems of Goa :
Significance, Uses and Anthropogenic Impacts

March 1998



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STUDY OF GOA AND ITS ENVIRONMENT FROM SPACE

A REPORT ON

**COASTAL SAND DUNE ECOSYSTEMS OF GOA:
SIGNIFICANCE, USES AND ANTHROPOGENIC IMPACTS**

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PREFACE

Until the 1970's, the coastal zone of Goa was largely pristine. However, the advent of tourism and the resultant construction boom along the coastline have induced large scale changes in the geological and ecological set up of the coast. It is observed that the sand dune ecosystems of Goa which are over 6000 years old have borne the maximum brunt of this "development".

The beach - dune environment is a highly organized system. Sand dunes which generally back wide beaches, are features of extreme fragility and sensitive to anthropogenic stress. Sand dunes are *Nature's line of defense* from the forces of the ocean. They also serve as "sand banks" maintaining the dynamic equilibrium of the beach. When vegetated, they support a large variety of plant and animal life, thus adding to the biodiversity.

The present report is the first comprehensive document which addresses human interference on coastal sand dune complexes. This work forms a part of the project "Study of Goa and its environment from space". The results have clearly brought out that anthropogenic activities such as constructions in sandy areas, beach resorts, coastal roads and sand mining are the major factors which have led to the desecration and consequent elimination of sand dunes.

The report discusses the present state of coastal dune belts and suggests measures for their restoration and management. It is hoped that the report will prove useful for microplanning of coastal development.

E. DESA
Director

GOA AND ITS ENVIRONMENT

The project called 'Study of Goa and its environment from space' was sponsored by the Department of Ocean Development, New Delhi. The aim of the project was to monitor changes occurring in Goa's environment due to both natural and man-made factors using past and present satellite images. The work was done jointly with the Department of Science, Technology and Environment, Government of Goa.

Following the liberation of Goa in 1962, the socio-economic development of Goa has been rather fast compared to many other regions in India. Mining, tourism, fisheries and other small scale industries saw a rapid expansion over a relatively short period of time. This required matching developments in other sectors such as transport, river navigation, housing, power supply and freshwater distribution. The land-use patterns also underwent significant changes during this period due to increasing economic activities. This led to the fast degradation of the delicate coastal, marine and terrestrial ecosystems in Goa. Incursion of saline waters into the main lands, disappearance of sand dunes, shallowing of rivers, flooding of residential and commercial areas, marginalization of grazing lands, spread of malaria and other diseases, accumulation of tar balls on beaches are but a few examples.

The present project studies various aspects of Goa's environment with special emphasis on changes that have occurred in them over time. This report" deals with the anthropogenic impacts on coastal sand dune ecosystems of Goa. Other reports under the project are:

- Status of Goa and its environment
- Mapping of sand dune vegetation from space
- Weather and climate of Goa
- Sea surface temperature distribution around Goa.
- Erosion and accretion in Goa
- Coastal geomorphology of Goa
- Mangrove environment of Goa
- Forestry in Goa
- Agriculture in Goa
- Water resources and industrial pollution in Goa
- Mining in Goa
- Urbanisation patterns of Goa

It is hoped that these reports will serve as important baseline documents for future environmental studies in Goa and for planning eco-friendly development in the region.

P. V.SATHE
Principal Investigator

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1. INTRODUCTION

Although humans have modified coasts over the centuries, large scale direct alteration of exposed open sea coasts is a relatively recent phenomenon (Nordstrom, 1994). The coastal zone of Goa had been exclusively used for agriculture, farming, traditional fishing and recreation (Dume, 1986). Nowhere did we have evidence wherein, for example, sand dunes were razed to build houses. Having understood their nature, our ancestors treated coastal dune belts with sanctity (Lobo, 1988). Traditional villages, ancestral mansions and roads along the coast were all located behind the dunes (and away from rivers and wetlands), which remained as areas of peace and tranquillity, this being a unique example of the harmony that prevailed between man and Nature (Lobo, 1988; Alvares, 1993; Mascarenhas et al., 1997).

Large scale development of the coastlines of the world has accelerated in the last few decades (Lundin and Linden, 1993; Nordstrom, 1994). In this, Goa has apparently not lagged behind. Several coastal areas have changed from virtual wilderness in 1970's to haphazardly developed stretches, full of concrete buildings and related structures, in less than 20 years. The Baga - Candolim coast is a classic example of frenzied development (Mascarenhas et al., 1997; Sawkar et al., 1997). Several shore fronts have been designed and built in such a manner that they bear little resemblance to the coast that formerly existed. Many coastal communities thus experienced a dramatic growth during this period with constructions of high rise buildings, resorts, residential dwellings that mushroomed almost all over the coastal zone of Goa.

Therefore, during the last two decades, the advent of tourism, population increase coupled with building activity and modern societal demands, has resulted in large scale changes in the geological and ecological setup, and has indelibly altered ecosystems, land use patterns and the coastal zone landscape (Mascarenhas et al., 1997). In this context, of all the coastal landforms, sand dunes which are sensitive geomorphic features that act as Nature's line of defense against the forces of the ocean, have suffered the greatest from anthropogenic pressures (Lobo, 1988; Mascarenhas, 1990, 1996; Narayan, 1997), as can be observed by any one who walks along the shores of Goa.

The nature of relationship between sand dunes and humans has seldom been attempted. This subject has now turned into a delicate issue mostly because of conflicts (Anonymous, 1995; Alvares, 1996) between real estate developers, builders, planners, bureaucrats and politicians who insist on shore front "development" under the banner of demands, and environmental scientists and NGO's who insist on basic ecological and environmental principles. More importantly, the influence of anthropogenic activity on the sand dune complexes of Goa has never been investigated either. Considering that the open sea front of Goa is being built up at a very fast pace, it is not known in what way the heavy developmental activity is affecting the sandy areas in general and the dunes in particular, as scientific documentation on the management of coastal sand dunes is hard to find. Therefore, with this objective in view, the purpose of this report is to describe the sand dune ecosystems of Goa, discuss their geological significance and utility from the societal point of view, identify various anthropogenic impacts, delineate

areas of concern and suggest measures to restore, manage and conserve them for posterity.

2. GEOLOGICAL SETTING

The coastline of Goa is characterized by continuous stretches of sandy beaches, occasionally interrupted by rocky promontories or headlands which protrude as far as 2 - 3 km into the sea (Figure 1). The headlands consist of basaltic / metamorphic formations capped by laterite, and intruded by basic dykes. Sandy beaches are found between promontories. In general, the width of the beaches in this region varies between 50 and 180 meters and are generally fringed by 1 to 10 m high sand dunes which extend almost half a kilometer or more before merging with the hinterland coastal plain.

Several places along the coastline are intersected by dynamic estuarine river systems which cut across hinterland formations and wind their way towards the Arabian Sea; these can be classified as tide dominated coastal plain estuaries. The coastal zone comprises an intricate system of wetlands and lowlands, tidal marshes, cultivated paddy fields, intertidal beaches, all intersected by canals inland lakes, bays, lagoons and creeks, features which are governed by regular tides which raise or lower water levels by 2 or 3 meters daily. It is these geomorphic features which support mangrove thickets which are today visible far into the hinterland along river banks, distributary channels, creeks and lagoons. Several mangrove islands and localised mangrove swamps can be identified along all the seven rivers (Untawale et al., 1988); these contain a variety of mangroves, most of which are in various stages of degradation mostly due to human interference.

3. PREVIOUS WORK AND ENVIRONMENTAL LEGISLATIONS

In the past, some scientific publications on selected physical and geological topics related to the beach - dune environments of Goa were published. These investigations include: grain size variations of Calangute beach sediments in relation to seasonal cyclic events (Veerayya, 1972; Veerayya and Varadachari, 1975); mineralogy of beach and dune sands of Morjim - Arambol beach (Kidwai and Wagle, 1975); geomorphology of the coast with descriptions of various land forms (Wagle, 1982); temporal variations in the geometric form of beaches over different time scales in response to wind and wave climate by measuring beach profile configurations (Murty et al., 1982); studies on a organic sediment deposit stratified within the dune sands of Colva where sand dunes are as old as 6400 years (Kale and Rajaguru, 1983); changes in the beach configuration of selected coastal sites of Goa to ascertain their stability and seasonal erosional and accretional phases (Shenoi et al., 1987); type and nature of sand dunes, dune sand ridges and their deflation by winds along the central parts of Goa where sand dunes are surviving since 5000 years BP (Sriram and Prasad, 1988); nature of beach profile changes in response to storm events and the storm depositional regime along the coast (Chakraborty, 1989); and spatial distribution and seasonal variations of calcium carbonate of some dune - beach systems (Veerayya, 1993). The synthesis of all the papers described above

explicitly indicates that all these publications on beaches are of pure research and academic interest only.

In comparison, scientific documents related to beach - dune environments of interest to the 'common man' are very few. Lobo (1988) authored the first scientific paper of societal importance dealing with the environmental impacts of sand mining on coastal areas, the accompanying erosion and the need for the preservation of dunes. Alvares (1993) briefly assessed beach systems but explained in detail the associated man made problems such as dune sand mining. Desai (1995) studied various aspects dealing with the ecology of sand dune systems, types and uses of dune vegetation, and their management. Mascarenhas (1990, 1996) described the functions, utility and the fate of sand dunes with reference to present societal demands. More recently, Mascarenhas et al. (1997) and Sawkar et al. (1997) demonstrated the influence of various human modifications and tourism related activities on the coastal zone landscape (including estuaries) and violations of coastal environmental regulations during the last few years.

Similarly, there a number of official (public) reports on various aspects of coastal issues and primarily deal with policy matters regarding coastal activities, land use and tourism. The Eco Development Plan (Anonymous, 1982) comments on the development along the rivers and beaches, tourism aspects, ecological conservation, potential damage to beaches, control of development along hill slopes and beaches and coastal area planning. The Master Plan for Tourism Development (Anonymous, 1987) describes infrastructural problems and classifies tourism development into tourism development areas, tourism resort areas and village tourism areas; it also introduced the concept of carrying capacity of an area. The status report on Environmental Management Plan (Untawale et al., 1988), an unpublished report, describes coastal ecosystems, the status of physical developments, areas for conservation, development of coastal stretches and preservation of beaches. The Regional Plan for Goa (D'Souza et al., 1988) highlights detailed town and country planning aspects, aims at rationalisation of disparities in development, discusses integrated rural development, environmental conservation and criteria for the improvement in the quality of life. It also discusses the general importance of sand dunes which includes the policy for the management of sandy beaches.

Although these documents were published in public interest, they are unheard of as they are not readily available for public reference. Although lot of publicity was given to the tourism master plan, it never saw the light of the day; likewise, other documents have been shelved. All these documents have therefore turned into an exercise in futility. Moreover, the government brought an ammendment empowering itself to alter and/or modify the regional plan whenever required; this plan is now obsolete. Thus, a sincere attempt to advocate sustainable development has been ruined by the authorities themselves.

With this objective in view, and since uncontrolled development had started along the coastal zone of the country, the Ministry of Environment and Forests (MEF), New Delhi, enacted a legislation called the Coastal Zone Regulation (CRZ) Notification (Anonymous, 1991) issued under the Enviroment Protection Act of 1986.

The main purpose of this notification which lists various rules and guidelines, was to control and minimise environmental damage to coastal stretches including estuaries and backwaters. Accordingly, all coastal states of India were bound to formulate coastal zone management (CZM) plans classifying coastal stretches as coastal regulation zones, based on the nature of existing ecosystems and/or development. The CZM plans (Anonymous, 1996, a) prepared by the state of Goa were rejected (Anonymous, 1996, b) as the document contained several flaws and some misleading information. In the meantime, flagrant misuse of coastal spaces of the country forced some environment conscious citizens to file a public interest litigation based on which the Supreme Court of India validated the CRZ Notification on 25 April 1996. In June 1996, The MEF requested the National Institute of Oceanography, Goa, for information on the ecosensitive areas of coastal Goa. After a detailed survey, all data was submitted to them, in August 1996 in the form of an unpublished report (Anonymous, 1996, d). The final approval of the plans, with certain modifications to be incorporated, was issued in September 1996 (Anonymous, 1996, e). This is the prevailing law which governs developmental activities along the coasts, rivers and backwaters of Goa.

With the formulation of CRZ, India can be classified amongst the first few countries in the world to take legal steps to protect its beaches and sensitive coastal ecosystems from unplanned development and to demarcate specific areas for conservation. This objective has been achieved by categorising coastal stretches under CRZ I, CRZ II, CRZ III and CRZ IV.

4. METHODOLOGY

This document is based on extensive field observations and surveys along the entire coastal zone of Goa over the last two years. Field checks were carried out in July and August 1996, and January, April and December 1997; this work is still continuing. Existing toposheets, aerial photographs and recent satellite imageries were consulted to delineate sandy stretches including pocket beaches. More than 200 sites were inspected and surveyed; detailed ground truth data has been collected with which the areas of concern can be identified. Various types of geological samples of different landforms including dune sands were also collected. The photography of natural features of various coastal ecosystems has been undertaken to justify their ecological importance and their intrinsic value, and also to depict the present coastal scenarios. Violations of coastal zone environmental regulations have been noted where they exist; this exercise mostly consists of identifying man-made structures in wrong places along the coastal tracts. Various official and other reports, published and unpublished, have been made use of for comparison with our data. Discussions with respective officials, planners, bureaucrats, scientists, politicians concerned with coastal issues are of immense use from the point of view of planning and management. Similarly, the talks with natives / locals throw details about the past scenarios along the shores as these inhabitants have lived on the coast since long.

