BEACHES AND DUNES OF THE GULF OF MEXICO: A VIEW OF THE CURRENT SITUATION

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Beaches and dunes are the most important sedimentary environments in the world. It is here that the greatest accumulation of sediment (grains of sand of different sizes) can be found, carried there by marine currents or the wind. Both beaches and dunes are extremely dynamic and inconsistent ecosystems, and act as a buffer between the sea, the land and the atmosphere. Beaches are unconsolidated deposits of sand and gravel along a coastline. At any given moment, the outline of a beach represents the dynamic equilibrium between transportation of sediments towards the sea (erosion), towards the mainland (sedimentation) and along the coasts (drift currents). The topography of a dune represents the equilibrium between the movement of the sand carried by wind (erosion or deposition) and amount of plant cover. The scale of these movements varies from a few hours (during storms) to weeks, months or whole seasons of the year, and even involves cycles of several years. Therefore, the surf, a high-energy environment that is capable of mobilizing sediments, dominates beach formation. Dunes, on the other hand, are created by wind energy.

Beaches are located between the lowest and highest tide levels, including storm tides. They are subject to periods of surface desiccation that are more pronounced at higher elevations (upper or posterior beach), where most of the vegetation is found. On the forebeach or lower beach, the remains of algae and marine grass thrown up by the sea and, occasionally, certain annual species, germinate and establish. Sometimes, seeds thrown up by the sea germinate, although the seedlings usually die quickly.

Behind the beach, terrestrial geomorphologic structures form (e.g., dunes or sand cliffs or swales containing plant communities such as wetlands or forest). They are formed by the movement of the wind, that lifts grains of sand small enough to travel through the air from a source of sediment such as a beach, carries the particles through the air, and then redeposits them elsewhere (Ranwell, 1972). The sediments that form dunes begin as sand thrown onto the beaches by waves, where it is exposed to the air. The sun and breeze dry the sediment, and grains of sand are left exposed and then moved by the wind. The first dunes (embryonic) form when wind that is carrying sand comes up against an obstacle such as a plant or a tree trunk. These small dunes grow as they continue intercepting sand until they join and form a ridge behind which the real dunes can be found. These accumulations of sand range in height from a few centimeters (embryonic dunes) to massive systems of undulating sand hills that are up to 35 meters high, are oriented by wind direction and may stretch several kilometers inland.

FORM AND TOPOLOGY

There are several different types of dunes, not all of which exist in Mexico. Dunes are greatly modified over time due to their interaction with the vegetation. Barrier islands, long bodies of sand that face the sea on one side and on the other side face the estuary that separates the barrier island from the mainland. These formations are constantly moving as they sand is accumulated and lost (Pilkey *et al.* 1998). Plant communities become established at different elevations that exhibit zonation typical of dune systems along mainland coastlines. Keys, islands formed in association with reef systems, are accumulations of calcareous sand that is formed from the different sized fragments of shells and skeletons.

Dune strands are accumulations of sand that form continuous, low strands, parallel to the sea. Where there is only sand and no vegetation, sand particles move freely and their movement depends entirely on the direction and intensity of the wind. In such cases, the so-called transgressive dunes form. These are great bands of sand that slowly advance perpendicular to the wind that moves them. Parabolic dunes are crescent shaped and form when a moving dune comes into contact with vegetation, where sand is retained. This area of the dune moves slower than the rest of the dune and becomes stabilized, getting left behind as the more mobile areas of the dune continue to advance, forming a parabola.

Dune orientation reflects the dominant wind direction. When the wind blows onshore, strands of transgressive dunes form parallel to the coast and move inland in waves. The longitudinal axis of parabolic dunes that form is perpendicular to the beach line and these dunes also advance inland, but more slowly. When the strongest winds are northerly and the orientation of the coastal line is also north-south, the axis of parabolic dunes is parallel to the beach, and parabolic and transgressive dunes move from north to south, as is the case in Tamaulipas and the north and north-central Veracruz.

Dunes are also frequently classified as active or stable. Whether or not dunes are stable depends largely on the presence of plant communities, because they play a major role in stabilizing sand and reducing wind strength. In active dunes, sand movement produces erosion in certain areas and accumulation in others, allowing dunes to advance or migrate. It not uncommon to find, within the same system, zones where the sands are active, semi-mobile zones where plants are beginning to retain the sand, and finally stable or fixed dunes, which are continually covered with vegetation.

BEACH AND DUNE ENVIRONMENTS

Dune topography and degree of stabilization (which in turn modifies topography) depend on certain environmental conditions and play a fundamental role in determining the plant communities that will become established. Figure 15.1 shows the different types of vegetation that inhabit dunes and as well as the mosaic that they form. There have been various attempts at describing or classifying these microenvironments with a view to understanding the heterogeneity of the conditions and communities (Doing 1981). Castillo and Moreno-Casasola (1998) have classified these environments as:

a. Active dune environments where sand movement is predominant (either erosion or accumulation) resulting in little organic material in the soils, limited water retention ability, scarce vegetation, and strong daily fluctuations in soil surface temperatures. In general, these environmental conditions are inhospitable and few species have adapted to these conditions. These conditions characterize beaches, embryonic dunes and active dunes. Figure 15.2 shows sand movement measured over three consecutive years on a dune in the Centro de Investigaciones Costeras La Mancha (La Mancha Center of Costal Research, CICOLMA) reserve (Moreno-Casasola 1982).

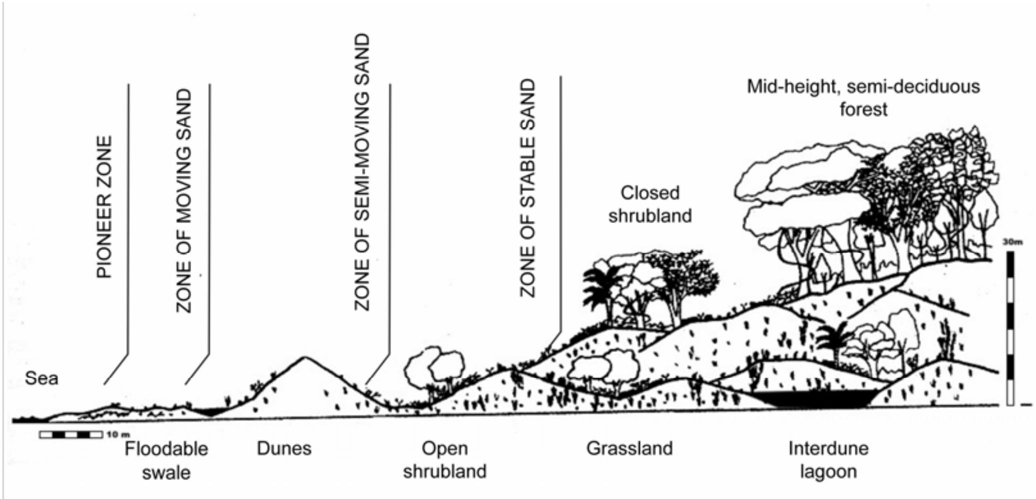

Fig. 15.1. Vegetation profile showing the physiognomy of the different plant communities of a dune system, in all of the microenvironments. Modified from Acosta (1993).

