

SAND DUNES: AN INTRODUCTION

What on earth are sand dunes? Ostensibly nothing but mounds of drifted sand on the beach, topped with vegetation one does not normally see in a Goan village. Sand dunes were not put up by human beings, but by nature, and can be millions of years old. Without them, habitation on the coastline would be a nightmare, extremely difficult, if not impossible.

Sand dunes are a sign of the ecological equilibrium between the powerful physical forces of the ocean waves, wind, tide and current on the one hand, and the natural resistance of the land on the other. A stable sea shore has two main lines of sand dunes: a sea dune which runs along the sea shore, and a land dune which runs parallel, but about 100 to 500 meters away from the sea shore. In between those two lines of dunes lies a sandy plain with minor dunes and coconut palms.

Formation, Significance and Uses of Sand Dunes —

The main prerequisites for the formation of sand dunes are wind, sand and vegetation, three elements with complex and dynamic interactions. 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. 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 plays 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.

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 (See figure A next page). 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 depends 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 condi-

tions 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 B-E on next page).

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 B). The surplus sand that is available forms a new sand dune seaward of the 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 paleo-shoreline 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 C). In such situations, high waves often wash over the dunes 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 D).

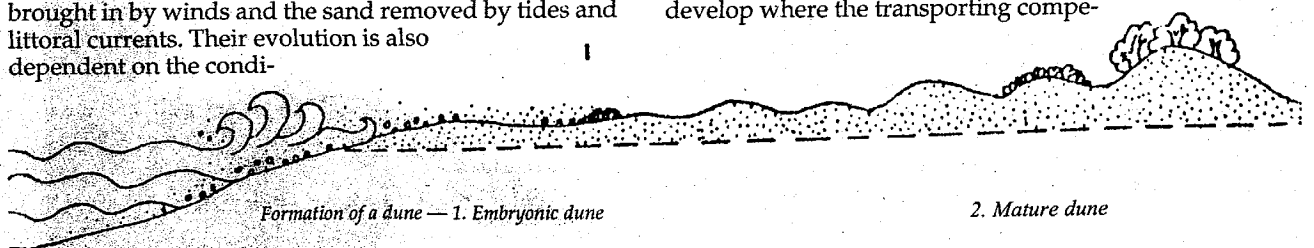
When the sea level shows an increasing tendency, as is the case world over at present, the sand budget is slightly negative. In such a case, there is a consequent sediment starvation; high waves and stormy seas force the shoreline to retreat, resulting in a landward migration of the sand dune and shoreline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

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 E 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.

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 and as a result consequences are noticed on the beaches with which they are associated. A sand dune belt has multiple functions and is 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.

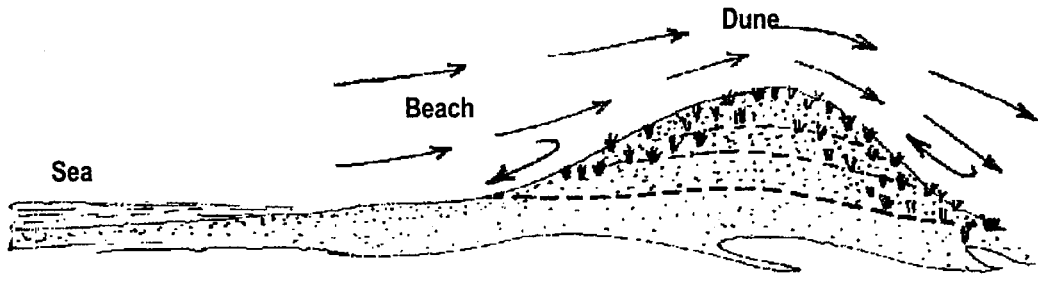
—Sand dunes are eolian bedforms and develop where the transporting compe-