5. COASTAL SAND DUNE ECOSYSTEMS OF GOA

The coast of Goa consists of a combination of beaches, rocky shores and headlands which protrude into the sea. Of the 105 km long coast, more than 70 km

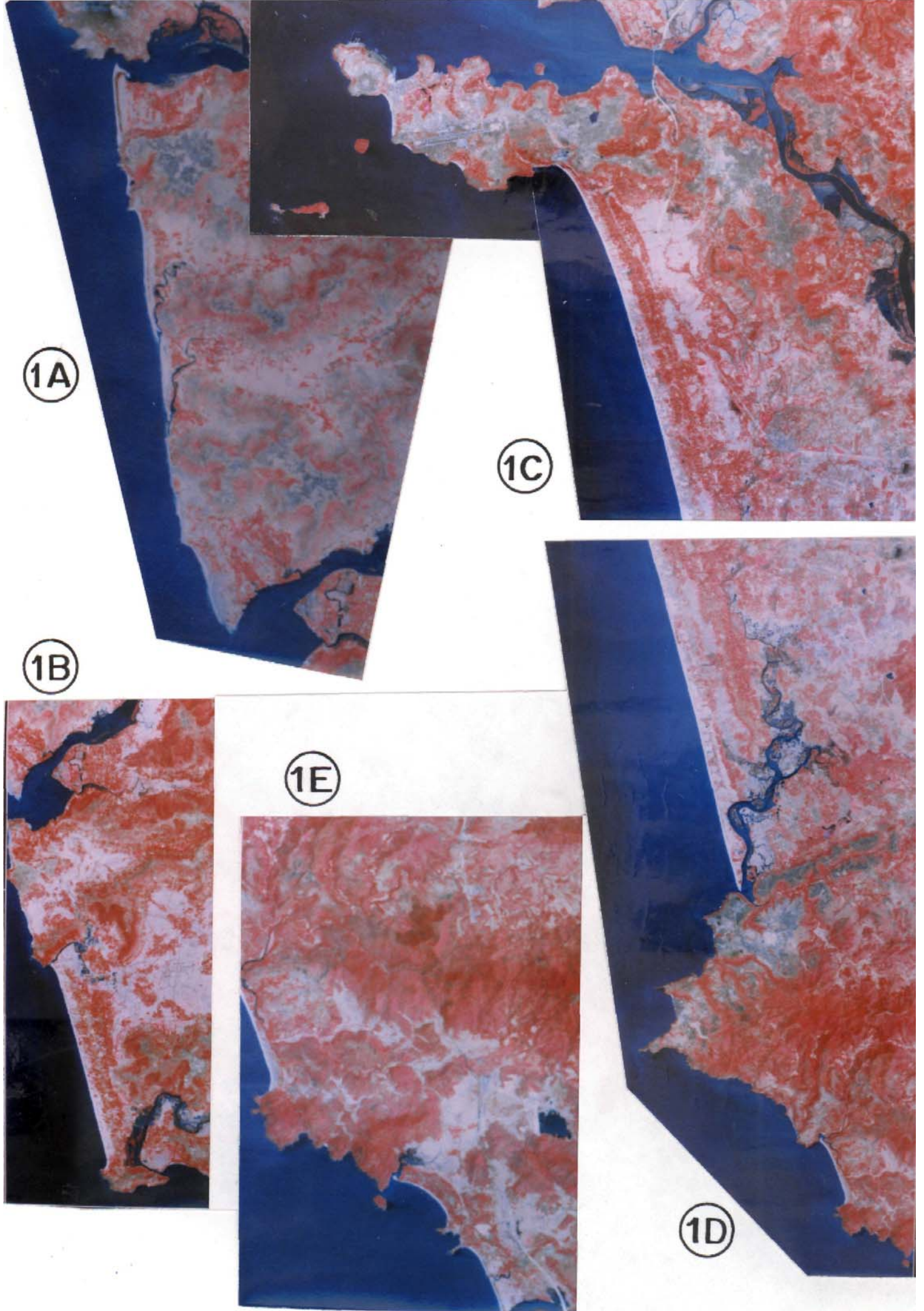
comprise sandy beaches (including those within estuaries), all backed by several rows of sand dunes (Figure 1). The following is a brief account of the sand dune complexes along the coastal zone of Goa; for seasons of simplicity and for the purpose of this report, the entire coast is subdivided into four major sectors and some small parts:

Querim - Morjim:

At Querim, the coastal area from river Tiracol southwards is characterized by a long belt of stable sand dunes (Figure 1A), is well preserved in its pristine form and hence can be termed a virgin area. Casuarina vegetation is very prominent. The Government of Goa has acknowledged Querim as one of the most beautiful beaches in Goa (Anonymous, 1996,a). The southern part of Querim comprises a rocky coast. At Arambol - Mandrem, in the northern part, a sweet water body is located adjacent to the beach at the base of a hill, being one of the two such ecosystems in Goa. The entire coastal stretch is protected by continuous 5 - 6 m high sand dunes with dune vegetation. Some of the sand dunes are shifting in nature as can be observed in Mandrem where new dunes, presently low in height, are being formed; this makes the area a prograding coast. In this stretch, two major creeks which open into the sea are lined with mangroves with a luxuriant swamp a little inland, all of which are found behind sand dunes (Figure 1A); these are some of the exotic areas found along the north Goa coastal belt. At Morjim, a long strip which terminates at the mouth of river Chapora is marked by extensive rows of sand dunes with dune vegetation, being more pronounced in the southern part. The coastal stretch is thickly populated by coconut trees. The Morjim area which is so far free from major construction activity, has been acknowledged as sensitive and important as sea turtles come to nest here; this is an annual post-monsoon event that has been demonstrated this year (Anonymous, 1997,a).

Chapora - Sinqerim:

Below the Chapora fort, and especially at Vagator, low sand dunes are common over a limited stretch. Dune vegetation with coconut trees are also seen. The southern part of Vagator comprises a rocky coast with some sandy pockets. Similarly, at Anjuna, south of the main tourist point, there are extensive sand dunes with vegetal cover along the coast. Many dunes are found to be degraded and altered. Coastal erosive processes, as evidenced by chaotic strandlines, are observed at several places along the shoreline in this sector. Anjuna beach terminates against a rocky headland which continues further south. The Baga - Calangute stretch consists of sand dunes, with diverse dune vegetation (Figure 1B). A large number of dunes are severely altered and some razed, levelled and eliminated as this belt is extensively and haphazardly built up. At Calangute, although this zone is the main point where tourists converge, sand dunes, with dune vegetation and casuarina, in various stages of degradation are found north and south of the Tourist Hostel. The Calangute - Sinqerim stretch up to the Aguada headland is marked by a continuous chain of 5 - 6 m high sand dunes with diverse dune vegetation and coconut trees. As in the north, this area is also overbuilt. Several roads, perpendicular to the coast and across dune



belts, have been constructed in these areas. To the south, the Aguada coast is rocky and barren up to mouth of the Mandovi estuary.

Dona Paula - Caranzalem - Miramar (Mandovi estuary):

A prominent sand dune belt is found backing the Caranzalem - Miramar beach. New dunes, presently low in height and capped by vegetation, are in the process of formation along the upper reaches of Miramar - Caranzalem beach; it terminates against the wooded hill slopes of Cabo promontory. However, sand dunes are progressively being destroyed. At Campal, due to severe erosion, the primitive beach no longer exists, except for a small portion near Panjim city. Instead, a sea wall, almost 2 km long, has virtually replaced the beach; this concrete / stone wall is placed in the intertidal zone. The opposite Nerul (Coco) protected beach does not show any significant dunes. The Miramar - Caranzalem strip is the most prominent dune belt within the estuaries of Goa.

Dona Paula - Agassaim (Zuari estuary):

This strip mostly consists of several pocket beaches backed by wooded hill slopes, now in various stages of degradation (Dona Paula). Notable sandy beaches are found at Vainguinim, Odxel, Bambolim, and particularly at Siridao where dunes are low. The opposite side of the estuary is generally devoid of beaches except the sandy portion at Vasco.

Vasco - Bogmalo:

The sea front comprises rocky headlands, sparsely wooded, with only two major beaches: the one at Baina is severely degraded whereas the one at Bogmalo, lined by dense coconut trees, is more natural. Here, low sand dunes are present but some of them are obliterated. To the south, the coast is mostly rocky (Chicolna, Dabolim) with a few pocket beaches and secluded coves such as the one at Hollant.

Velsao - Mobor:

This linear stretch with a very wide beach is backed by the largest and the longest strip of sand dunes of the entire coastal zone of Goa (Figures 1C and 1D). Dunes are mostly concentrated within 500 - 600 m from the shore (Lobo, 1988) but are often seen to extend as far as 5 km from the coast as is the case near Margao.

At Velsao, the coastal area is characterized by thick coconut plantations; sand dunes are low. Most of the shoreline is under threat of erosive processes as evidenced by eroded berms and uprooted trees. The Cansaulim - Arossim part consists of very prominent 6 to 8 m high vegetated sand dunes. Many dunes have been levelled. The Utorda - Majorda - Consua - Betalbatim coastal zone is marked by long strips of sand dunes, some as high as 8 m, with associated vegetation. Coconut plantations are prominent. At several places in this stretch, sand dunes have been flattened and obliterated. Severe beach erosion is observed near Majorda beach resort. At Colva, sand dunes, 5 to 6 m in height, with dune vegetation and coconut plantations are still

seen on either side of the main beach point which has turned into a crowded area. A small seasonal lagoon along the beach is an annual hydrodynamic feature at Colva. The Sernabatim - Benaulim - Varca - Cavelossim - Mobor coast is the most prolific as it is packed by protective sand dunes, varying in elevation from 3 to 10 m (Sriram and Prasad, 1988), with associated vegetation including luxuriant casuarina plantations as in Varca. Here, several dunes have been flattened and even removed. A similar situation is observed at Cavelosim and particularly Mobor where sand dunes are severely damaged. Large dune areas have been razed. Sand extraction is rampant in the entire stretch. Several new coast perpendicular roads have been built during the last few years. The Cavelossim - Mobor coastal strip, a unique sandy peninsula about 250 m wide found between the ocean and the river Sal, is being built up at an exceedingly fast rate. The stretch from Velsao up to Mobor peninsula, characterized by the most majestic sand dunes, is the most exquisite dune belt of the entire coastal zone of Goa.

Cola - Agonda - Palolem:

At Cola, the northern and southern parts have numerous small sandy pockets and beach fronts, all located within promontories which consist of evergreen hill slopes that extend into the sea (Figure 1E). The area displays an outstanding natural beauty (Anonymous, 1996,a). The Agonda area which comprises a kilometer long secluded beach between two wooded headlands is backed by low sand dunes in the southern part only. The complete shoreline is prone to erosive forces. This is more evident in the northern part of the beach which appears to be a geologically dynamic shoreline, is prone to monsoon inundation and has been subjected to severe erosion as seen from a large number of uprooted trees lying on the beach. In the northern extremity, two sheltered creeks with luxuriant mangroves makes it an unique ecosystem adjacent to the open sea. Palolem is another popular protected beach between two thinly wooded rocky headlands. The entire coastal area consists of luxuriant coconut groves; low sand dunes are seen in the southern part being less prominent in the north. Although localised, this shoreline is eroding and retreating at a fast rate. Further south, the virgin Koloma beach between two promontories, and the pristine Rajebag beach backed by dunes and with a sweet water lagoon at one end, are the two noteworthy sandy areas.

Talpona - Galgibaga:

The Talpona river mouth area comprises a unique ecosystem with prominent sand dunes and associated casuarina vegetation along the northern sea front, a luxuriant growth of mangroves within the estuary and a headland with a thick forest cover in the south. The Talpona - Galgibaga stretch comprises a linear beach with a minor wooded headland in between. The entire belt is characterized by majestic sand dunes, some as high as 6 - 8 m. At some places, close to the existing parallel road, high dunes have been blatantly razed and obliterated. The southern extremity of this beach stretch is marked by casuarina trees. The Galgibaga river mouth is almost identical to the Talpona estuary with sand dunes and casuarina vegetation in the northern side, mangroves within the estuary (Maxem) and a lush green wooded headland forming the southern part.

Maxem - Polem:

Except for the mangrove clad Maxem backwaters, the entire shore up to the southern border is rocky but with vegetated slopes jutting into the sea. Pocket beaches and sandy patches are found along this stretch, the most prominent being the secluded Xendrem beach with a rocky shore, and Polem beach less than a kilometer long and well protected with promontories; sand dunes are now consolidated and hence appear to be very ancient.

6. FORMATION, SIGNIFICANCE AND USES OF SAND DUNES

6.1. Formation And Evolution Of Coastal Dune Systems

The main prerequisites for the formation of sand dunes are wind, sand and vegetation, three elements with complex and dynamic interactions (Carter, 1988). Wind plays the most important role; its direction, frequency, duration and speed are to be considered as only winds with a speed greater than 16 km/hour can lift, displace and transport fine dry sand (Paskoff, 1989, 1994). This is more so along low gradient beaches particularly when they are subaerially exposed at low tides, and when strong winds blow perpendicular to a particular coast.

The vegetation which constitutes inland plants that grow immediately behind the beaches also play a key role in dune formation since these objects act as wind breakers due to which wind is forced to drop sand along its path. Vegetation thus traps and stabilises moving sand. These plants are adapted to an inhospitable environment characterized by a mobile substrate, saline atmosphere and a regular bombardment of moving sand (Paskoff, 1989).

The first step in the formation of a dune, by plants tolerant to salt, is a berm which is an accumulation of sand brought up by the waves on the beach at a point just above the highest high tide (Figure 2A). These plants flourish with the organic matter brought by high waves during storms or heavy winds. The berm swells due to the eolian import of sand. Thus these small sand mounds which form, finally develop into a continuous chain of sand dunes. These eolian bedforms can be symmetrical, several meters in height and can vary in size from place to place. Their dimension depend on the degree of evolution and the aptitude of vegetation to trap and retain sand.