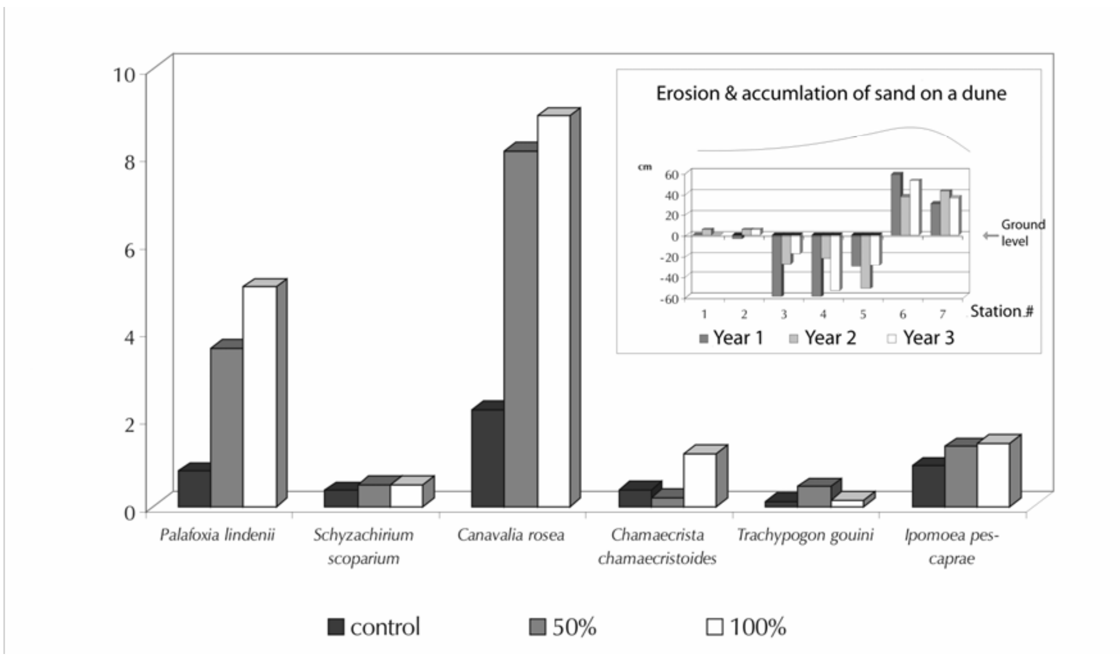

Fig. 15.2. Growth response (dry weight) of various pioneer species to burial under sand. Two treatments were applied (meristems totally covered in sand and meristems of which only 50% of the surface was covered) and the control, not covered with any sand at all. The species are: shrub-like and endemic *Palafoxia lindenii*; grass *Schyzachirium scoparium*; creeping legume *Canavalia rosea*; endemic, shrub-like, legume *Chamaecrista chamaecristoides*; grass *Trachypogon gouini*; and creeping *Ipomoea pes-caprae*. Statistical comparisons between the three experiments were made for the same species. Different letters indicate significant differences. The graph shows the movement of sand in a dune measured at the same point over three years (data from Martínez and Moreno-Casasola 1996).

b. Humid and floodable environments in the lowest areas, where wind has carried the sand until coming into contact with the humid substratum due to the closeness of the water table, that is, a depression has been created between the two arms of the parabola. In

c. some cases, where flooding is permanent, lagoons form between the dunes, with open bodies of freshwater and emergent, floating and submerged rooted wetland vegetation.

d. Stable environments, where vegetation has stabilized the substratum and allowed incorporation of some organic material into the soil. These soils are better and more complex plant communities become established, including grasslands, brush or scrub, low and intermediate forest, and live oak mottes.

BEACH AND DUNE DISTRIBUTION

In Mexico, beaches and dunes are not homogeneously distributed. Accretionary processes predominate on the Atlantic coast (includes both Gulf of Mexico and Caribbean Sea). Low, sandy beaches and great deal of sediment accumulation characterize this region. The Gulf of Mexico coastline is located in the center of a tectonic plate therefore, the coastal plain and continental shelf slope gently. The Gulf Coast includes important river deltas such as those associated with the Rio Grande and Pánuco, Papaloapan and Grijalva-Usumacinta rivers. The Yucatán Peninsula is made up of an emergent karstic platform, with carbonated sediments and although there are no surface rivers, there is a flow of subterranean water into the Gulf and Caribbean (Britton and Morton 1989; Ortiz-Pérez and Espinosa 1991; Contreras 1993).

Barrier islands and sand bars are found on Atlantic coastline and vary greatly in width and length (Fig. 15.3). Most are uninhabited, although others contain large settlements such as Ciudad del Carmen (Campeche). In Tamaulipas, the coast is deltaic. In the Laguna Madre region, accumulated riverine sediments predominate along the mainland coast of the lagoon with sediment accumulation as a result of marine processes along the Gulf of Mexico. There are barrier peninsulas and/or islands along most of the Tamaulipan Gulf Coast, forming the boundary between the Laguna Madre and the sea.

Laguna de Tamiahua is located in Veracruz. It is delimited by a barrier island (Cabo Rojo) and could be considered a tombolo (Britton and Morton 1989). From a geomorphologic point of view, the area stretching from Tuxpan (south of Cabo Rojo) to Nautla includes accretionary coasts of low, sandy beaches that are exposed to the sea (no barrier islands). These beaches were formed when ancient lagoons that separated barrier islands with dune fields and beaches from the mainland filled with sediment. To the south, the coast becomes modified as coastal plain diminishes. Here there is a coast of rocky points of volcanic origin interspersed with small lagoons with narrow flood plains. Sandy beaches and active or stable dune fields are also found between Laguna Verde and Alvarado. Further south, in the Papaloapan region, there is a large, prominent sand barrier, that protects the Alvarado lagoon-estuary system, as well as extensive elevated dune fields that reach as far as Punta de Roca Partida with sand fingers that penetrate up to 10 km inland. The coast in the Los Tuxtlas region, where mixed abrasive-accumulative coastlines are predominant, contains stretches that alternate between projections of volcanic rock and sandy beaches. Interspersed between them is the Sontecomapan bar and lagoon system. In addition, south of Veracruz, Laguna de Ostión contains a barrier lagoon and broad floodplains or mangrove marshes, as well as a coastal barrier plain with active dune fields (Ortiz-Pérez 2005).