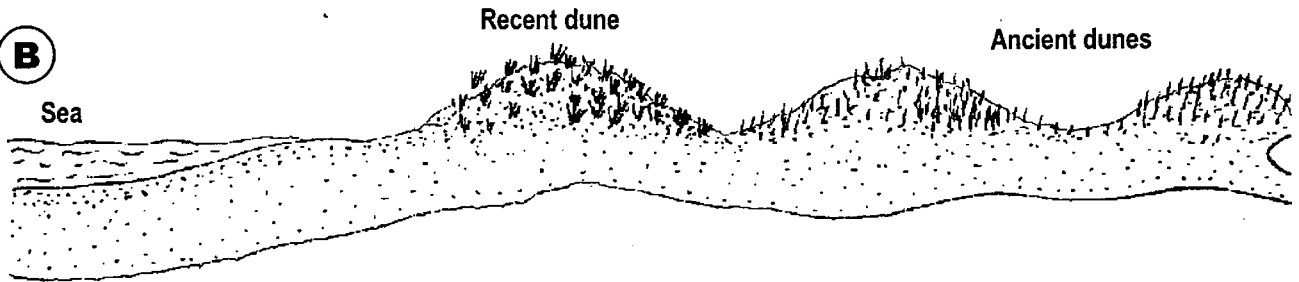
Formation of a dune — 1. Embryonic dune

2. Mature dune

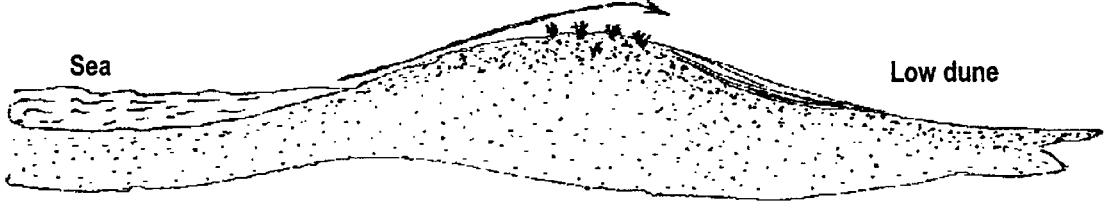
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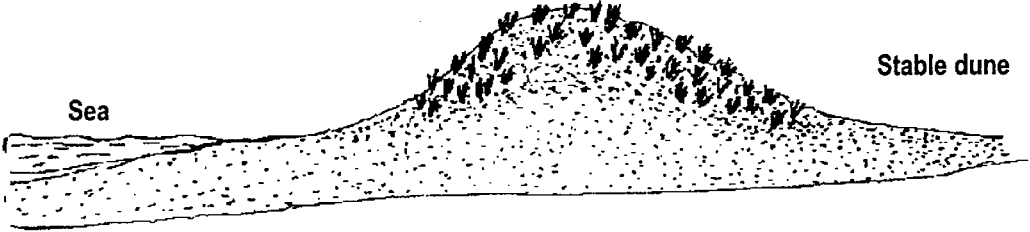
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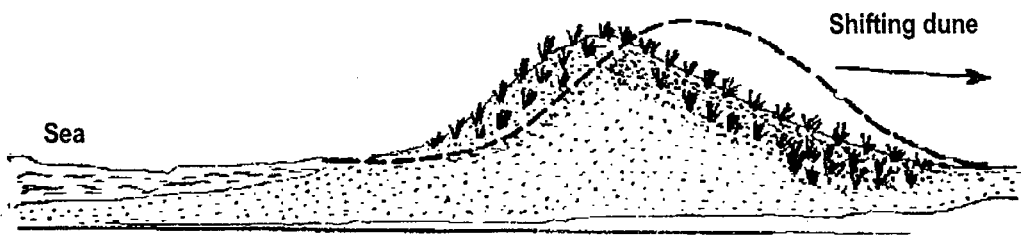
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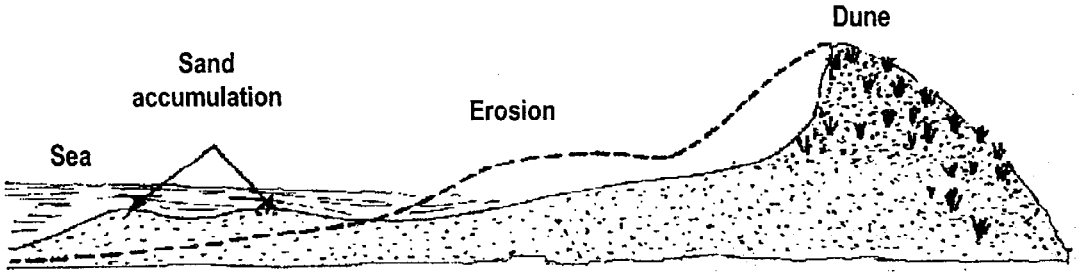
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E



F



Graphics by Antonio Mascarenhas

tence 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

—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.