The evolution of a coastal dune system strictly depends on the sedimentary budget of the beach which refers to the relation between the quantity of sand brought in by winds and the sand removed by tides and littoral currents. Their evolution is also dependent on the conditions of the sea level which can be stable, or in increasing or decreasing mode. Based on the above criteria, four major typical models can be proposed (see Figures 2B - 2E):

When the sea level decreases, the subaerially exposed beach area increases; the sand budget is positive and hence the beach progrades and advances towards the sea (Figure 2B). The surplus sand that is available forms a new sand dune seaward of the

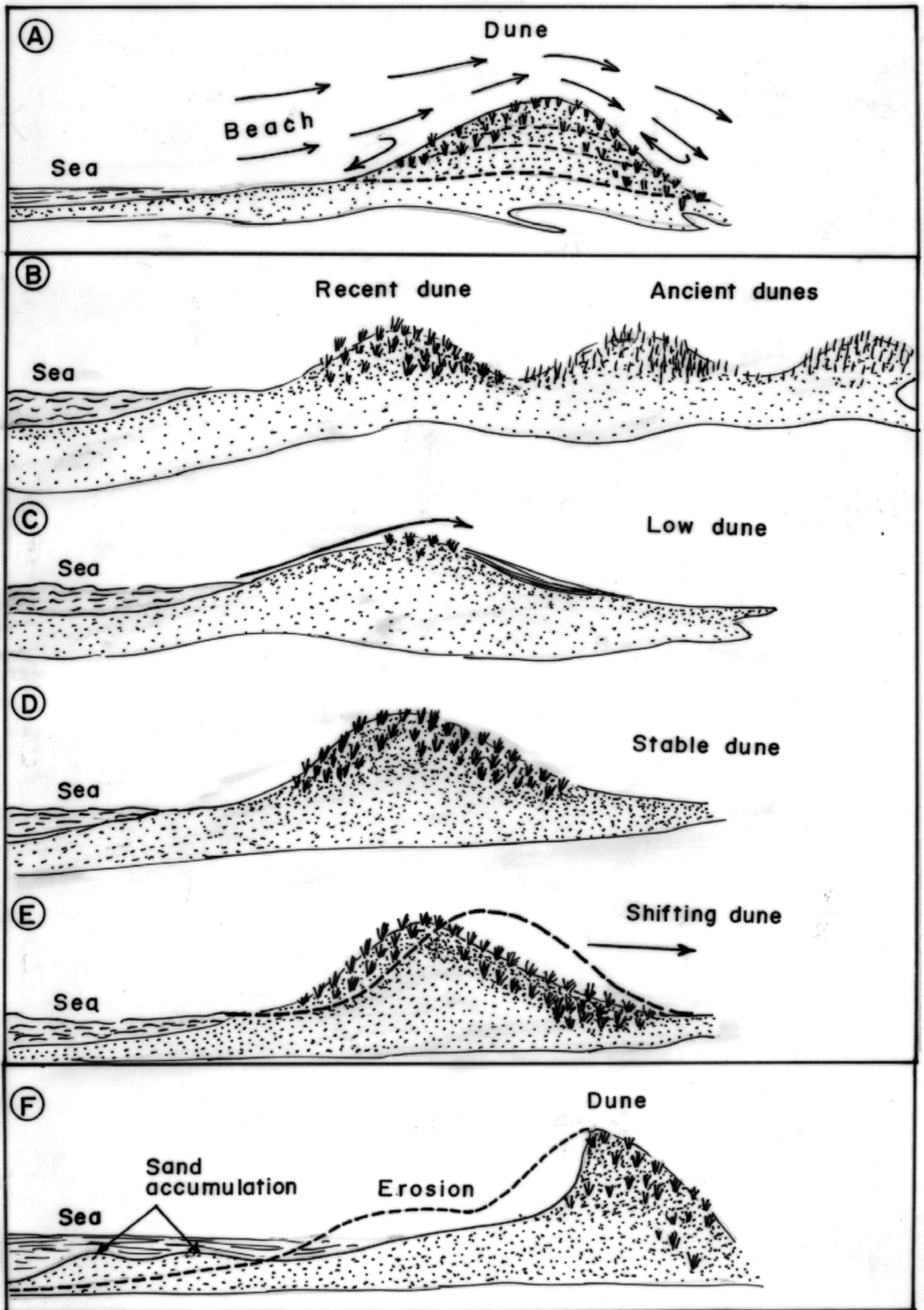


FIGURE -2

existing ones which become stable or inactive as they are no longer fed by sand. In this way, coast parallel new dune chains are formed. The inner limits of the new dune strip would signify the paleoshoreline as the coast advances.

When the sea level rises, beaches are flooded due to which they narrow down and thin out; thus, the sand budget is negative. In such a case there is hardly any possibility for the formation of new dunes; only a low berm with minor vegetation is normally found (Figure 2C). In such situations, high waves often wash over the dunes and is accompanied by erosion of the sand body.

When the sea level is stable, the sand budget is in a state of equilibrium. Therefore, the shoreline remains stable and so is the adjacent dune belt with individual dunes which are broad and high (Figure 2D).

When the sea level shows an increasing tendency, as is the case worldwide at present, the sand budget is slightly negative. In such a case, there is a consequent sediment starvation; high waves and stormy seas force the shoreline to retreat resulting in a landward migration of the sand dune and shoreline as well (Figure 2E).

The above models depict various stages of sand dune evolution and hence the evolution of the coastal landscape on a geological time scale, depending upon the environmental conditions. However, it is the model shown in Figure 2E which should generally be applicable at present, considering the fact that the global sea levels are on the rise. This criteria has to be considered and be given due importance in the planning and management of open sea fronts; these aspects are elaborated in the later parts of this report.

6.2. Temporal Geological History Of Sand Dunes

The temporal evolution and geological history of the sand dunes of Goa has never been studied in detail; but some pertinent facts are mentioned here (Figure 3). At Miramar, our unpublished data (Figure 3C) of two vertical sections (one of a dune and the other a road trench) indicate that, from the top downwards, the sediment is exclusively composed of medium sands only. The section shows colour contrasts in various shades of yellow evidently related to the climates which prevailed during the past. The most prominent feature of this section is the occurrence of a seam of black sands near the base of the sequence. This black layer rich in heavy minerals, about 10 to 30 cm thick, shows irregular but sharp top and bottom contacts (unpublished data). Detailed field observations revealed that this black sand layer has a significantly wide spatial distribution as it is found to extend from Campal to Miramar and even further to Caranzalem and Dona Paula; this layer thins out within a kilometer towards the hinterland. A similar black layer intercalated within dune sands has also been observed at Velsao. In the entire area, the black mineral seam is found at different depths from the surface.

Similarly, at Galgibaga river mouth, an indurated sandstone outcrop, resembling a beach rock, was identified at the base of a sand dune (Figure 3B). As this consolidated material was also found at another place in the vicinity, this rock

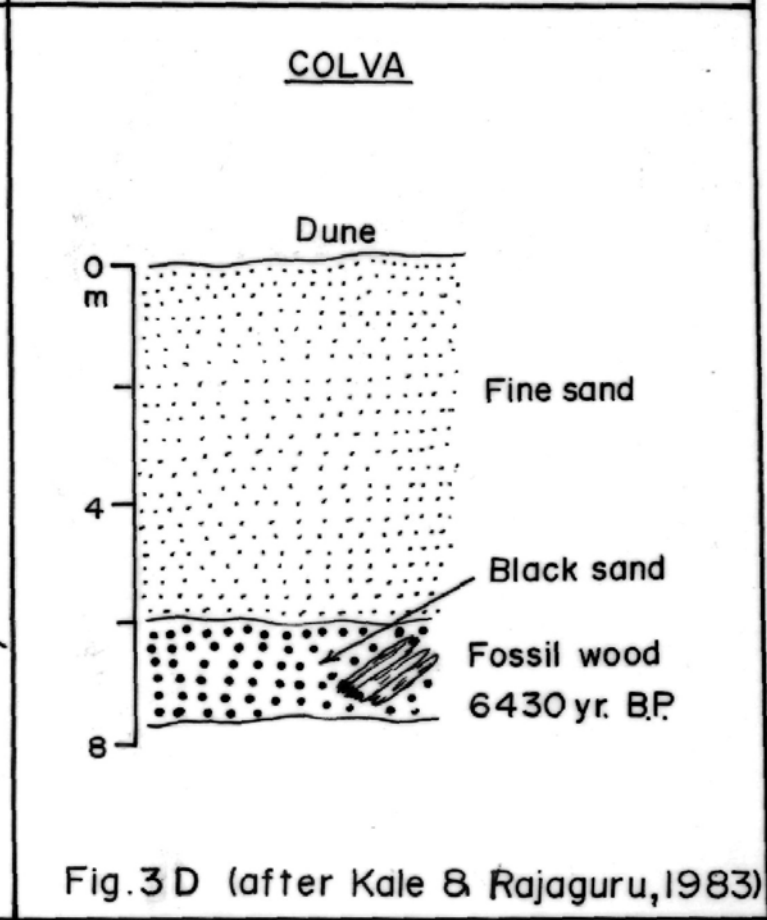
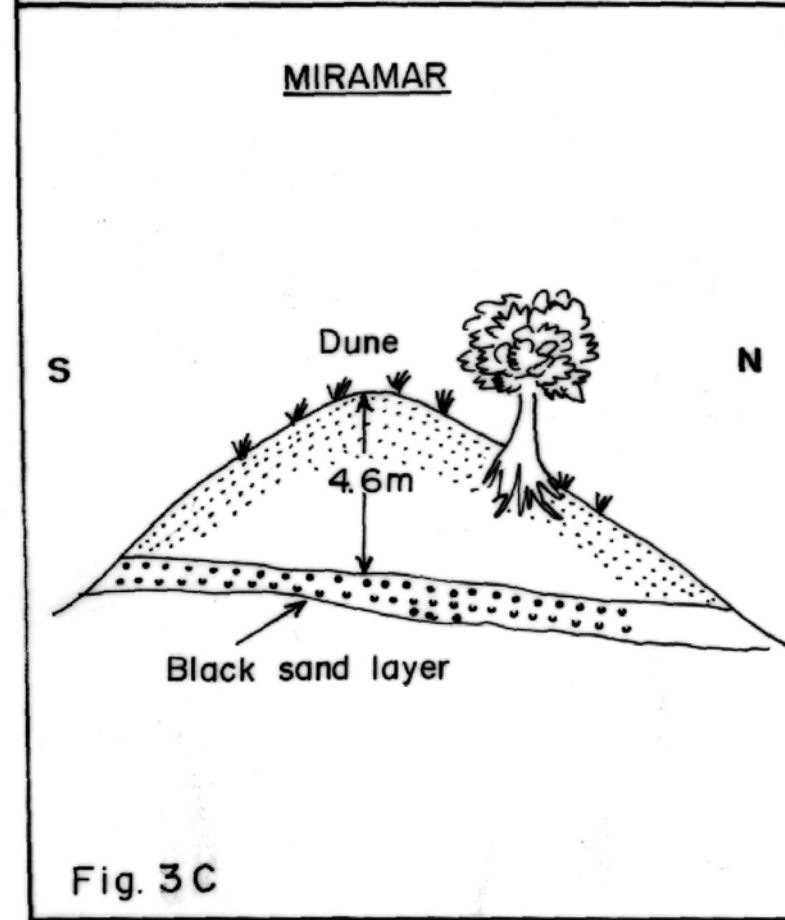
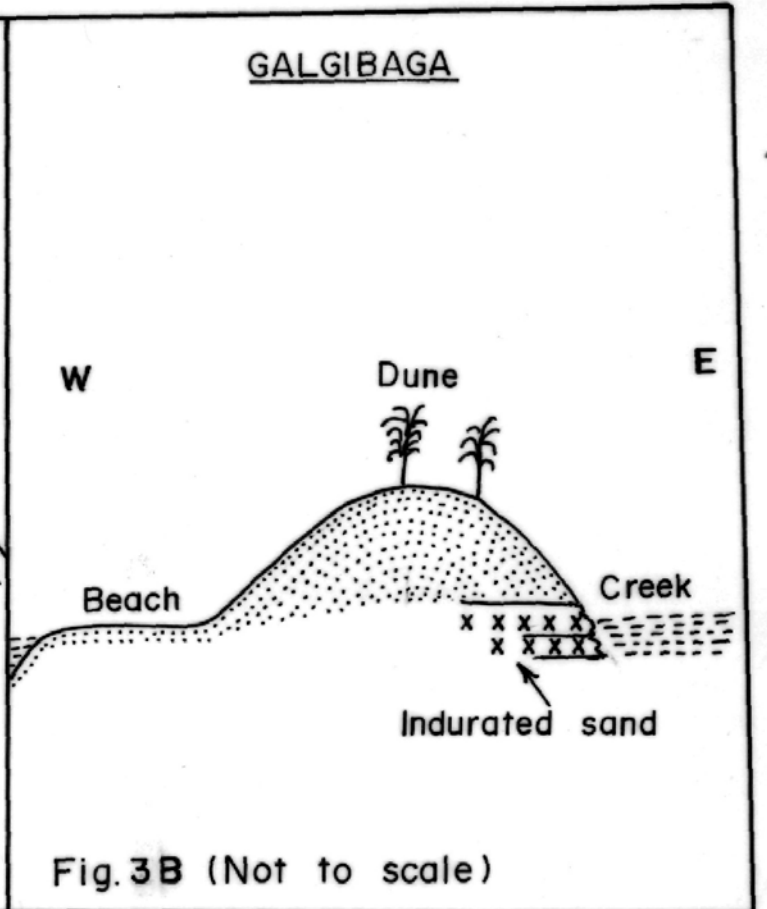
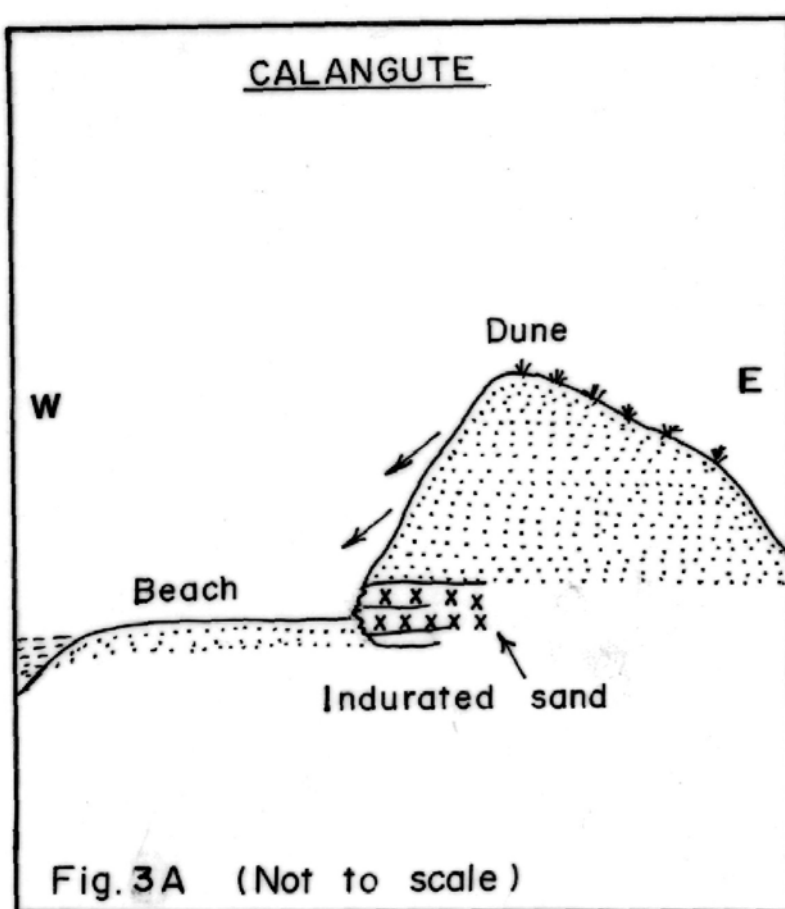