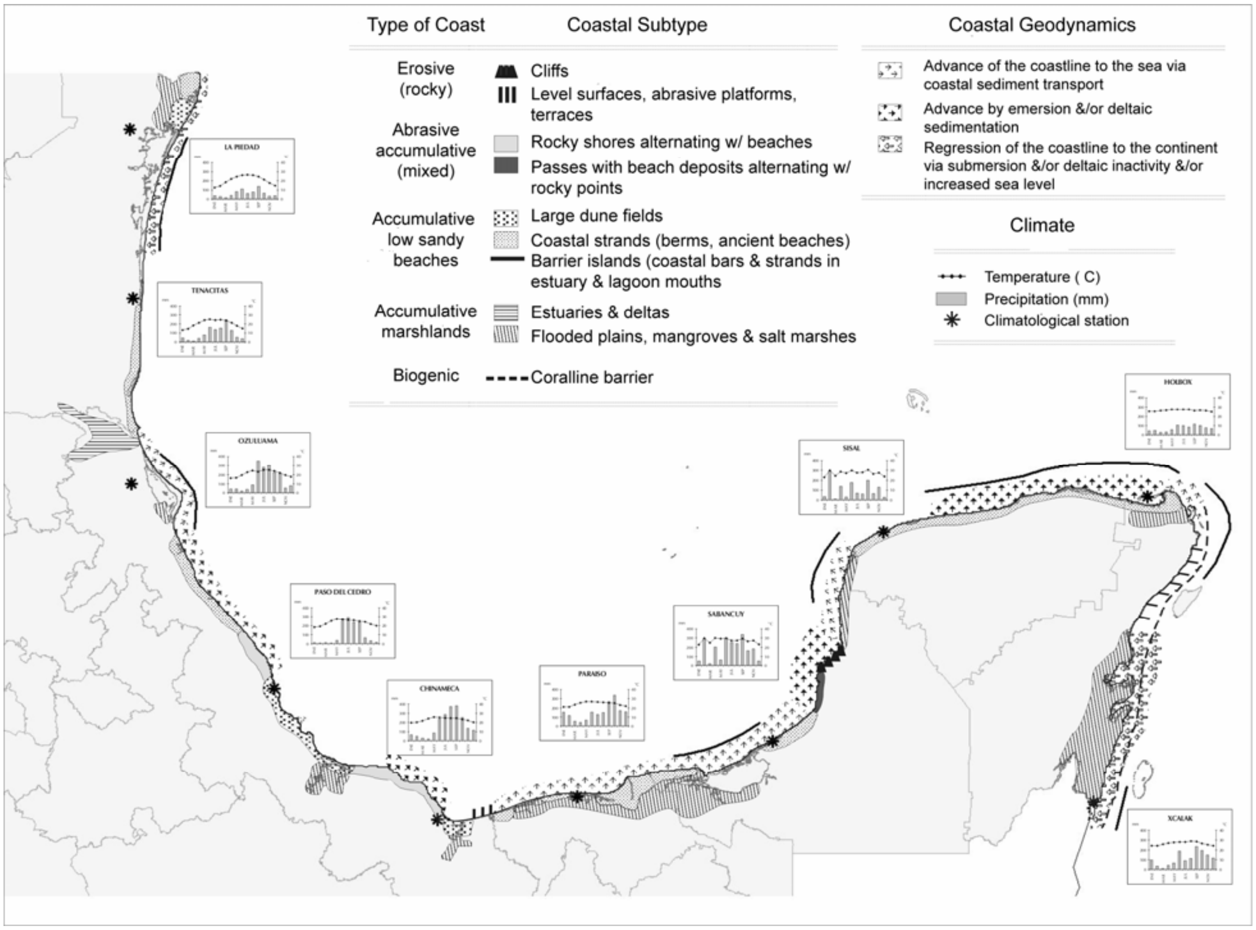

Fig. 15.3. Distribution of barrier islands, coastal strands, dune fields and rocky areas intercalated with beaches in the Gulf of Mexico and Mexican Caribbean. Advancing coasts are indicated. Climatic data for some zones are provided. Based on Geographic Atlas, UNAM and Ortiz-Pérez and Espinoza (1991).

In Tabasco, Laguna del Carmen, La Machona, La Redonda, Laguna Cocal, Laguna Flores and Laguna Mecoacán are bordered by a series of coastal ridges that form barrier islands that are elongated in the Barra del Grijalva and Barra de San Pedro regions. Parabolic dune fields are formed in an extensive area between Barra de Tonalá (Laguna Chicozapote) and Barra de Santa Ana (Laguna del Carmen), and reach heights of 15 m. In the deltaic and swampy zone at the southern end of Tabasco there is an abundance of fine-grained clastic sediments of riverine origin. On Isla del Carmen, towards Isla Aguada, the beach is relatively wide (20 m) and a few meters in elevation, with low dune fields. Towards Champotón, relief of the dune ridge decreases and the beach is only 3 m wide (Britton and Morton 1989; West *et al.* 1969; Castillo *et al.* 1991). Isla del Carmen is the barrier island that separates Laguna de Términos from the Gulf.

Approximately 20 km south of Ciudad Campeche there is a small extension where the calcareous platform has emerged to form a rocky coastline in the region of Punta Mastún Grande (Britton and Morton 1989). Towards the Celestún estuary, a small sand tongue stretches out parallel to the mainland. The Yukalpetén, El Islote, and Río Lagartos estuaries and Laguna

Flamingos are located in the northern part of Yucatán. Here the beaches are narrow and dune strands are low and not very extensive due to the proliferation of wetlands such as *petenes*, and mangroves, that are frequently found inside the estuary, and floodable savannas. The lagoons are shallow and frequently contain obstructions to water flow; this is the region of the Gulf of Mexico with the lowest precipitation. In Yucatán and Quintana Roo dune strands are frequently found parallel to the coastline.

The Yahalán Estuary is located in the north of Quintana Roo and, further south, the Laguna de Nichupté where the barrier island forms part of Cancún. From Tulum to Punta Allen is a barrier headland separating Laguna Campechén and Laguna San Miguel from the Caribbean Sea. Bahía de Ascension and Bahía Espíritu Santo also contain this type of formation. Narrow beaches and dunes, largely used for growing coconuts, are bordered inland by extensive floodplains covered in freshwater wetlands, mangroves and *petenes.*

The Veracruz Reef System, located offshore from Veracruz, contains keys and islands of calcareous sand, such as Isla de Lobos and Isla de Enmedio. At Laguna de Tamiahua there are also sandy islets containing large quantities of calcareous sand. Numerous islands are located around the Yucatán Peninsula, some of which lack vegetation. Triángulo Oeste, Cayo Arcas and Isla Jaina are all in Campeche. Arrecife Alacranes in Yucatán includes Isla Desterrada, Isla Muertos, Isla Chica, Isla Larga and Isla Pérez, with Cayo Arenas close by. In Quintana Roo, in addition to the three largest and most well-known islands (Cozumel, Mujeres and Contoy), there are Cayo Lobos, Cayo Centro and Cayo Norte in Banco Chinchorro, Cayo Culebras and Isla Holbox (Bonet and Rzedowski 1962; Flores 1983, 1984).