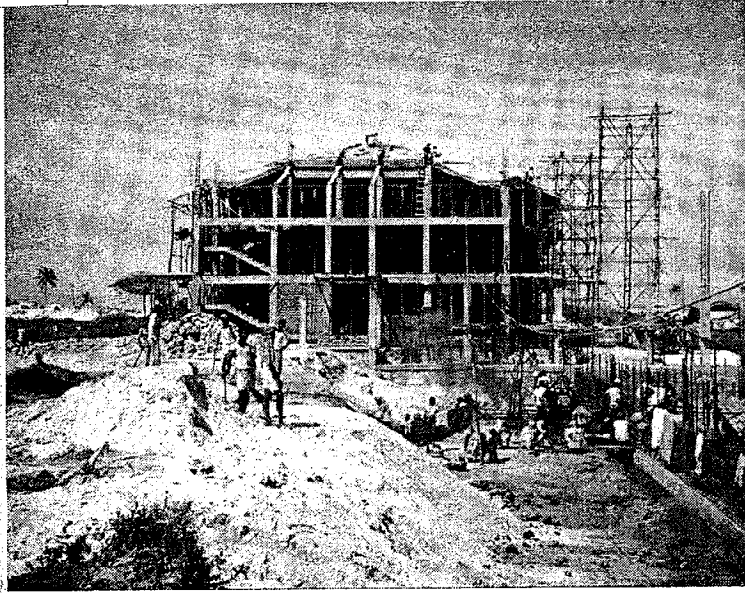
—Dunes therefore protect the hinterland from winds and other forces and hence make the zones behind dunes as areas of peace and tranquility. Historically, in Goa, areas behind dunes had developed as peaceful areas of habitation and agriculture, examples that can still be observed at Baga, Candolim, Caranzalem, 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.

—Sand dunes of Goa are about 5000 years old. They formed after the sea-level almost stabilized in its present position during the Holocene. At places, they are as high as 10 meters as in Benaulim and Cavelossim.

—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.

The Fate of the Sand Dunes — A quick review of various anthropogenic impacts clearly indicates that (i) construction of resorts and buildings, (ii) sand dune 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 violation 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 groundwater withdrawal.

The natural behaviour of sand dune systems has to be respected, 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

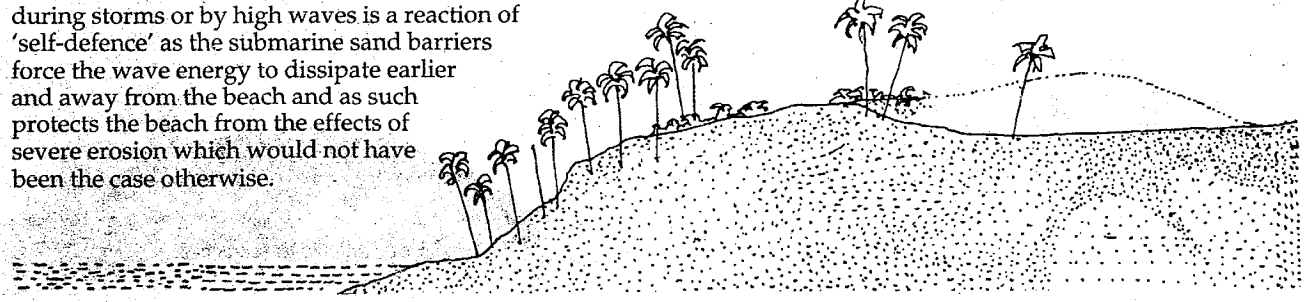


Construction with total disregard for dune ecology

restoring sediments lost due to erosion in the coastal zone. Therefore, the conservation of sand is required to protect the 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 F*). 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, which are 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.

Ozor (Anjuna) Beach Section



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. 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 leveled 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, etc have rapidly degraded sand dune vegetation which is particularly sensible to human interference. Recreation can have adverse effects on sand dunes. Native plant species are prevented from colonising because of the preference for 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 stretches which have so far remained free from development.