FIGURE - 3

appears to underlie the entire dune of the area. A similar rock type was also identified at the base of a dune north of Calangute (Figure 3A); the type and nature of this rock has not been ascertained yet.

Based on the cases (unpublished data) presented above, it is obvious that dune sands were deposited only after the mineral layer (Miramar) and the indurated sand body (Galgibaga) were formed. Therefore, it can be suggested that if the two events can be reliably dated, it is possible to correctly estimate when the sand dunes of the two respective areas came into being.

However, it may be pertinent to note that Kale and Rajaguru (1983) identified a black organic layer with vegetal debris at the base of a dune at Colva (Figure 3D). A piece of wood which was dated yielded an age of 6400 years. Since the dunes overlie this layer, it is obvious that the dunes were formed soon after this period. Therefore, based on available data, it can be concluded that the sand dunes of Goa can be as old as 6400 years.

6.3. Why Sand Dunes Are Needed

Coastal dunes show a dynamic behaviour which has to be understood, respected and not contradicted, as is often being done, by anthropogenic influences as dunes cannot simply follow a pattern which is not naturally theirs. Thus their intrinsic value is lost (Nordstrom, 1990), and as a result, consequences are noticed on the beaches with which they are associated. A sand dune belt has multiple functions and hence of immense value to coastal populations:

- The beach - dune environment is a highly organized system, the result of a delicately balanced ecological equilibrium between the forces of the ocean and loose coastal sediments. Dunes are typical features of coastal stability.

- Sand dunes are eolian bedforms and develop where the transporting competence of wind is impaired. Vegetated or bare, the dune environment is classified as edifices of extreme fragility, sensitive and vulnerable due to its propensity for changes under even slight environmental stress.

- Sand dune chains are categorized as Nature's line of defense. They arrest blowing sand, deflect wind upwards, assist in the retention of fresh water and protect the hinterland from attack by waves, cyclones and storm surges and thus obstruct the ingress of saline marine water into the hinterland, and hence protect the hinterland lowlands from attack by the forces of the ocean.

- Sand dunes are sources of beach nourishment and also neutralize and dissipate wave and current energy in the coastal zone and hence play a specific role in maintaining coastal ecological equilibrium by supplying and restoring sediments lost due to erosion in the coastal zone. Therefore, the conservation of sand is required to protect coast from erosion and replenish the loss of sand due to wave and current energies.

- During stormy periods, high waves attack and remove dune sand which then accumulates on the beach or just beyond the low tide point, in shallow water in the form of submerged barriers (Figure 2F). During calm periods, normal waves return the same sand back onto the beach where, subsequently, winds blow sand inland thus reconstituting the dune. Therefore, coastal sand dunes serve as "sand banks" or security reserves (Paskoff, 1989) which is extremely essential to maintain the sedimentary and dynamic equilibrium of the dune - beach ecosystem. This is because the sand removal and its transfer during storms or by high waves is a reaction of "self-defence" as the submarine sand barriers force the wave energy to dissipate earlier and away from the beach and as such protects the beach from the effects of severe erosion which would not have been the case otherwise.

- Dune vegetation helps in dune stability. However, it is vulnerable to even slightest interference due to its fragility. Moreover, sandy stretches including dune vegetation contain many species of specific flora (and fauna) and thus offer an ecological storehouse due to their rich genetic diversity.

- Sand dunes, especially if covered by dune vegetation which acts as sand binders, preclude loose sand from advancing inland on the coastal zone, thus menacing coastal populations and structures.

- More importantly, the development of tourism has made use of their scenic beauty; their height gives an unobstructed view of the sea and their peculiar topography makes them an ideal place for recreation.

- Sand dunes of Goa are about 5000 years old (Sriram and Prasad, 1988) but can be as old as 6400 years (Figure 3D; Kale and Rajaguru, 1983). They formed after the sea level rise almost stabilized in its present position during Holocene. At places, they are as high as 10 meters as in Benaulim and Cavelossim (Lobo, 1988).

- Dunes therefore protect the hinterland from winds and other forces and hence make the zones behind dunes as areas of peace and tranquillity. Historically, in Goa, areas behind dunes had developed as peaceful areas of habitation and agriculture (Lobo, 1988), examples that can still be observed at Baga, Candolim, Caranzalem, Campal, Cansaulim, Colva, Benaulim, Varca and Cavelossim. For this reason, in several countries of the world, the conservation of sand dunes is mandatory and development is strictly regulated (see section on global examples at the end of this report).

- The predicted sea level rise is bound to inundate coastal areas and hence have a profound effect on the coastal zone. Sand dunes stand guard against any sea level rise consequent upon global warming as they will act as Nature's wall of defense against the eventual rise in sea levels. Therefore, these sandy geomorphic edifices have to be preserved.

7. COASTAL SCENARIO BEFORE AND AFTER DEVELOPMENT

7.1. The Coastal Zone Of Goa: Then

Since time immemorial, the coastal zone of Goa had been exclusively used for agriculture, farming, shell fishing, traditional fishing and low key recreation (Dume, 1986). Native goans of yesteryears used the shoreline to fish by using hand-cast and hand-pulled nets, gather shells for economic and various other purposes; but they never occupied or grabbed dunes or beaches. Traditional fishing was the main economic activity of coastal populations. The only identifiable structures along the shore were a few cabins and matched huts made of coconut tree leaves that housed sea going canoes, some of which can still be seen today. The large plain areas behind the dune belts were used for farming and paddy cultivation, activities which are common at certain places even at present. Recreation was restricted to certain areas only, Calangute, Miramar and Colva being the only beaches which were most sought and frequented by pleasure seekers.

It may be pertinent to note that our ancestors had understood the nature and importance of coastal sand dunes and hence treated the dune belts as sacred (Lobo, 1988). Although little was scientifically known those days, our forefathers had somehow grasped the sanctity of Nature, the sand dune ecology for example. This is based on the fact that till the 1970's, nowhere did we have evidence wherein, for example, sand dunes were razed to build houses. Beach side hotels and resorts and multistoried dwellings did not exist then. Ancestral mansions, roads, traditional villages, and any major activity along the coast were all located at safe places away from and behind the dunes, and also away from rivers and wetlands. Although obscured by modern development, this type of age old planning can still be seen from Baga to Candolim, Panjim to Caranzalem, and the entire stretch from Majorda to Betul. Between ancient coastal dwellings and the beach, vast strips of luxuriant paddy fields can still be found today, being prominent in the central parts of Goa. Such places landward of dune belts thus remained as areas of peace and tranquility. The coastal zone environment was largely pristine, well preserved and free from anthropogenic influences (Figure 4). Therefore, such a setup could be cited as a unique example of the harmony that prevailed between man and Nature (Lobo, 1988; Alvares, 1993; Mascarenhas et al., 1997).

7.2. The Coastal Zone Of Goa: Now

During the the last two decades, we have witnessed a drastic change in the face of the coast. The advent of tourism, population increase coupled with building activity and modern societal demands, has resulted in large scale changes in the geological and ecological setup, and has indelibly altered ecosystems, land use patterns and the coastal zone landscape (Mascarenhas et al., 1997). In this context, of all the coastal landforms, sand dunes which are sensitive geomorphic features that act as Nature's line of defence against the forces of the ocean, have suffered the greatest from anthropogenic pressures (Lobo, 1988; Mascarenhas, 1990, 1996,a; Narayan, 1997), as can be observed by any

one who walks along the shores of Goa. Some areas therefore bear little resemblance to the primitive coast that existed before (see Figures 4-15).

Human pressures on the beach - dune systems started during the 1970's and have gone unabated till now. At that time, tourism was declared a potential revenue earner for Goa, a place that was projected as a major tourist destination. Subsequently, the first starred beach resort was set up at Sinquerim in 1974, the second being at Dona Paula in 1982 and another in Majorda in 1984. This is coupled with the fact that, during 1971 - 1991 period, almost 80% of the urban growth is concentrated in the coastal talukas (D'Souza et al., 1988; Wilson, 1997,a); this does not include the floating population. Moreover, during the last decade, a large number of people chose to move towards the coast as can now be observed at Caranzalem or Dona Paula, for example. Since then there has been a dramatic growth and a proliferation of innumerable coastal resorts, residential flats, dwellings, small restaurants, roads and beach shacks along and across the sand dune belts. This growth resulted in an undesirable over urbanization of coastal regions with an associated deterioration in the quality of life.

7.3. Sand Dunes And The Coastal Regulation Zone (CRZ)

In 1991, the Ministry of Environment and Forests of the Central Government issued a Notification, enacted to protect sensitive coastal ecosystems from any unplanned human interference or development. Accordingly, the government declared coastal stretches of seas, bays, estuaries, creeks, rivers and backwaters which are influenced by tidal action (in the landward side) up to 500 metres from the High Tide Line (HTL) and the land between Low Tide Line (LTL) and HTL as Coastal Regulation Zone (CRZ), and imposed restrictions and formulated guidelines for various coastal activities.

Of the four main categories, the CRZ -1 includes: (a) areas that are ecologically sensitive and important, such as national parks / marine parks, sanctuaries, reserve forests, wildlife habitats, mangroves, corals / coral reefs, areas close to breeding and spawning grounds of fish and other marine life, areas of outstanding natural beauty / heritage areas, areas rich in genetic diversity, areas likely to be inundated due to rise in sea levels consequent upon global warming and such other areas as may be declared by the Central Government from time to time; and (b) area between the Low Tide Line and the High Tide Line.

It may be noted that sand dune ecosystems were not included in the CRZ Notification of 1991. Since sand dunes are ecologically sensitive and geomorphologically fragile features that are vulnerable to even small environmental stress, and since they act as Nature's line of defense against the forces of the ocean (discussed above), a case was made for sand dunes fields as CRZ - I (Anonymous, 1996,d; Mascarenhas, 1996,b). This was following the request made by the Ministry of Environment and Forests (in June 1996), to the National Institute of Oceanography, Goa, to identify areas which are ecologically sensitive. Accordingly, a report was submitted to them in August 1996 (Anonymous, 1996,d). Based on this report, and considering the ecological importance and immense use of sand dunes to society, the Ministry of Environment and Forests declared and classified the sand dunes belts under

the CRZ - I category. Subsequently, in September 1996, the Ministry issued separate orders (Anonymous, 1996,e) categorically directing that sand dunes are to be independently included under CRZ - I, a parameter that had to be incorporated in the coastal zone management plans of Goa. Therefore, in coastal areas characterized by sand dunes, no new constructions are permitted up to 500 m from HTL.

7.4. The High Tide Line (HTL) Controversy

The basic concept of the above notification is that the CRZ categories have to be demarcated with respect to the high tide line which, according to the guidelines, has been defined as the line up to which the highest high tide reaches at spring tide. On any beach, the position of this line can be easily and practically delineated by the naked eye, as it represents the trace along the beach - dune intersection where, on moving seaward, the sand dune vegetation can no longer be observed. This line may not always be a continuous one as it depends on the condition of dune vegetation. The high tide line is therefore a natural line.

When the CRZ notification came into force in 1991, the set back of 200 m or 500 m from the HTL became mandatory for open sea fronts. But it was observed that the term "tidal action" and the concept of HTL was deliberately being misinterpreted, by vested interests who tried to undermine the essence of the regulations, particularly in the case of rivers. One of the hypothesis was that there is no tidal action in the estuaries and rivers, a presumption that is scientifically wrong. Along open beaches, the natural vegetation line was not considered. Therefore, the position or location of HTL turned into a matter of debate, as no known definition of HTL was accepted. Subsequently, directions were issued to all coastal states asking them to follow the definitions and guidelines proposed by the Naval Hydrographic Office. Accordingly, the HTL is to be considered as the line up to which the highest water reaches during spring tide. This criteria will have to be included in the approved CZM plans (subject to corrections) for Goa.