The three previously mentioned environments are present throughout the length of the Gulf and the Caribbean (Castillo and Moreno-Casasola 1998). In general, active dunes and permanently flooded swales are more frequently found in the Gulf. These environments appear on the barrier islands, on the systems formed by parallel dune strands and in the large systems of parabolic dunes. Figure 15.3 also shows some climatic characteristics that facilitate an understanding of the physical patterns affecting distribution of plant species. In addition to important differences in total rainfall amounts along the Gulf and the Caribbean (Moreno-Casasola *et al.* 1998), the variety of its distribution is significant. The seasonal nature of rainfall is most clearly perceivable in the central Gulf zone. In the Gulf of Mexico, siliceous sands with different proportions of calcareous sands predominate, whereas calcareous sands are predominant in the Caribbean.

BEACH AND DUNE FLORA

The plants found on beaches and dunes are not usually considered distinct flora; however, the communities do contain characteristic species as well as endemic species that only live in these environments and they are relatively rich in terms of their composition. To date 1,638 phanerogams (140 families) have been documented in Mexico as part of the coastal flora (Moreno-Casasola *et al.* 1998). These represent 5-7% of the total number of species thought to exist in the country (20,000-30,000 depending on author). This represents a relatively high proportion if one considering the narrowness of the beach-dune system. The number of families and species varies considerably from region to region; in the Gulf of Mexico 429 species and 89 families have been recorded, and in the Caribbean, 456 and 78, respectively. Due to its length and environmental heterogeneity, the Pacific Coast is richer in species than the Atlantic, as the latter contains 706 species (97 families) whereas in the Pacific 1,133 species and 125 families have been recorded.

In terms of species, there are similarities between the Pacific and Atlantic coasts (Moreno-Casasola *et al.* 1998). Using a similarity index to compare the two plants lists for the five regions into which the Mexican coastline is divided, there is a striking resemblance between the floras of the north Pacific, the Gulf of California and the southern Pacific coast (Table 15.1). The regions of northwest Mexico are most similar (0.41), basically due to their similar geological origin and relatively dry climate; for this reason they share the same kind of desert flora. The floras that distinguish them are those of Los Cabos and the Mediterranean type area, both rich in endemic species. The costal flora of the north Pacific and Gulf of California is considerably different from that of the southern Pacific coast. To a lesser degree, although still of great interest, is the floral similarity between the Gulf of Mexico, Caribbean and the southern coastal region of the Pacific. This is explained by the presence of species belonging to low semi-deciduous forest and semi-evergreen areas, for example, the numerous leguminous species that are found on the sandy substrata on both coasts with similar climatic conditions.

The Gulf of Mexico and the Caribbean floras are fairly similar (0.39; Moreno-Casasola *et al.* 1998). This similarity is slightly less than that of the floras of the north Pacific coast and the Gulf of California. The resemblance between the two floras of the Atlantic coast is probably due to the size of the coastal plain that allows species to disperse into areas with similar climatic conditions. The most extreme climates, those with low precipitation levels, are located in northern Tamaulipas and the northeastern Yucatán Peninsula. Differences in composition are due to siliceous substrate in the north and calcareous substrate in the south that allows emergence of Caribbean elements as well as species endemic to the Yucatán Peninsula and the semiarid areas of northern Yucatán. The central area of the Gulf is noteworthy because its dune systems have complex topographies with a greater number of habitats that favor the presence of specific species, for example, those of the aquatic habitats (Martínez *et al.* 1997). It also has a richer variety of species (Moreno-Casasola 1988).

The coastal areas with greatest floral endemism are the Baja California Peninsula and the Yucatán Peninsula, followed by the Gulf of Mexico and the southern Pacific coast (Moreno-Casasola *et al.* 1998). In the Gulf of Mexico region coastal endemism is very low with just 8 families and 9 species. The Asteraceae include two endemic species. Some of these species grow more vigorously when buried, as in the case of *Palafoxia lindenii* and *Chamaecrista chamaecristoides* (Martínez and Moreno-Casasola 1996), and they act as important stabilization agents in the mobile dunes of the central region of the Gulf of Mexico (Fig. 15.2). In the Caribbean, the number of endemic species is greater: 32 species (21 families) of which the most important are the Cactaceae (6 endemic species), Rubiceae (3) and Polygonaceae (2) and Leguminosae (2).

Local floral species richness comes from the presence of numerous species belonging to a handful of families and the contribution of a great variety of families with few species, the presence of which varies greatly throughout the length of the coasts of Mexico (Moreno-Casasola and Castillo 1992). In order to understand this phenomenon, the species inhabiting the coastal beaches and dunes were subdivided into three types. The first corresponds to those species with a predominantly coastal distribution, that is, in ecosystems restricted to coasts such as beaches, dunes, salt marshes and mangroves. The second group corresponds to dune species that are also frequently found in other types of vegetation (low and intermediate height forests, savannahs, wetlands, oak mottes, etc.); and the third is made up of those that basically form a

Table 15.1. Similarity indices between the flora of beaches and dunes of five regions in Mexico, on both coasts (Moreno-Casasola *et al.* 1998).

	Northern Pacific	Gulf of California	Southern Pacific	Gulf of Mexico	Caribbean
Northern Pacific	--	0.41	0.07	0.06	0.06
Gulf of California		--	0.07	0.05	0.06
Southern Pacific			--	0.30	0.24
Gulf of Mexico				--	0.39
Caribbean					--

part of secondary or ruderal vegetation (Castillo and Moreno- Casasola 1996). The percentage of coastal species is close to 15%, ruderal species, 40%, and 45% belong to other types of vegetation. This means that for a large amount of inland species, coastal dunes provide a favorable environment for establishment and reproduction.

BEACH AND DUNE VEGETATION

Beach and dune vegetation is made up of communities of pioneer plants, grasslands, scrub or brush, forests and woods, and wetland and aquatic vegetation. Structurally, these communities can be high or low, open or closed, thorny or thornless, and frequently intermingled to form a complex spatial mosaic (Fig. 15.1). Poggie (1962) and Sauer (1967) provide the first descriptions of vegetation. After that, Espejel (1984), Moreno-Casasola and Espejel (1986) and Castillo *et al.* (1991) described and classified the vegetation of the Gulf of Mexico and the Caribbean based on 44 sample sites. Table 15.2 presents a synthesis of the flora of this region based on that classification. The terms beach and dune refer to geomorphologic structures and, as we saw previously, can be formed by distinct microenvironments. For this reason, the term dune vegetation is somewhat vague.

Pioneer vegetation is formed by herbaceous and shrub species, that are tolerant of the inhospitable conditions that are common in the most instable areas of the system, where there is sand movement (erosion or accretion), large fluctuations in air and sand temperature, and sometimes soil salinity, and wind (Table 15.2). Creeping and prostrate herbaceous plants are most common, along with bunchgrasses with stolons and low, shrubby species that tolerate burial. Toward the Caribbean, larger shrubby species act as pioneers. A comparison of species distributions and community structure reveals latitudinal changes. Figure 15.4 shows the distribution of species and growth forms along transects of beach in southern Tamaulipas (García 1987), central Veracruz and northern Quintana Roo. Several of these species tolerate burial and some grow more vigorously when surrounded by accumulated sand, increasing humidity (Fig. 15.2).