The damage and destruction of dunes, irrespective of the agents responsible, pose various consequences for the coastal environment. 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 induces 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 and reduce the velocity on the lee. Structures built on dunes induce localised deposition, cause local increase in the height of the dunes and reduce the



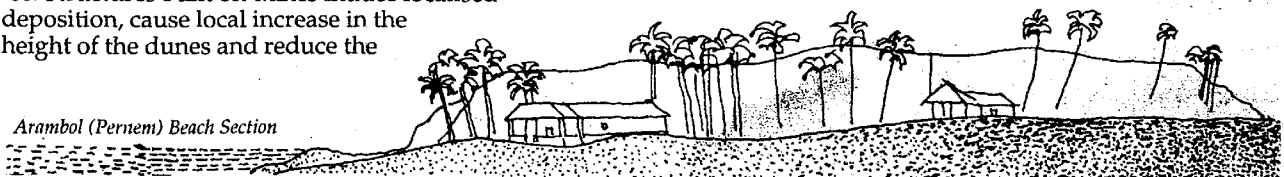
Resort constructed on sand dunes (Cavelossim)

inland migration of the dunes. Even a moderate development on dune belts strongly affect sediment transfers. Buildings also change the location of accretion and scour on beaches and dunes. Large buildings cause a reversal of regional wind flow; windblown sand accumulates against buildings, houses, boardwalks and roads, creating a diverse dune scape, distinctly different from the one created under natural conditions. 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. 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 dunes are rarely considered. For this, ample space is necessary 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

Arambol (Pernem) Beach Section



significant at Arambol, Anjuna, Majorda and Colva. A proper scientific proof pending, these events may be attributed to annual changes that a beach undergoes. The area at Colva, for example, regenerates itself during the post monsoon period as has been observed 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 107 m in the recent past. At Velsao and Agonda, coastal erosion is evidenced by a large number of tall uprooted trees. 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.

The most alarming erosive processes are seen along the Miramar-Campal sector. The entire stretch which constituted a dune belt with a thick vegetal cover as late as the 1950s 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 and used for the constructions. 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 as a defence mechanism. Here, the planners got the taste of their own medicine; most of the wall collapsed 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.

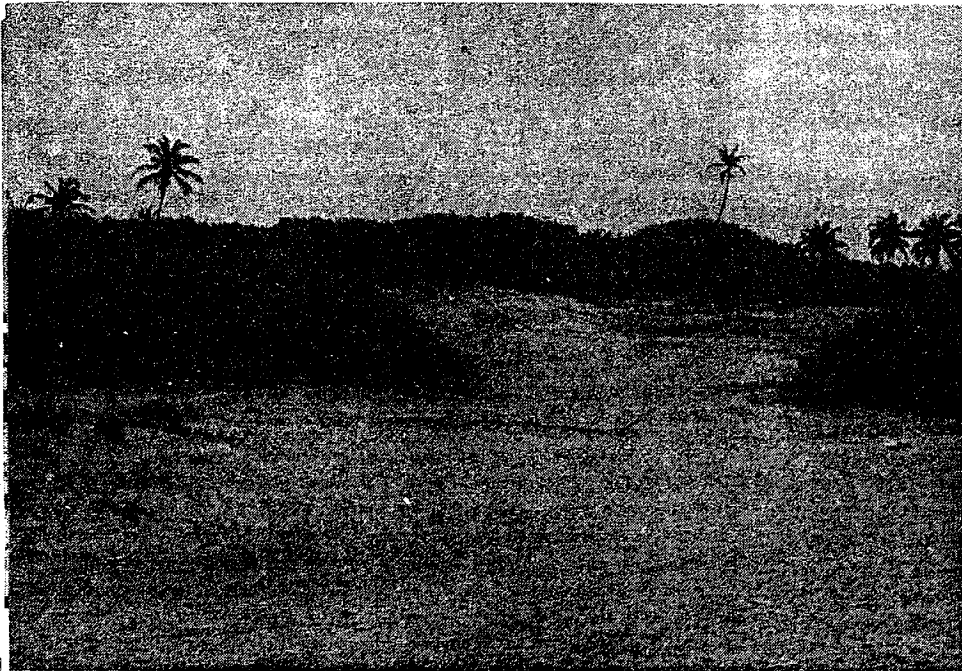
Despite the fact that the shoreline is prone to erosion, a huge hotel complex is now under construction on a dune at Miramar, precisely at a place where it should not have been. A concrete wall built in 1996, about four meters landward of the earlier (1958) wall, is already showing signs of decay with 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 a 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 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.

Antonio Mascarenhas



Sana dunes on Candolim beach

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. 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.

Calangute (Bardez) Beach Section