7.5. Field Observations

The following is a site by site account projecting vital details concerning human intervention along the open sea coast of Goa, based on field surveys during the last two years. The areas are described from the northern border to the southern extremity. All the structures identified are seen within 500 m, some are located within 200 m in CRZ, whereas many are found right on the HTL (see Figures 5-15). Therefore, this list is by no means complete:

Querim: Beaches are untouched, dunes are well preserved and pristine; no anthropogenic influence was observed (Figure 4).

. Arambol: The area around the famous sweet water lake is highly contaminated; some small tenements have now come up; a polluted fresh water well (plastics, garbage, dead animals) close to the village beach was observed; except for a bar along the HTL, the coast is largely primitive.

Mandrem: Residential houses are seen on dunes close to HTL; a factory (?) was noticed close to the beach; most of the coastal area is virgin.

Morjim: No major construction activity is observed here; this stretch is quite intact and natural; however, the well known turtle nesting sites are being threatened by beach users.

Vagator: Condominiums are seen on the dunes within the palm groves; a restaurant has been erected on the HTL, seaward of sand dunes, virtually in the water; the rocky shore is very polluted with litter.

Anjuna (village): Several new structures including houses are erected on the dunes and also along HTL partly on the beach (Figure 14); shoreline erosion is observed, electric poles are uprooted; a part of the dune field is intact.

Baga: Several houses are seen on the dunes; rows of restaurants are found along the HTL; a huge hotel is under construction by encircling a high dune adjacent to the beach (this has been stopped by the courts) (Figure 5); some other hotels are located close to the beach; large sand dunes are highly obliterated, some are flattened and used as play fields; dune vegetation is severely affected; the area is haphazardly organised and crowded.

Calangute: A large pit (mined?) in the dune belt is used as garbage dump; one hotel which was demolished being on the dunes close to the beach has now been rebuilt; the seaward face of a high dune is damaged by human action; the site around the main tourist point is heavily crowded, dirty, and a row of structures are found along the HTL; a boundary wall made of laterite stone is seen perpendicular to the beach, with a very narrow access; a dune area close to the shore is razed to make place for tourist activities (Figure 12); dune vegetation is under threat; this part of the coastal tract is chaotic and highly disorganised.

Candolim: As above, this sector is packed with resorts, hotels and a variety of dwellings almost all on sandy belts, a few being very close to the HTL; sand dunes in this area are severely degraded; dune vegetation is slowly vanishing, sand is rendered mobile; plastic litter is a common sight; a number of shore-perpendicular roads, some tarred but now covered by sand, lead up to the beach (Figure 8); at several sites, levelled dune areas in proximity to the beach are used for parking all types of vehicles (Figure 11).

Sinquerim: Construction activity is noticed close to HTL; a barbed wire fencing obstructing access to beach was noted; litter was found on the beach; some of the sand dunes are intact; the first beach resort of Goa (1974) is located on the hill slopes in the south close to the beach.

Nerul: At Coco beach, some restaurants have encroached the shoreline along the HTL.

Campal: A stone wall has been erected in the intertidal zone; the age-old lighthouse is now found in the water; the primitive beach has disappeared, an earlier wall has collapsed as erosion continues unabated.

Miramar: A high dune was mined in 1992 (Figure 7), a building is now seen; a massive starred hotel occupying a large area is being built on the bank of the estuary; a concrete sea wall constructed recently is now found in the intertidal zone and the former beach in front gets submerged at high tide; the older stone wall has now collapsed; the age-old round about (circle) is a former dune surface, it remains covered by sand for most part of the year.

Caranzalem: A dune belt now almost entirely occupied by a variety of structures mostly dwellings; a broad coastal road has been constructed partly on sand dunes (Figure 9); a prefabricated structure (for sports) is seen on the beach; only a few sand dunes remain.

Dona Paula: All sandy pockets are taken over by developers; heavy construction activity is seen along the coastal hill slopes.

Bogmalo: An older resort is located on the beach at the base of a hill; several new bars / restaurants are mushrooming along the HTL.

Baina: The area is degraded and concentrated with various types of hutments.

Velsao: This is a relatively unspoilt coastal belt.

Utorda: Some hotels are under construction on the dunes; dunes have been mined at several places; a small structure was being built close to HTL; some dune areas are virgin.

Cansaulim: Several dunes have been levelled to make place for buildings; sand mining is also reported.

Betalbatim: Several resorts / hotels and dwellings are seen on dunes.

Majorda: The second beach resort of Goa (1984) lies on the dunes along the HTL; several new constructions have come up in sandy areas; beach is prone to erosion.

Colva: A crowded area with resorts, hotels, houses most of which are located on the dunes; a coast parallel road (within 200 m from HTL) is existing; a large area is occupied by the parking lot at the main tourist point; this part is generally remains covered by sand; the area is highly polluted as the canal is used as a garbage dump.

Sernabatim: A shack now converted into a bar / restaurant is situated right on the HTL; some dwellings are seen on dunes; a road, part of which is tarred, leads to the beach.

Benaulim: Restaurants are located close to the beach; a guest house is seen on the dunes; the tarred parking lot, generally covered by sand, is right on the HTL; litter is observed all over.

Varca: Several resorts are found on the dune fields; several dunes have been levelled whereas some are razed and removed completely. In this sector, one can still find virgin areas.

Cavelossim: An area of high dunes, this zone is being built up at a frenzied pace where resorts, hotels and new dwellings are mushrooming all over; several dune areas have been flattened, sand has been removed and transported elsewhere; sand mining is rampant.

Mobor: An exotic peninsula, now occupied by several starred hotels, resorts and other structures all exclusively on sand dunes (Figure 6); estate owners have levelled dunes and replaced them by lawn grass; natural dune vegetation is fast disappearing; some areas are fenced with barbed wire; a former site of sand mining which is still common.

Agonda: Except for old houses in the north and an abandoned resort (?) in the southern corner, the entire stretch remains untouched; this sector is however threatened by erosive processes.

Palolem: This secluded beach has lost its charm as it is being built up in a most haphazard manner; the central part is entirely concretised with houses turned restaurants, and retaining walls; a ramp has been constructed to allow vehicles onto the beach, the only such peculiar feature identified along the entire goan shore (Figure 15); severe erosion has set in at places.

Rajebag: There are signs of a major construction; a barbed wire fencing surrounds a large area.

Talpona: The coastal sandy stretch is largely vacant and well preserved.

Galgibaga: Except for the area around the church, most of the coastal zone is intact; however, a little north, a couple of majestic sand dunes have been levelled and now consist of flat tops.

8. ANTHROPOGENIC IMPACTS ON BEACH - DUNE ECOSYSTEMS

The effects of development on sand dune systems can be assessed by comparing the coastal configuration and topography prior to major human occupation with conditions that exist today. Similarly, reference to ancient documents, maps and planning literature, supplemented by discussions with natives who lived in coastal areas for long, offer valuable information.

The relationship between human activities and coastal changes and evolution is not fully understood (Nordstrom, 1994). There appears to be a lack of scientific

interest in the evolution of developed coasts because geomorphologists do not study human altered coastal systems; they mostly deal with landscape evolution at large time scales, as they feel that geological principles are inappropriate where the agent of landform change is man with his earth moving machinery (Nordstrom, 1994). Nevertheless, there are several reports on the effects of man made structures on the coastal zone ecosystems world wide (see references). We can also find field oriented studies on the effects of buildings, dwellings and roads on the adjacent coastal beach - dune systems as well as impacts of recreation and similar activities of shore front residents on the coastal morphology with most geomorphic studies aimed at coastal dunes (see references).

In Goa, to our knowledge, only meagre data on human intervention on the coast is available and as such, we do not have detailed information about the present state of the entire coastal sand dune ecosystems. Such an attempt made in the sections to follow.

8.1. Impact Of Constructions / Buildings On Sand Dune Fields

There is no published information which indicates the actual number of structures presently located in the CRZ of Goa. From the survey details described above, it can be surmised that the growth is uncontrolled and as such several areas are overcrowded. The large number of edifices include hotels, resorts, dwellings, houses, small restaurants, bars, all of which are mostly located on the dunes within 500 m from HTL (Figures 5, 6, 13, 14, 15).

Heavy construction activity and associated infrastructure requirements of the tourism industry have led to a chaotic and haphazard growth of many coastal stretches. The Baga - Candolim strip is a classic example as, at many points there is no proper public access to the beach. It is therefore obvious that these coastal areas have crossed a saturation point (Mascarenhas et al., 1997; Sawkar et al., 1997; William, 1997). Whereas Colva and the Cavelossim - Mobor areas will meet the same fate in a short time, Palolem will follow very soon.

Of all coastal geomorphic features, sand dunes have borne the maximum brunt (Figures 5 - 15) and have suffered the greatest from indiscriminate anthropogenic pressures (Lobo, 1988; Mascarenhas, 1991, 1996,a,b). Large scale conversion of dune belts have taken place, and thus, the functions of dune ecosystems have virtually changed to residential areas. These effects are identified where ever man-made structures have encroached on dune fields. These impacts can be observed along most of the sandy coast of Goa, particularly from Baga to Mobor including the two major estuaries in between.

Based on our surveys along all dune belts of the areas mentioned above, we find that high dunes have been razed, levelled, flattened or simply removed so as to make place for hotels, resorts or other structures. Large dune areas are thus found obliterated and damaged due to human intervention (Figures 5, 6, 11, 12, 13). All these anthropogenic activities have resulted in irreversible alterations to the dune



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systems as removal of large volumes of sand has created a negative sand budget which in turn has affected their stability. Since parts of the coastal zone have changed from virtual wilderness to areas where buildings are mushrooming, many of the coastal stretches bear little resemblance to the primitive shore that existed before.

Along the entire goan coast, several structures have been identified on the dunes along the HTL, the most prominent being a resort at Miramar and other smaller ones at Anjuna and Palolem. Excavations and removal of dune sand close to the beach have created deficiencies in the volume of sand. All these sites are precisely the ones where significant erosion has been noted (Figures 8, 13, 14, 15). Although the erosive processes are localized at the moment (except at Miramar), it is found that these hard structures which are in direct contact with marine water are mainly responsible for shoreline erosion, as clearly observed at Palolem. Pertinent details are discussed in later sections.

8.2. Impact Of Dune Sand Extraction

Coastal sand deposits have been under constant human onslaught for various reasons: (a) the common man uses sand (on a low scale) as cement mixture for houses and homes, (b) industrialists and builders plunder sand which is used as a raw material for a variety of major purposes such as buildings, (c) all coastal resorts and hotels are located in sandy areas and find sand as a readily available resource, (d) levelled dunes can be converted into plots for further development (Figure 7).

During the Portuguese rule, permission was required to mine sand. After liberation, sand mining leases were granted to private parties for as long as 20 years (Alvares, 1993). Even during the late 1980's, there were sand mining sites at Anjuna, Baga, Candolim, Arossim, Benaullim, Cavelossim and Mobor. As a result, thousands of tones of sand were extracted and even exported outside the state (Alvares, 1993). Following protests from people and expert advice from the scientific community, in 1983, the state government issued orders canceling all leases. Nevertheless, sand extraction continued unhindered till 1988 when the courts intervened decisively forbidding sand mining. Our observations however show that clandestine sand extraction still continues (Figure 7).

The dune sand extraction has shown many impacts in the form of danger signals (Lobo, 1988). Saline water entered paddy fields in the hinterland at Mobor, fruit bearing trees were destroyed. In 1977, a dune which was removed left a scarp/ gap through which storm winds blew tons of sand onto the hinterland paddy fields affecting paddy output and fruit trees which were scorched by salt air (Alvares, 1993). At Varca, truckloads of sand from dunes of a large area were plundered by contractors to supply sand for constructions; the area is now flat and featureless. In 1977 and 1978, disturbances of dune systems resulted in a storm surge in Mobor, and attack by storm waves and inundations in Majorda, Betalbatim, Varca, Carmona, Cavelossim (Lobo, 1988). The elimination of dunes has lead to leveled areas which are later converted into plots. Thus, dune sand extraction has shown disturbances in the form of erosion and



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salt water invasion inland as such anthropogenic activities work against the sound ecological principles of the coastal zone, the dune systems in particular.

8.3. Impact Of Roads On Sand Dunes

Coast-perpendicular access roads are seen at many places along the coast, being more concentrated on the dunes of Baga - Siquerim sector (Figure 8), the rest being found in the south. Roads over the dune belts have led to obliteration of dune topography (Mascarenhas, 1996,a), removal of sand, levelling of dunes, desecration of dune vegetation which acts as sand binders, all of which generate loose and free sand resulting in its excessive mobility. In all cases therefore, such roads are covered, sometimes in totality, by a layer of sand; this is a recurring process. Such a phenomenon is very evident wherever roads occupy former dune fields, and very conspicuous at Calangute and particularly the parking lot in Colva. In fact, each and every approach road to the beaches are now covered with sand.

As a typical example, the Miramar circle which was built about more than 100 years ago can be cited as a human failure. It has been observed over the years that during windy days in summer, large quantities of dry sand are blown inland and can be felt as far as Tonca. This can be experienced by anyone who stands there as sand grains sometimes rise to knee level. The small beach which is excessively used is devoid of dune vegetation and therefore bare in most of the area. The result is that the Miramar round-about and the radiating roads are covered by sand for most part of the year, creating dangerous road conditions for traffic. This is due to the imbalances in the sand budget wherein the sand which has been rendered mobile, tries to find equilibrium and comes to occupy its rightful place: the circle, now located on former sand dunes. Unfortunately, instead of dumping the sand back on the beach so that the latter can recuperate, the authorities collect sand in trucks and dump it elsewhere (and is even sold by unscrupulous elements to the building industry).