After stabilization of the sand in the dune begins, little by little, grasslands replace pioneer vegetation (Table 15.2). In these environments, plant cover increases, sand movement decreases and, in general, conditions are more hospitable. At the same time, this matrix of grasslands starts being invaded by shrubby species. This phenomenon is very clear in swales where humidity is greater and there is protection from the wind. The first shrubby species are isolated within the grassy matrix. After the grassland is established, open areas composed of low shrub form, with abundant grasses in their interiors. With grassland development, a seed bank appears (Pérez 1993) which, along with seed drop (Acosta 1993), is a fundamental to succession. Gradually, more shrubby individuals appear. Frequently, the first successional stage is

Table 15.2. Herbaceous and woody species present in different types of plant communities which develop in the coastal dunes of the Gulf of Mexico and the Mexican Caribbean.

Pioneers	Grasslands	Shrublands & Forests	Flooded Zones	Interdune Lagoons
		Herbaceous Plants		
Ipomoea pes-caprae	*Schizachyrium scoparium* var. *littoralis*	*Bidens pilosa*	*Cyperus articulatus*	*Sagitaria lancifolia*
I. imperatii	*Trachypogon gouini*		*Limpia nodiflora*	*Pontederia sagitatta*
Canavalia rosea	*Panicum purpurascens*		*Hydrocotyle bonariensis*	*Typha domingensis*
Sporobolus virginicus	*□exicana adsencionis*		*Iresine celosia*	*Acrostichum aureum*
Uniola paniculata	*□exica saturejoides*		*Ambrosia artemisiifolia*	*Echinochloa pyramidalis*
Schizachyrium scoparium	*Commelina erecta*		*Panicum maximum*	*cyperus articulatus*
	Bidens pilosa		*Schizachyrium scoparium*	*Ipomoea tiliacea*
	Florestina tripteris			*Calapogonium caeruleum*
				Laportea □exicana
				Hymenocallis littoralis
				Hydrocotyle unbellata
				Thalia geniculata
				Fuirena simplex
		Trees and Shrubs		
Palafoxia lindenii	*Porophyllum nummularium*	*Andira inermes*	*Pluchea odorata*	*Pachira aquatica*
Croton punctatus	*Verbesina persicifolia*	*Tabebuia pentaphylla*	*Chrysobalanus icaco*	*Annona glabra*
Chamaecrista chamaecristodes	*Crotalaria* spp.	*Bursera simaruba*	*Chiococca alba*	*Salix chilensis*
Suriana maritima	*Turnera ulmifolia*	*Scheelea leibmanii*	*Enterlobium cyclocarpum*	*S. humboldtiana*
Tourneforia gnaphalodes	*Opuntia stricta* var. *dillenii*	*Pseudophoenix sargentii*	*Psidium guajava*	
Coccoloba uvifera	*Randia laetevirens*	*Thrinax radiata*	*Lantana camara*	
	Diphysa robinioides	*Cordia sebestena*		
	Tecoma stans	*Pithecellobium keyense*		
		Coccoloba uvifera		

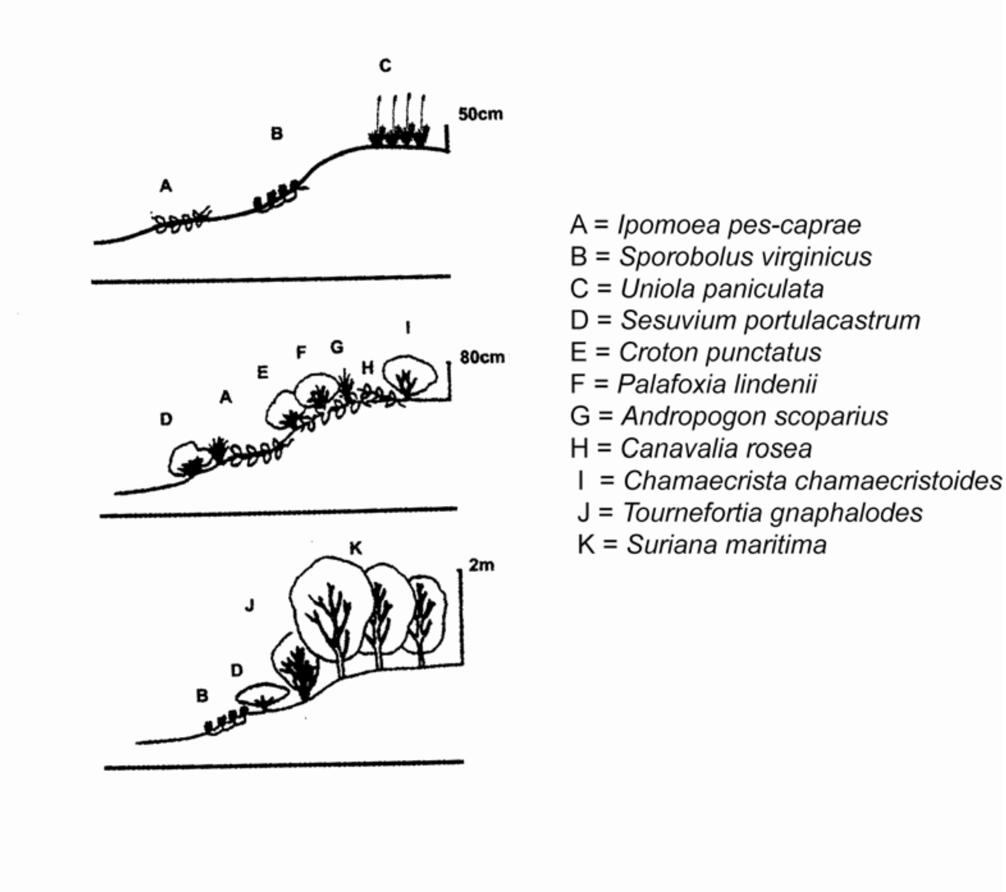

Fig. 15.4. Profiles of pioneer vegetation at embryonic beaches and dunes along the Atlantic coast of Mexico A – Tamaulipas and northern Veracruz; B – central Veracruz; C – northern Quintana Roo.

characterized by a predominance of a few species as well as greater numbers of anemocorous species that continue forming open shrubby areas that are of greater height. As the shrubby canopy closes, community species richness increases.

Morrison and Yarranton (1974) define three processes by which succession occurs. In dunes, facilitation is the more frequent process, that is, the community modifies the environment, facilitating colonization by another group of species. This process occurs in distinct steps, from the first phases of colonization by pioneers (Salinas 1992; Martínez *et al.* 1997, 2001), to establishment of grasslands and, later, growth of open scrub.

In coastal dunes, forests and woods are more complexly structured communities. In Tamaulipas, there are oak woodlands (Cabo Rojo), although very little is known about them. In Veracruz, low deciduous forests and medium semi-evergreen forests are the dominant communities. There is a remnant of the latter remnant community on CICOLMA land (Novelo 1978; Castillo and Moreno-Casasola 1998; Castillo-Campos and Medina 2002). West *et al.* (1969) have reported this type of patches of this vegetation in Tabasco, although it is not clear whether these persist today. Towards Yucatán and Quintana Roo, these forests are structured in such a way that the palms give them a very particular physiognomy (Espejel 1984, 1987; Moreno-Casasola and Espejel 1986).

Wetlands and even permanent bodies of water can be found in the humid and floodable environments of dune systems (Table 15.2). This is the reason that 40 of the 44 dune systems in the Gulf and Caribbean analyzed by Castillo and Moreno-Casasola (1998) exhibited evidence of such environments. In swales, flooding constitutes the mechanism that regulates plant succession. When rainfall is light or there is a period of several years without rain, succession advances until a scrubland and finally a low semi-deciduous forest containing flood-tolerant arboreal elements is formed. On the other hand, frequent flooding that continues for several weeks, allows persistent herbaceous communities become established (Moreno-Casasola and Vázquez 1999).

In central Veracruz, wetlands totally covered by hydrophytes form, as well as inter-dune lagoons with open water bodies. The wetlands remain flooded for 3-6 months, and are characterized by vegetation that is tolerant of short periods of flooding; these types of communities also surround water bodies that contain aquatic vegetation. The lagoons are permanent shallow bodies of freshwater, fed by the water table, with aquatic trees and shrubs. The above description, as well as representing a sucessional sequence in central Veracruz, also describes a spatial mosaic made up of different communities representing the different successional stages. Each of them has different floral structure and composition, creating a heterogeneous landscape with herbaceous communities, patches of scrub and areas of bare sand.

THE CURRENT SITUATION AND PROBLEMS CONCERNING ITS CONSERVATION AND MANAGEMENT

Today, beaches are a main recreational attraction. Dunes are transformed, flattened out and replaced by concrete structures. In tropical zones, more and more emphasis is being placed on tourist development as a means of providing services and generating much needed sources of income. However, throughout this process, preserving ecosystem characteristics and dynamics is not always of primary concern. Carter (1988) mentions that, of all the costal ecosystems, sand dunes have been most subjected to major pressures exerted by human society. He argues that many dune systems have been irretrievably altered by human activity, both accidentally and intentionally. Modifying sediment transport and, as a result, permanently altering the cyclical dynamic of erosion and accretion, has been the greatest impact. Indirectly, beaches and dunes are also affected by inland activity. A large proportion of the world’s coasts (70%) are eroding. In many cases, human activity has caused erosion to increase by, for example, limiting the availability of sediments from inland areas (through damming of rivers), or through coastal protection programs that prevent sediment movement different coastal cells (Bird 1996). Therefore, it can be concluded that beaches and dunes are among the most threatened tropical ecosystems. Mexico is no exception to this.

ENVIRONMENTAL SERVICES

Dunes are ecologically important not only because they are a integral part of many coastal ecosystems, but also because of the environmental services they provide. Hesp (2000) and van der Maarel (1993, 1994, 1997) considers beaches and dunes important because:

a. They are an essential source of sediments that, because they move and change form in coastal areas; protect inland areas from erosion caused by storms and potential increases in sea level. That is, they play a fundamental role protecting inland life at the land-sea interface.
b. When they are covered by vegetation, they trap wind blown sand and stabilize beaches and dunes, thus maintaining the supply of sediments that allows them to fulfill their protective role.
c. They provide plants and animals, including birds, with specialized habitats.
d. They are one of the most dynamic ecosystems on Earth.
e. They filter rainwater seeping into the subsoil, helping to maintain its quality.
f. They provide a valuable source of recreation.
g. They provide space for human settlements. A large number of coastal towns have been built on sand fields, increasing the value of the area.
h. They have favored the evolution of species that have adapted to the prominent physical conditions of the system, such as plants tolerant of sand movement, one of the characteristics of the dunes.
i. They provide a variety of different habitats ranging from conditions of extreme aridity to both temporary and permanent aquatic environments.
j. They provide us with a unique range of geomorphologic structures and ecosystems of a high natural value.

NATURAL DISTURBANCES AND ALTERATIONS OF BEACHES AND DUNES

“Nortes” (cold fronts with strong north winds) move around a great deal of sand (Poggie 1962; Moreno-Casasola 1982), forming a part of the recurring disturbances that allow dunes to function as sediment deposits. On shorter time scales, tropical storms and hurricanes displace enormous amounts of sand along with providing vast quantities of rain to dune systems. On one occasion as much as 119 mm of rainfall was measured in one day at La Mancha (Kellman and Roulet 1992). The surf is an important modifier of the morphology and topography of the beach and first dune strands (Pilkey *et al.* 1998). It can open up new entrances to a lagoon by breaking down the barrier islands. In addition, it can destabilize dune systems creating new areas of active sand and it can greatly increase the duration of surface flooding by grounding water to several months, killing vegetation in low-lying areas (Moreno-Casasola and Vázquez 1999). The other extreme is drought, which causes the death of plants in the dunes themselves as well as in the inter-dune lagoons and depressions. One of the principal causes of the death of young *Chamaecrista chamaecristoides* in the dunes is the lack of humidity (Martínez 1994).

These phenomena cause the death of individual plants and/or plant populations, opening up spaces where sand movement resumes. In these zones a pioneer community re-emerges, able to withstand being buried beneath sand, and the process begins anew. The heterogeneous landscape of dunes persists through time and over space thanks to continual alterations that return the system to its initial stage of great sediment movement and also due to processes that make it easier for a plant community to modify environmental conditions (i.e., sediment stabilization with concomitant) and allows the arrival of another group of species (Fig. 15.5).