The new coastal road to Dona Paula will meet the same fate. A major part of the road is laid on dune sands. It is already evident, atleast at two places, that sand is attacking the road; small accumulations of sand are noticed along the road. Here again, a significant portion of the dune is being used as a parking place by revellers. This misuse has taken a toll on dune vegetation thus increasing the mobility of sand. It is this sand which has started invading the road, although on a low scale (Figure 9). If remedial measures are not taken, it is obvious that this problem will aggravate further and the road (as in other areas discussed above) may be drowned in sand, thus creating hazards to drivers in general and motorists in particular.

8.4. Impact Of Beach Shacks

The presence of beach shacks is probably a unique sight on goan beaches as they are common all along the entire shore and on all major beaches (Figure 10), except at some places where they have not been permitted. These comprise simple huts, made of bamboo and coconut tree leaves, and are of a purely temporary nature. In the past, there were few of them but at the moment, the ever increasing competition has resulted in their proliferation as almost 220 shacks (and numerous unauthorised ones)



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have been granted licences for about 60 km of beach length (Collasso, 1997; D'Mello, 1997).

A sandy beach falls under CRZ I category. Strictly speaking, even a temporary stall such a shack cannot be allowed on the beach according to the CRZ notification. However, since shacks are seasonal and form the livelihood of hundreds of unemployed individuals, it appears that their existence is required, and as such, the beach shacks have come to stay.

A sandy beach is dynamic in nature, the profile of which keeps changing and adjusting itself towards an equilibrium. A beach generally restores itself. Therefore, beach shacks which come and go are not expected to induce any large scale damaging effects from the environmental point of view. The only major problem is their number which is on the rise. This has resulted in severe crowding which is gradually leading to over exploitation of limited beach space. The carrying capacity of goan beaches has seldom been studied. As they are frequented by a large number of people in search of food, shacks generate huge quantities of garbage which unintentionally mixes with sand and hence litter large areas, and invariably finds its way into the estuaries.

Although shacks are bound to occupy only the upper part of beaches, many of them have gone beyond and invaded the adjacent sand dunes, as seen in Candolim - Calangute belt (Figure 10). This is where ecological degradation takes place as dune vegetation is uprooted and cleared to make place for them, an environmental damage that can be significant and sometimes irreversible. This is also because sand dunes are flattened and as such lose their intrinsic value. Therefore, beach shacks, although simple in design, have not only flattened dunes and added litter onto the beach, but have their own share towards coastal degradation.

8.5. Influence Of Recreation On Dunes

Activities of pleasure seekers and picnickers are not restricted to a particular area, but can be observed almost along the entire coast particularly where sandy stretches as the dunes are found. Two dune areas, in Baga and in Candolim, are regularly used as a football ground by the villagers and also tourists. Although these recreational activities may not be termed as harmful to the dune environment, it does create ecological degradation in areas which are most sought and frequented. Parking of vehicles on sandy bodies, driving on the beach as often noticed, play fields on dunes, continuous movement by pedestrians and cyclists destroys dune vegetation, flatten dunes and renders the sand mobile (Figures 11, 12), factors which induce shifting of sand and thus affect the stability of sand dunes.

8.6. State Of Dune Vegetation

Our study did not include any aspect of sand dune vegetation but is briefly discussed here as additional information. The status, importance, uses, types, ecological aspects and management implications of dune vegetation has been studied earlier (Desai, 1995).

Around 59 species of dune plants are found along the coast of Goa (Desai, 1995); dune vegetation is therefore common along the entire sandy stretch. Sand dunes generally owe their existence to the vegetal cover, being an integral part of the dune ecosystem. Dune vegetation plays a crucial role as it is an effective sand binder and hence promote the stability of dunes. It also reduces erosive processes and prevents internal desertification. These plants can survive under adverse natural conditions such as high wind velocity, shifting sand and salt spray. However, it is vulnerable to even slightest human interference due to its fragility.

Nevertheless, our observations have revealed that sand dune vegetation is in various stages of degradation in different parts of coastal stretches. The maximum damage appears to be along the Baga - Candolim strip. There are innumerable anthropogenic factors which are responsible for the destruction of dune vegetation: real estate owners who prepare plots for buildings, hotels or resorts clear all dune vegetation (Figure 6); roads are laid over levelled dunes thus eliminating the vegetal cover (Figure 8); beach shacks and various other recreational activities have shown similar effects as dunes are rendered bare (Figure 10). However, it may be noted that there are several tracts along our coast (where the bull dozers have not yet reached) where sand dune vegetation is still found in its pristine form (Figure 4).

8.7. Litter On Beaches

With the ever increasing pressures on the coastal belt as more and more people are moving towards the coast, our beaches are getting dirtier. The Baga - Candolim stretch, Miramar, Colva and even Benaulim can easily be singled out. For instance, the annual sea food festival held at Miramar produces heaps of garbage, a part of which gets mixed with the sand unless combed. It was noticed that a large pit in the dunes at Calangute is used to dispose garbage. At Colva, the creek is used as a dumping site for all types of waste. Hotels in south Goa produces large dumps of non-biodegradable garbage which along with sewage is discharged in the river Sal. Interestingly, large rafts of plastic waste were found floating in the river Sal; a close look revealed plastic items (and even seals) dumped by starred hotels and not by the locals.

Litter scattered along the coast ultimately finds its way into the rivers or the sea and is subsequently thrown back on the beach as can be observed along most beaches during the post monsoon period. According to newspaper reports, the Navy identified large rafts of plastics floating in the sea off Goa. Therefore, irresponsible disposal of garbage in the coastal zone has resulted in a progressive build up of plastic waste in our estuaries.

8.8. Salt Water Ingress

No systematic observations concerning salt water intrusion were done in our study; only some salient points are mentioned. In coastal areas, sweet water floats over saline water, with the interface located somewhere below the beach. Modest use of water from coastal wells does not modify the ground water table as it gets continuously recharged and the system thus sustains. However, quick and excessive pumping of water with heavy duty pumps results in a rapid depletion of fresh water with

corresponding dynamic imbalances in the form of an irreversible alteration of the groundwater table. If such an area is close to the shore, salt water is sucked in and occupies the place of freshwater.

Till a decade ago, there were no complaints of salt water intrusion into coastal aquifers as well water was used only for domestic consumption by manual withdrawal; there was no excessive pressure on water resources. Problems started in recent years when a large number of bore wells with powerful pumps were installed within the 200 m limit, notably by the builders, the hotel industry and also by private parties (Alvares, 1993). But it must be noted that pumping of underground fresh water in the dune belts is forbidden by CRZ regulations particularly within 200 m from HTL. Beyond this limit, permission of competent authorities is needed. Excessive pumping of ground water can also lead to subsidence of land (Haq and Milliman, 1996). Despite this, several infringements are reported, as large number of cases were detected beyond 200 m where borewells are regularly used to draw water particularly by the hotel industry (Alvares, 1993). In some coastal places, water is openly sold by private parties to starred hotels for use in their swimming pools. Thus, this ban is routine violated. Since domestic water supply is grossly inadequate to meet the rising demands of hotels for their lavish use, no action is taken on builders and hotel owners for tapping underground water for consumption.

This kind of unchecked withdrawal of ground water has resulted in lowering the groundwater table and seepage of saline water into fresh water wells. In 1992, several wells of Mobor peninsula were invaded by salt water (Alvares, 1993). Similar cases were also reported around Caranzalem. Coastal aquifers in north Goa have been affected by ground water fluctuations and seasonal increases in salinity, as wells near the sea shore show influence of salt water encroachment as it is hydraulically connected to coastal water table; therefore ground water quality is deteriorating (Kalavampara, 1994; Chachadi and Kalavampara, 1995). Following several complaints about coastal fresh water wells turning saline, citizens realized the gravity of the problem and many NGO's sought recourse to the courts. Thus several bore wells of starred resorts were shut after the courts intervened.

The outcome of deliberate tampering with coastal aquifers under dune systems is distinctly demonstrated in south Goa. A resort located between the sea and the river excavated a huge dune area to be converted into an artificial sweet water lagoon without a proper assessment and despite repeated warnings against this adventure. To their dismay, saline water trickled, attacked and filled the artificial lake and today we only find a salt water lagoon. Such an unwanted human interference with the dune system sent right signals as this is a clear example of salt water ingress into a former fresh water aquifer. Salt water ingress into coastal aquifers cannot be reversed.

8.9. CRZ Violations

The 500 m ban on construction activity was applied, in principle, in 1981 all over the country, following late Mrs. Indira Gandhi's famous letter to the Chief Ministers of all states. It read: "The degradation and misutilisation of beaches in the coastal states is worrying as beaches have aesthetic and environmental value They have to be kept clear of all activities atleast up to 500 meters from the water". The concerned notification however came into force only ten years later in 1991. Since then, and despite clear rules and guidelines, the notification is being deliberately misinterpreted to suit vested interests. The result is seen in the form of blatant large scale violations of CRZ regulations observed along the open sea front as well as along the rivers and backwaters. The sanctity of this unique regulation is therefore at stake.

One of the important strategies of the (now defunct) Regional Plan (1988), a good proposal of sustainable development for Goa, was that: "location of new beach resorts should be considered not only from point of view of land availability but also beach ecology. Further, spreading thinly on all available sandy beach stretches from Terekhol/Arambol in the north to Betul/Agonda in the south is not advisable, from the standpoint of conservation of resources both natural and man-made. Instead, it is suggested that beach-head developments at certain selected centres should be encouraged." On the contrary, the CZMP of Goa (1996) actually recommends tourism related development almost everywhere along the 70 km long sandy beaches. The planners and policy makers thus keep contradicting their own guidelines. Such a laxity coupled with a lack of political will has resulted in unauthorised structures, haphazard organisation and uncontrolled growth along the coastal zone. The fact that unauthorised constructions thrive, proves that the environmental regulations are rarely considered, or, are being observed more in the breach (Sawkar et al., 1997).

The CRZ violations can be summarised thus:

Buildings and constructions: Based on our field observations (described above), it is amply clear that there are numerous infringements and irregularities on coastal sandy stretches (Figures 5, 6, 13, 14, 15). The setback lines as stipulated in the notification have been conveniently set aside (Anonymous, 1997,c,d). There are many such cases in the Baga - Candolim sector; the Calangute panchayat has been hauled up for the maximum number of environmental violations (Anonymous, 1996,c). Miramar - Campal area also deserves mention. During the last few years, south Goa dune belts are under assault (Figure 6). The Mobor peninsula which was once declared as a green cover area, has witnessed a frenzied proliferation of resorts which have violated almost all rules stipulated in the environmental guidelines (Anonymous, 1997,b). Our observations show that the latest negative developments are in Palolem where a number of small illegal buildings have mushroomed close to the beach, even on the HTL (Figure 15).



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Sand extraction: Unscientific clandestine dune sand extraction (Figure 7) which has gone unchecked is rampant at several sites along the sandy coasts (Anonymous, 1997,e), although this activity is prohibited by law.

Bore wells: Since piped water supply is often irregular and does not meet the existing demands, many real estate owners, the hotel promoters in particular, resort to unfair methods of ground water tapping by sinking bore wells (Alvares, 1993). Although several defaulters been booked, many such cases go unnoticed and clandestine operations continue.

Roads: In some cases, ancient paths used by beach users are slowly being converted into roads some of which are already tarred, whereas others are incomplete and/or stopped by legal means (Figure 8).

Fences / public access: Several promoters of hotels and resorts have put up fences in the no development zone, sometimes up to the HTL. Existing law does not allow fences or walls within the 200 m zone and yet they are seen, at Calangute for example. Courts had to intervene in some cases so as to restore public access to the beach. Several resorts in north and south Goa and a starred hotel in Dona Paula can be cited as such examples.

Judicial intervention: It may be noted that a large number of structures presently found along the coastal zone tantamount to blatant violations of CRZ regulations. Many constructions have been stopped by the courts, some judicial cases are pending, some structures were demolished but were subsequently rebuilt in the same place. Different types of infringements in the coastal zone and their legal implications have been documented elsewhere (Alvares, 1993). Recently, based on site visits (state government committee) in 1996, more than 20 starred hotels and resorts were issued show cause notices for violating CRZ regulations (a personal communication); their replies are not known as details are not available.

Following complaints from citizens and NGO's, the first writ petition was filed in 1988 and have continued since then. Courts have intervened in coastal matters for a variety of reasons. The EIA for some hotels was not satisfactory as they lacked details on sewerage, treatment of waste and water supply (Alvares, 1993). In some cases constructions started before obtaining requisite clearances. Letters from concerned individuals have been converted into writ petitions. Similarly, courts have ordered hotels to remove all structures within 200 m area, including houses, rooms, wells, roads, fences. The state government was also ordered not to allow constructions within 200 m from HTL. Courts have also ruled that disturbing sand dunes threatens coastal ecology and hence sand mining leases had to canceled. Stay orders have been imposed in several cases, the latest being a resort in Baga (Anonymous, 1997,c).

9. SYNTHESIS AND DISCUSSION

9.1. The Fate Of Sand Dunes

A quick review of various anthropogenic impacts discussed and enumerated above clearly indicate that (i) construction of resorts and buildings, (ii) dune sand mining and (iii) roads in sandy strips are the major factors responsible for the large scale degradation and consequent elimination of sand dunes of coastal Goa. In addition, flagrant violations of prevailing legislations has complicated matters further as changing coastal configuration has remained unchecked. Marine salt water ingress (seasonal) is beginning to show up in coastal aquifers due to excessive ground water withdrawal. All the remaining man-made effects related to dunes can be termed to be minimal as, in most cases, these impacts can be fully reversed, depending on the will of policy makers.

The natural behaviour of sand dune systems has to be respected but not contradicted. Littoral sand dunes which constitute spaces of recreation complementary to the beaches behind which they are located, are edifices of extreme fragility and are essential for the sedimentary and ecological equilibrium of coastal environments. Their destruction can sometimes be attributed to natural causes. If the vegetation is destroyed by prolonged dry periods, or other reasons, they are destabilised as they are laid bare. If subsequently, a dune is cut by high waves leaving an escarpment, the latter is capable of increasing wind speed manifold. Wind then opens cavities through which free sand is liberated and bombarded inland thus attacking populations and buildings located along its path.

The destruction of sand dunes in Goa is exclusively anthropogenic. Although they had remained free from human intervention, they are now too frequented subsequent to the promotion of coastal tourism. They have thus suffered greatly from the assaults of tourism and other related activities which have spread over coastal spaces during the last two decades or so (Figures 5-15). Their existence is therefore in peril: destabilisation due to the degradation of their vegetation which is sensitive to the human presence, flattening due to sand extraction, or their destruction and elimination due to the creation of plots by the sea side. Their disappearance is total where sand is being extracted for construction activities, and also where dunes have been simply levelled and flattened to erect buildings and resorts.

Similarly, the destruction of dune vegetation which is crucial as sand binders appears to be exclusively anthropogenic and is attributed to several factors discussed above. In several areas, the frequent visits of picnickers, tourists, revellers, vehicles, cycles have rapidly degraded sand dune vegetation which is particularly sensible to human interference. Recreation can have adverse effects on sand dunes (Vogt, 1979). Native plant species are prevented from colonising because of the preference for the lawn grass and exotic shrubs for landscaping. Real estate developers and owners of resorts have replaced natural vegetation with gravel, cemented paths, or simply maintained an unvegetated barren surface which is used for other purposes such as

parking. Natural dune vegetation can only be seen on existing stretches which have so far remained free from development (Figure 4).

The damage and destruction of dunes, irrespective of the agents responsible, pose various consequences for the coastal environment (Nordstrom and Gares, 1990). Disrobing a sand dune results in the formation of free sand which is rendered mobile; and therefore keeps shifting. Along the coast of Goa, the transfer of sand landward far into the hinterland is a common phenomenon observed particularly during windy days at several places; the Baga - Candolim sector is one such example. This phenomenon is most pronounced at Miramar where large accumulations of sand are often noticed on the road. The risks of inundation are increased when sand is removed on a large scale. Excessive pumping of fresh water leads to salt water ingress and contamination of coastal aquifers. Elimination of dunes also induce erosion, as beaches are starved of the requisite sand budget. All these factors adversely affect coastal equilibrium and hence its stability.

It has been demonstrated that coastal buildings alter wind flow around them, reduce the velocity on the lee; structures built on dunes induce localised deposition and cause local increase in the height of the dunes and reduce the inland migration of the dunes. Even a moderate development on dune belts strongly affect sediment transfers (Nordstrom and McCluskey, 1985; Bauer et al., 1996). Buildings also change the location of accretion and scour on beaches and dunes. Large buildings cause a reversal of regional wind flow; wind blown sand accumulates against buildings, houses, boardwalks and roads creating a diverse dune scape, distinctly different from the one created under natural conditions (Nordstrom and Jackson, 1993). In our case, the major drawback is that the human intervention on the sand dunes of Goa has never been quantified. This exercise requires immediate attention.

Since sand dunes are eolian bedforms which are dynamic and mobile, they should be allowed and be able to evolve freely and naturally in form and space. Research has shown that dunes in certain areas have displaced and migrated naturally by tens of meters towards the sea as well as away from it as compared to their primitive location. This has been ascertained by successive aerial pictures (Psuty, 1986, 1988; Paskoff, 1994). Since a natural sand dune is in a natural equilibrium with the beach, if the beach retreats the dune should be able to do likewise (retreat) so as to assure its role as a sand reservoir in order to maintain the equilibrium between the dune - beach ecosystem. Since a majority of beaches are in a process of retreating due to a slow rise in sea levels, the dunes should also retreat landward by rolling on themselves. Such a mobility and flexibility of sand dune are rarely considered. For this, ample space is necessary and is to be reserved for migration and sand dunes should be at liberty to do so. That was precisely the reason why our ancestors always built houses and roads away from beaches and always lived behind sand dunes, a system that can still be observed along the entire west coast of India. A perfect coastal equilibrium was thus maintained.

Erosion of beaches and dunes has been observed at several places along the open sea front and within estuaries. This phenomenon, although localised, is significant at Arambol, Anjuna, Majorda and Colva. A proper scientific proof pending, these

events may be attributed to annual changes that a beach undergoes as the area at Colva, for example, regenerates itself during the post monsoon period as has been observed by the author over the last few years. Sea erosion is however most pronounced at Anjuna (main point) where a high hill is in the process of collapsing every year and has created a high vertical scarp; its base has receded by more than 10? m in the recent past. At Velsao and Agonda coastal erosion is evidenced by a large number of tall uprooted trees (Mascarenhas, 1996,b). At Agonda, the sea has often risen beyond normal levels and emptied into the creek which runs parallel to the coast. Marine gravels thrown beyond the high water mark indicate intense wave energy accompanied by heavy erosive tendency.

Near Verem in the Mandovi estuary, the existing small sandy beaches are gradually disappearing. This is attributed to a series of walls erected recently, mostly by hotels. Such structures increase the turbulence of waves resulting in the removal of sand. Similarly at Palolem, many hard structures have been built along the beach. This human intervention has resulted in shoreline changes, wherein the sea is advancing landward as observed over the last two years (Figure 15). A remarkable erosive activity is proved by breaches in concrete embankments as well as uprooted trees along the high tide line. Marks left on these walls show a lowering of the level of the beach indicating that a large volume of sand has been washed away. The erosive activity at Palolem, attributed to human action, is definitely and undoubtedly irreversible.

The most alarming erosive processes are seen along the Miramar - Campal sector (Figure 13). The entire stretch which constituted a dune belt with a thick vegetal cover as late as the 1950's has now ceased to perform the functions of a beach dune - ecosystem. It has been postulated that when the capital city of Panjim came into being during the earlier part of the century, sand was being mined from the Campal dune (Alvares, 1993) and used for the constructions then. This led to the depletion of sand resulting into a negative sand budget. As the system could no longer sustain due to sand starvation, erosion set in. A long stone wall was then erected in 1958 (Lobo, 1988) as a defence mechanism. Here, the planners got the taste of their own medicine; most of the wall collapsed (some remnants can still be seen in Figure 13) and erosion continued unabated. Another stone/boulder embankment was erected during the last decade and can be seen at Campal. Erosion continues with full vigour as hardly any sand can be seen along this structure. The lighthouse which was once on the shore is now found in water and is hence under threat as it faces an imminent collapse.

Despite the fact that the shoreline is prone to erosion, a huge hotel complex is now under construction on a dune at Miramar, precisely at a place where it should not have been (Figure 13). A concrete wall built in 1996, about four meters landward of the earlier (1958) wall, is already showing signs of decay with breaches at many places. The narrow beach in front is slowly disappearing as the entire area gets submerged during regular high tide. Therefore, this concrete wall which was erected in the intertidal zone is not only a blatant violation of CRZ regulations but can also be termed as monumental human blunder.

Sand eroded from a particular site has to be deposited elsewhere. We have identified various sand bars / spits at river mouths as in Talpona, accretion of beaches

as in Miramar, and also islands, shoals (and mud flats) within all the seven rivers of Goa. A jetty / ramp at the mouth of river Tiracol has been rolled over and engulfed by sand deposits; a new ramp had to be built for ferry users. It is not known whether these accretionary processes are a direct consequence of erosive phenomena discussed above; a formal scientific proof in this regard is lacking.

9.2. Possible Impacts Of Sea Level Rise On Beaches And Dunes

A topic of paramount importance is the predicted sea level rise due to global warming. A sea level rise of about 1 to 2 mm/yr is occurring world-wide. As a result of global warming and greenhouse effect, the eustatic sea level may rise by as much as 70 cm by 2065 and up to 110 cm over the next century (Haq and Milliman, 1996). The model of the Environmental Protection Agency however suggests a 1.2 - 2.2 m sea level rise by the year 2100 which is called the mid range scenario with extremes ranging from 0.6 - 3.7 m above the present sea level by the end of the next century. Thus the present rate of average sea level rise of 1 - 2 mm/year could amplify up to 6 mm/year in the next hundred years (Watson et al., 1996).

The impacts of a more rapid advance of the sea on the coastal areas can be placed in three major categories: intensified flooding, enhanced erosion and increased intrusion of marine saline water into estuaries and coastal aquifers (Haq and Milliman, 1996). The accelerated sea level rise in the coming decades is bound to induce shoreline retreat due to enhanced coastal erosion. A sandy coast with dunes will recede in the event of a rise in sea level unless it is offset by an influx of sediment. Depending on the type of sand and the gradient of the shore face, dunes will recede inland by 40 to 400 m (or even more) per meter sea level rise (Haq and Milliman, 1996). Unconsolidated cliffs would recede whereas indurated promontories will remain stable. A rise would normally reduce the rate of sediment input into the estuary. Global warming is also likely to increase the storminess of the weather with an increased incidence of storms and floods.

Along western India including Goa, the rise in sea level over the past decades is estimated to be 1 to 1.5 mm/year, based on tide gauge records at several sites along the coast (Subrahmanya, 1996). Although a nominal rise in sea levels will have profound influence on flat beaches, estuaries and lowlying khazan lands of Goa, this effect may be less severe on the sandy beaches of Goa as most of them have an appreciable gradient and, as such, the dunes are situated at a significantly higher level, beyond the reach of normal sea waves. However, it must be cautioned that, in the event of a (predicted) one meter rise in global sea levels, the erosive capacity and storminess of the seas will increase manifold. Such a scenario will eventually invade and erode beaches, the flat ones in particular, as large volumes of sand are expected to be washed away by stormy waters. Erosion will start on many beaches that are presently stable. Beach erosion is induced by rising seas which shifts wave action to progressively higher levels, leading to extensive and rapid erosion. This will inturn influence and modify the sand dune systems (Carter, 1988) as a large part of beaches may disappear. Although the future trends cannot be questioned, the nature and intensity of losses cannot be accurately predicted.

9.3. Restoration And Management Of Sand Dunes

It is extremely doubtful whether the countless dunes which have disappeared from all over the coast can ever be restored; this is because we have lost track of such losses. Nevertheless, before the dune-lined shore turns into a concrete coast, it is imperative that further losses be curtailed and the existing dunes be conserved at all costs.

Restoration of sand dunes and nourishment of beaches has been classified as a modern scientific strategy against the erosion of sandy areas (Psuty, 1986,a; Avis, 1989; Guinon and Allen, 1990; Psuty and Moreira, 1992; Jackson and Nordstrom, 1994; Marti et al., 1995). It comprises a simple, easy and cheap solution which in almost all cases can substitute costly measures such as sea walls and stone embankments (Davidson et al., 1992). To rehabilitate a coastal dune which is destroyed, *it* has to be determined whether the dune-beach system is stable, whether the beach is prograding or retreating. Field details, maps and photographs can give some basic details. Therefore, a position which will be in a state of dynamic equilibrium has to be chosen: this is important due to the fact that if a dune is close to the shore, it may be eroded by waves; if it is too far, sand transport and feeding may be deficient. Hence a new dune should be located away from the annual changes which the beach undergoes, but ahead of the permanent land vegetation (Paskoff, 1989, 1994).

There are various ways of restoring dunes which are destroyed. Planting of dune plants is the best and the cheapest method available as species act as excellent sand binders. To ensure its stability, the dune can be covered by (planting) vegetation which should not cover more than 80% of the dune to be constituted (Paskoff, 1989, 1994). Fences can be erected so as to avoid them from being overrun by humans; movement of pedestrians is to be controlled along fixed passages. Also, artificial objects such as wooden planks or nylon nets may be used as these provoke winds to deposit their sand content. Sometimes, depending on the sand reserves in a locality, sand from the beach is dumped on fractured dunes to cover the degraded areas. This method has to be exercised with caution and may not be advisable as removal of sand from beaches can deplete the sand budget as beach profile gets brutally modified. In the course of time this can cause erosion; and the remedy turns into enemy.

Since littoral dunes and beach complexes are delicate and dynamic environments, their conservation strategy needs to consider their mobility, a factor ignored by the present day managers, as a basic requirement for the protection of the coastal environment. A rational approach thus demands a close link between planners and scientists who study, know and understand their evolution and behaviour as only research results can help in the maintenance of these fragile coastal ecosystems.

Fencing of dune areas as has been done along along the Miramar - Caranzalem stretch is a welcome step. Other existing dunes which are bare and devoid of vegetation as the ones in Baga - Candolim can be protected from further deterioration by fixing dune plants and erecting fences. This exercise will not only preserve dune vegetation but will also fix sand which, in these areas, is in a state of mobility. Dune vegetation can recuperate by itself if dunes are left to themselves; sand dunes thus remain stable.

From the point of view of the management of eroding beaches and shorelines, society and/or policy makers and planners have three options available: hard stabilisation (emplacement of hard structures on fixed locations), soft stabilisation (replenishment and replacing the beach with a new one); and retreat or relocation (Pilkey and Wright, 1988). The traditional response to shoreline changes has been hard stabilisation which is generally intended to protect upland property and buildings. But there are a number of mechanisms by which sea walls and hard shore parallel structures induce accelerated erosion of beaches in front and adjacent to them, and are hence detrimental to the ecosystem (Kraus and Pilkey, 1988; Granja and Carvalho, 1995). Dry beach width is significantly narrower in front of them. The more dense the hard stabilisation, the narrower the beach (Pilkey, 1981, 1993). Sea walls have been found to degrade beaches in three major ways: passive erosion which existed before the wall was in place will continue unabated, active erosion due to interaction of the wall with local coastal processes due to an intensification of surf zone processes and a corresponding increase of energy that results in the narrowing of the beach.