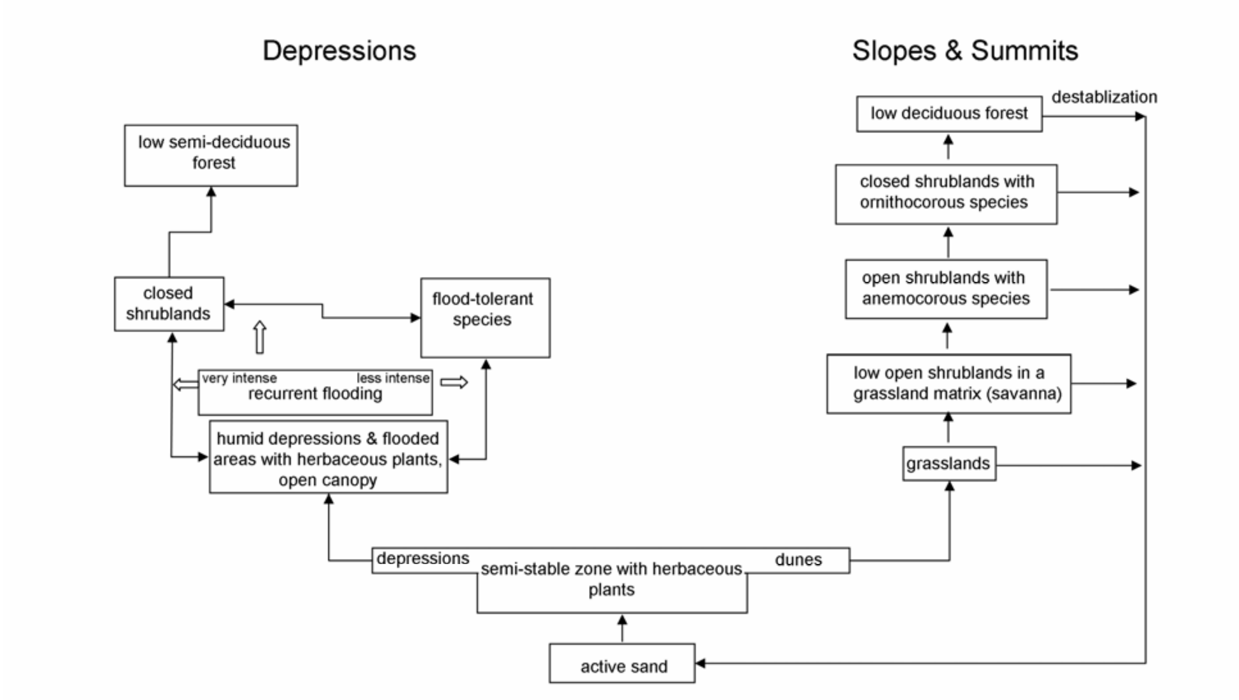

Fig. 15.5. Model of the sucessional stages in a dune system depressions and swales.

HUMAN ACTIVITY AND BEACH AND DUNE ALTERATION

As well as the transformation and replacement of dune systems, there are numerous other activities that alter these ecosystems. The main effects are the alteration of the functioning of the ecosystem and its erosion (due to the modification sediment regimes), the transformation of plant cover, loss of habitats and, therefore, biodiversity, and pollution. The effects often generate both social conflict and financial loss. Currently the main threats to this important store of sediments are:

a. Destabilization of dunes by various income-producing activities such as construction, tourism, recreational activities, farming, and mineral extraction because they eliminate plant cover, allowing sand movement to resume.
b. Construction of rows of tourist facilities (or holiday homes) by those seeking the most direct route to the beach.
c. Flattening of dunes to create different environment or for different uses (e.g.,golf courses, parks, fields, etc.), altering topography and eliminating their function as an environment for sediment accumulation.
d. Filling of inter-dune lagoons to construct buildings and made land.
e. Draining inter-dune wetlands for grazing.
f. Beach erosion due lack of sediments caused by damming of rivers.
g. Modification of sediment transport by drift tides caused by construction of marine infrastructure.
h. Legal and illegal invasion of the terrestrial federal maritime zone
i. Increased littoralization and uncontrolled urban growth

j. Introduction of native and exotic pasture grasses and disappearance of plant cover in favor of farming activities. This happens so frequently that it has become a major threat. .
k. Introduction of exotic plant species (e.g., *Casuarina esquisetifolia* [sea pine] for dune stabilization; tilapia in inter-dune lagoons), which eliminate native species locally and change biodiversity, as well as community species composition and structure.
l. Population growth and increased consumptive habits mean that dunes are now included in areas visited for recreational purposes, such as off-road vehicle use and golf courses.
m. Exploitation of sandbanks and dunes for sand and rocky beaches for stones and gravel.
n. Pollution of beaches due to wastes left by visitors or deposited by the sea, or pollution of waters reaching beaches (e.g., from cities or industrial centers) and pollution entering inter-dune lagoons through drainage systems.
o. Desiccation of inter-dune wetlands when groundwater is extracted to irrigate sugar cane plantations.
p. Salinization of the surface groundwater caused by freshwater extraction and changing habitat conditions.
q. Lack of regulations governing use of coastal beaches and dunes, and lack of control over recreational activities.
r. Erosion caused by sea level changes and changes in the frequency of events such as hurricanes, that affect beaches and dune morphology and sediment storage.

The grasslands and brushlands of coastal dunes recover slowly after disturbances. Experiments by Boorman and Fuller (1977) in Great Britain showed that just walking over the same piece of land 80 times in one month, caused bare sand to appear. After 150 such walks, more than half the vegetation was lost. Experiments on dune disturbances carried out in La Mancha showed that the system required time to recover. In more humid depressions less time was needed (Moreno-Casasola 1997; González and Moreno-Casasola 1982), but in drier areas, plant cover requires several years to close up again. Furthermore, paths made by hikers, once established, leave a mark that will persist years before disappearing. Continual walking on these areas causes erosion and leaves them at lower elevations than the surrounding area. This is why management plans that encompass pathways are necessary to protect those areas that receive the most visitors.

PROTECTED NATURAL AREAS

In coastal beach and dune systems several different areas need protection: beaches, barrier islands, keys and islands, grasslands, dune scrublands and forests, wetlands and inter-dune lagoons. Protected natural areas in general include few of the above-mentioned ecosystems. On the Atlantic Coast there are 32 coastal natural protected areas (NPA), 9 in the Gulf of Mexico and 23 in the Caribbean. Of these, only 5 in the Gulf of Mexico – Sistema Arrecifal Veracruzano (key), La Mancha (beaches, dunes, coastal forest), Playa Rancho Nuevo and Lechugillas (turtle-breeding beaches), Isla del Amor (beach), and 13 in the Caribbean (Sian Ka'an, Ría Celestún, Ría Lagartos, Isla Contoy, Tulum, Yum Balam, Dzilam, Chan-Kanaab, the turtle-raising beaches of El Palmar, the beach adjacent to Ría Lagartos and the beaches of isla Contoy, the keys of Banco Chinchorro and Arrecife Alacranes) have documented protected beach and dune environments. In none of the NPAs are barrier islands and dune wetlands considered truly protected environments.

In general, this is not enough. All the different coastal regions of the Gulf and the Caribbean should be protected because they are enormously rich in flora, endemic plant species, and vulnerable fauna (both resident and migratory) that need these habitats for shelter and food. The Gulf faces a dramatically precarious situation due to the general scarcity of protected areas. It is in urgent need of attention. An analysis of the number of protected natural areas in Mexico reveals a highly unbalanced situation (Moreno-Casasola 2005). The northern Pacific region (that is, the Pacific coast of Baja California and Baja California Sur) together with the Gulf of Mexico, are the poorest regions in terms of protected natural areas (only 6% of the surface of coastal reserves are located in these two extensive regions). Fifty-four percent of the protected coastal land surface is located in the Gulf of California and surrounding states. Twenty-five percent of the protected areas are in the Caribbean and 15% in the tropical Pacific region, whereas the Gulf of Mexico (5%) and northern Pacific regions (1%) are very poorly represented. Systems of protected natural areas are required in dune and beach areas in order to control activities there and guarantee their preservation.

On the other hand, it has been reported that once dunes are protected and damage is stopped, sucessional processes begin rapidly, leading to establishment of communities in the final successional stages and eliminating pioneer and even grassland environments. This has been clearly observed at the CICOLMA reserve. Therefore, it is important for these extremely fragile environments to be protected in a way that guarantees survival of different sucessional stages, all of which make up the dune system. This implies that the protected natural dune areas should have a areas of pioneering communities, grasslands, scrublands and finally, forest. Furthermore, there should be management plans permitting these different stages to coexist.