In Goa, the most dramatic negative impact of sea walls on the beach is the one along Campal - Miramar sector. Here, we have observed that the rebound of the energy liberated by the waves pounding against the sea wall leads to a significant increase in the turbulence of water, and therefore, such obstacles only magnify the erosive power of waves, cause transport of sand and lead to erosion of beaches. This process has resulted in a gradual disappearance of the beach along the sea wall, due to which the light house, formerly on land, is now found in the water. It is therefore recommended to first investigate whether the restoration of dunes will remedy erosive processes rather than opting for heavy defence mechanisms (walls, embankments) without a proper scientific study. This is because construction of walls in the intertidal zone between the high and low tide lines, as is the case at Campal, results in an immediate loss of the recreational value of the beach. This option thus proved to be the most harmful and very costly as has been amply demonstrated at Campal.

Having encountered negative impacts wherever beaches are backed by sea walls, or wherever embankments are located in the intertidal zone, coastal scientists and engineers are now adopting simpler and softer measures against shoreline erosion. Beach nourishment is now the preferred alternative (Psuty and Moreira, 1992) because groynes and shore parallel structures have shown profound effects on shoreline change (Pilkey and Wright, 1988). Beach nourishment is a method which involves filling a threatened portion of the beach with sand brought from an area which has a surplus sand budget. This exercise involves a detailed study of the beach behaviour over the years, including wave and current regimes. For example, sand which is collected from Miramar circle could have been used to replenish the eroding shores in the vicinity; this is unfortunately not done, but instead, sand is dumped elsewhere. Erosion of coast lines can be curtailed only if the wave energy is dissipated naturally and mildly over a large area of a gently sloping surface.

In Goa, an accelerated rise of the sea is bound to inundate coastal tracts and hence have a profound effect on the coastal zone and its inhabitants. Whatever the

scenario, shoreline erosion rates will be enhanced and a great deal of coastal property will be endangered. Such a rise would have significant implications for coastal population and shore front structures. Therefore, coastal communities have three options: hard options (construction of sea walls), soft options (beach nourishment, mangrove plantations), or retreat (maintaining adequate set-back lines) (Pilkey and Wright, 1988; Haq and Milliman, 1996). Nevertheless, the best protective measure against rising sea levels is the retention of natural ecosystems, by retreat and appropriate setback lines, to allow natural resilience of the environment to find its own adaptation to the changing marine conditions.

It may be pertinent to note that the coast of Goa also displays natural ecosystems comprising sand dunes backed by a river or creek, and behind which mangrove swamps or marshes are located. Such a framework can be identified at a few places along the open sea coast. Considering their intrinsic value, these exotic settings can be conserved and be designated as state parks which can also be developed for the purpose of ecotourism, an activity which is yet to take of.

The fact that beach - dune ecosystems are characterized by delicate and complex dynamic behaviour, any intervention in such ecosystems requires a close cooperation between policy makers, planners, bureaucrats on the one hand, and environmental specialists and coastal scientists on the other. The planners have to admit wherever degradation has occurred and understand the need to check further deterioration. A close cooperation between the planning and executing authorities and the coastal scientific community who use scientific research results are some of the modern techniques used in the upkeep of coastal dune ecosystems. The Atlantic coast of France with a coastal dune system of 220 km in length which was largely destabilised by various anthropogenic and natural erosive factors was successfully restored as a group of coastal scientists intervened and suggested several remedial measures for the restoration of the entire system (Miossec, 1988; Paskoff, 1989, 1994).

Errors committed in the protection measures are often due to an inadequate knowledge about the natural and dynamic behaviour of beach-dune ecosystems. This is because those who are in charge of such rehabilitation measures do not appear to have a proper scientific background and do not follow the progress of research. This is also due to the bureaucratisation of restoration methods which are applied in a routine fashion without actually considering the natural conditions of morphology and sedimentology of given coastal area. In the process, money is spent and lost.

Education and awareness among the public in collaboration with the industry is indispensable and can be achieved by fixing posters and distribution of folders that can draw attention to the fragility of the dunes and the importance of their conservation for posterity.

9.4. Global Examples Of Sand Dune Conservation

In this document, a large number of references are given at the end as additional information. The main purpose of this exercise is to demonstrate the

sincere efforts of several countries of the world in the conservation and management of their beach - dune ecosystems.

The proportion of coastlines of the world which are significantly altered by human development is estimated at 13% in Italy, 21% in Korea, 38% in England, 40% in Japan, and nearly the entire coast of Belgium is lined by seawalls. By mid 1970, 37% of the ocean frontage of the coastal barriers of US Atlantic and Gulf coasts were occupied by buildings, roads and related structures (see Nordstrom, 1994, for details). In India, the coastal city of Bombay can be cited as one such example. In many such cases, the adjacent undeveloped shorelines are profoundly affected by human-induced sediment starvation. Therefore, most developed coasts bear little resemblance to the shores that existed prior to development.

Intense development of shorelines of the world led to negative impacts along the adjacent coastal areas. Many countries bitterly learnt from their past extravagant and unplanned use of the beaches and dunes for tourism and related activities. Corrective measures and environmental guidelines are issued in collaboration with the citizens and even public hearings are held to elicit their views; stringent regulations are now enforced. A literature survey regarding conservation of sand dune ecosystems reveals a commendable success in various countries: U.S.A. (Psuty, 1986,a,b; Nordstrom, 1989, 1994; Guinon and Allen, 1990; Leatherman, 1997); France (Bigot et al., 1987; Miossec, 1988, 1992; Paskoff, 1989, 1994); Holland (Arens and Wiersma, 1994; Van Bohemen, 1996; Van der Meulen and Salman, 1996); Portugal (Psuty and Moreira, 1992; Granja and Carvalho, 1995); Greece (Babalonas and Papastergiadou, 1993); Denmark (Jensen, 1994); Turkey (Demirayak, 1995); Egypt (Frihy, 1996; Frihy et al., 1996,a,b); England (Carter, 1988; Pye and Neal, 1994); Israel (Perry and Dmiel, 1995); Lithuania (Olenin, 1995); Cuba (Marti et al., 1995); South Africa (Avis, 1989; LaCock et al., 1992; Nichols, 1996); West Africa (Sikirou, 1986); Seychelles (Wilson, 1997,b) and China (Wu and Wu, 1990).

The "Sand Dune Law" in various countries explicitly forbids destruction of dunes as it results in irreversible damage of coastal strips which cannot be reconstructed. The coast of Holland provides one of the best examples of integrated sand dune management in the world (Arens and Wiersma, 1994; Van Boheman, 1996). The New Jersey coast of USA is the most densely built sandy barrier islands; such activities are now severely restricted by stringent regulations governing the use of coastal spaces (Nordstrom, 1994). In France, a special law was drafted in 1986 which makes the protection and restoration of sand dunes mandatory and asserts the intrinsic value of the coastal zone with a 100 m wide band of no development (Paskoff, 1994; Miossec, 1992). One successful example of regulated tourism development is Seychelles; it spared its beaches from concretisation and allowed resorts only behind the sandy stretches (Wilson, 1997,b).

In all these countries, various planners, bureaucrats, coastal managers and builders have understood and admitted the importance of sand dunes, an integral part of the coastal zone, in the preservation of natural littoral equilibrium. Thus coastal scientists, NGO's and citizens today contribute towards the conservation of sand dunes

by insisting on proper integrated studies between beaches and dunes. Such an approach which involves the natural ecosystems and the socio-economic system can alone preserve the sanctity of coastal sand dune ecosystems of Goa.

10. SUMMARY AND RECOMMENDATIONS

A. Sand dune belts which back sandy beaches are the most characteristic features of the open sea front of Goa. These geomorphic edifices are most conspicuous from Querim to Morjim, Baga to Sinquerim, Miramar to Caranzalem, along the long linear stretch from Velsao to Mobor, and Talpona to Galgibaga. These dunes, often as high as 10 m, sometimes extend even beyond 500 m from the HTL. These geomorphic edifices, about 6000 years old and categorized as Nature's line of defense, are typical features of coastal stability. The dune environment is classified as fragile, sensitive and vulnerable due to its propensity for changes under even slight environmental stress. Therefore, sand dunes have to be preserved at all costs by maintaining free coastal spaces.

B. Our study reveals that (a) construction of resorts and buildings on dunes, (b) mining of dune sands and (c) roads on sandy strips, are the three major factors which are responsible for the degradation of sand dune vegetation, increase in the mobility coupled with a landward migration of loose free sand, impacts on dune stability, alterations of sand budget, risks of inundation and accompanying erosion. These factors collectively result in the large scale irreversible degradation and consequent elimination of sand dunes. Seasonal marine salt water ingress is beginning to show up in coastal aquifers; this is attributed to excessive pumping of ground water. In comparison, the effects of other human interference such as beach shacks, recreational activities and litter on beach - dune systems can be termed as minimal and are largely reversible.

C. During the last fifteen years, several management plans have been proposed. Of these, The Eco-Development Plan (1982), The Environment Management Plan (1988) and the Regional Plan (1988) indeed address sand dunes and the need to maintain open coastal spaces. On the contrary, the Tourism Master Plan (1987) and the Coastal Zone Management Plan (1996) recommend unrestricted development along the coast. Moreover, the CZMP has completely ignored sand dunes which are sensitive landforms along the open sea front, and in fact approves tourism related development along the entire 70 km long sandy beaches. Thus, planners and policy makers keep contradicting their own guidelines. Such a laxity has resulted in unauthorised structures and uncontrolled growth along the coastal zone. This proves that the environmental laws are rarely considered.

D. Blatant large scale violations of CRZ regulations are observed along the open sea front as well as the estuaries. Sand dunes have borne the maximum brunt and have suffered the greatest from indiscriminate anthropogenic pressures which mostly include haphazard construction activities. High dunes have been razed and obliterated to make place for hotels and roads. Some structures are seen even along the HTL. Unscientific dune sand extraction and ground water withdrawal is rampant and goes unchecked. Such anthropogenic activities have changed and are still altering

the configuration of the coast, factors which work against the ecological principles of the coastal zone.

E. Mandatory setback lines are imperative. Sand dunes are landforms essential for coastal stability, they are ecologically sensitive, they are sometimes mobile and hence shifting in nature; the threat of an impending sea level rise will make dunes act as Nature's line of defense. These factors collectively demand that coastal dune strips, as already defined by law, have to be compulsorily designated as no development zones.

F. Several areas along the open sea coast and also within estuaries are undergoing erosion. In some cases this process appears to be natural (Agonda), whereas in others it is man-made (Campal). All such places under threat call for (natural) protection under CRZ rules.

G. Hard options (sea walls) employed to control beach erosion are obsolete as they only magnify erosive processes leading to disappearance and consequent loss of sandy beaches, a phenomenon that can be observed at Campal where erosion continues unabated. What is required are soft options such as beach nourishment and more modern methods of beach management. The sea wall at Campal is a monumental human blunder.

H. Restoration of degraded sand dunes is a modern scientific method used for their management. Fencing of dune strips and planting appropriate vegetation is a simple and effective method in restoring dunes. Vegetation can often recuperate itself if dunes are left undisturbed; such dunes remain stable.

I. The crucial issue of predicted sea level rise has neither been considered nor visualised by local planners, although this factor is to be examined under CRZ rules. Since the sea levels are rising, coastal communities will have to adopt extensive measures to protect structures closer to the coast. In Goa, the beaches in general and the flat ones in particular are bound to be influenced by enhanced erosion. However, no matter what technique is applied, the protective measures would only be a temporary solution requiring continual upkeep accompanied by prohibitive expenditure. The most cost-effective long term solution is to set aside land for future marine transgressions; hence the need for open coastal spaces.

J. The sea front of Goa can be classified as overdeveloped, developed and undeveloped depending upon the modern activity observed after 1991, subsequent to the CRZ Notification. The first category includes the Baga - Calangute - Candolim sector in the north and Colva in the central part; the second category would include Anjuna, Caranzalem - Miramar, Bogmalo (part), Utorda - Betalbatim, Benaullim, Cavelossim - Mobor in particular and Palolem. All the remaining part of the coast can be said to be relatively undeveloped. In the last category, we observe that many stretches, within and outside CRZ, still remain unsullied and in a pristine form (Querim, Arambol - Mandrem - Morjim, Velsao - Cansaulim, Varca, Agonda and Talpona - Galgibaga).

K. Natural ecosystems comprising sand dunes backed by a river or creek which is in turn backed by mangrove swamps or marshes are found at a few places along the open coast. Such exotic settings can be designated as state parks and can be reserved for the purpose of ecotourism.

L. Proper management and sustainable development of the coastal zone of Goa is an issue of critical importance as more than half the population inhabits the coastal zone. Ecological considerations are being overstepped and sidelined so that demands can be met. We are therefore faced with a conflict: builders, planners, bureaucrats and politicians favor "development" under the banner of demands, whereas environmental scientists and NGO's insist on ecological and environmental principles. A lack of political will appears to be the main impeding factor.

M. The concept of "build here, build there, build everywhere" has created multiple use conflicts of coastal spaces. In view of various problems and impacts described above, it is imperative that an environmental impact assessment of the effects of human activity on the beach dune ecosystems of the entire coastal stretch be carried out so as to ascertain the health of the coastal zone.

N. We need a stringent enforcement of CRZ laws coupled with an integrated coastal zone management with a holistic approach which includes the natural ecosystems and the human socio-economic system. This exercise will undoubtedly be helpful in the preservation and protection of the remaining shreds of the coastal environment of Goa.

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