CLIMATE CHANGE

In the Gulf of Mexico and Caribbean some coastlines are receding towards the mainland. This might be due to submersion, deltaic inactivity or rising sea levels, or even to a mixture of all of these factors. These coasts are extremely vulnerable to the effects of climate change and its populations are at risk. On the coasts of northern Tamaulipas, the Rio Grande floodplains and all along the Laguna Madre, the barrier islands in particular are heavily affected. These islands will continue to erode and become thinner until they eventually fragment.

The coastal lines of southern Tamaulipas and most of Veracruz are either accreting or are in equilibrium. There are dune strands or extensive dune fields that suffer from erosion, but they are big enough to withstand loss of sediments. More specifically, the temporary sandbars that separate the sea from coastal lagoons in this area are also at risk. In these cases, equilibrium and, therefore, the duration of time that the barrier remains open, depends on the quantity of sediment moved along the coast, and the amount of rainwater that falls and accumulates in the lagoon. Breakwaters and construction projects opening up the sandbars are also increasing the vulnerability of these barriers.

The Grijalva and Usumacinta delta is another vulnerable area since the coastline is receding and the provision of sediment is reduced, leaving it in a situation similar to that of the Mississippi delta (Day *et al.* 1999). Thus, in western Tabasco, the sandbars in front of the smallest lagoons disappear when they eroded by the sea, leaving a markedly indented coastline. The stretch of coast from Tupilco (Tabasco) to Champotón is very low and narrow and will erode quickly as higher sea levels remove its sediments (Ortiz-Pérez 1994; Ortiz-Pérez *et al.* 1996). The Laguna de Términos region is also a fragile zone.

In general, the coastline of the Yucatán Peninsula is either advancing towards the sea or its coasts are in equilibrium, whereas in southern Quintana Roo, they are receding (Ortiz and Espinoza 1991). Increased sea levels will particularly affect the barrier islands of the Caribbean (Isla del Carmen, northern Yucatán and Cancun) as well as the wetlands and bay islands of Bahía Espíritu Santo and Bahía Ascension.

A LOOK AT THE CURRENT SITUATION AND PROBLEMS AFFECTING BEACHES AND DUNES IN THE GULF OF MEXICO AND MEXICAN CARIBBEAN

TAMAULIPAS

Tamaulipas has a large number of barrier islands that are used extensively for cattle-raising rendering the islands vulnerable to rising sea levels. The Laguna Madre is extremely deteriorated, water bodies have been silted and it has suffered a significant decrease in both the amount of sediment it contains and its freshwater inflow due to damming. It is an important fishing area, so the barrier islands have been modified to improve access to the sea. In the south there is urban growth and tourism. There are no protected natural areas.

VERACRUZ

The plant cover of the Tamiahua barrier island in Tamiahua has been severely transformed by cattle-ranching, which has affected most dune areas in the state in the same way. There is growing tourist development in the central zone, principally in dune cordon areas (Tecolutla, Tuxpan, Costa Esmeralda) and new development projects are underway, seeking to substitute dune fields with urbanized tourist areas (San Julián, La Antigua, Alvarado). Invasion of the terrestrial federal maritime zone is frequent but there is little information concerning the sand zones. There are large dune systems that are extremely rich environments with plenty of flora and fauna, although the forests have been almost entirely eliminated. The two reef systems that protect and modify the mainland coastal zone, are located at two extremes of industrial and urban development and, therefore, are under a great deal of pressure. Only one small dune system, located in La Mancha and the islands of the Sistema Arrecifal Veracruzano (Veracruz Reef System), are protected, since the coast is not a part of the central area of the Reserva de la Biosfera de los Tuxtlas (Los Tuxtlas Biosphere Reserve). In the Alvarado region, the barrier islands and other areas are notable for their low zones (Mandinga, La Mancha etc.) and are extremely vulnerable to rising sea levels.

TABASCO

This is a very fragile deltaic zone where grasslands and coconut plantations have almost entirely replaced natural vegetation. The coastal forests have disappeared. The activities of PEMEX (Petróleos Mexicanos) have modified water flow restricting sediment transport. Industrial operations are leading to the subsidence in deltaic areas. This area is extremely vulnerable to the effects of global climate change. The protected costal area only encompasses the wetlands.

CAMPECHE

A region of quite distinct characteristics is emerging. It has a great karstic platform; its main hydrological flow is in the subsoil; and barrier islands and sand islands of biogenic origin are abundant. One barrier island is undergoing significant urban development. It is vulnerable to global climate change and has already suffered the effects of passing hurricanes. Most of the beaches and dunes are far from the main communication routes and there is no significant tourist development in the costal zone.

YUCATÁN

Coastal vegetation has been replaced by coconut plantations, most of which have been abandoned. This is a region with important coastal plant endemism on the beaches and in its dunes. Ports are being developed, in the form of rows of tourist constructions. Consequently, there has been exploitation of salt from coastal lagoons, modification of hydrological and sediment flow, and the opening of sand bars. There are important protected natural areas in this state.

QUINTANA ROO

Like Yucatán, the coconut plantations modified a large part of the costal vegetation and currently are being replaced by tourist constructions. In some areas, buildings are replacing the geomorphological structure of the dunes, while in other areas preservation of a small portion of original vegetation is being encouraged. However, the large amount of construction along the coast is putting pressure on the very narrow and fragile barrier islands and peninsul;as, such as the Sian Ka'an reserve.

CONCLUSIONS AND RECOMMENDATIONS

1. Mexico has extensive coastlines with different climates and types of sand, creating extremely rich coastal ecosystems. The Gulf of Mexico is located on the central part of a tectonic plate and constitutes an enormous sedimentation zone.
2. The dune systems consist of three types of environments: active dune environments, humid and floodable swales, and stabilized environments. Different micro-environmental conditions predominate in each and they contain diverse floristic groups. The first of them is the habitat of the endemic species, which act as dune stabilizing agents. These are extremely dynamic and, for the same reason, fragile systems.
3. There is a rich source of coastal floral species, many of which are endemic. These are located on both peninsulas, reflecting significant regional differences. Most similarities are between the flora of neighboring areas such as the northern Pacific region and the Gulf of California, or the Gulf of Mexico and the Caribbean, or, to a lesser degree, the Atlantic and the southern Pacific coasts, mainly because they have common pan-tropical species and numerous rainforest shrubs and trees. The flora and vegetation structure of the Gulf of Mexico and the Mexican Caribbean is fairly well known. The flora of the Gulf region of Tamaulipas needs more research. It needs to be studied and described especially in the central and northern parts of Tamaulipas and northern Veracruz, and in

the Cabo Rojo region. The rich coastal flora there, with its own functional attributes, must be taken considered and protected.

4. The beach and dune vegetation is made up of pioneer communities, grasslands, scrublands, forest, wetlands and aquatic environments. These form a mosaic over both space and time making coastal dunes a diverse and heterogeneous system. The coastal flora consists of species that only inhabit coastal systems, species frequently found in damaged zones (ruderals, secondary tropical forests), and species frequently found in other types of inland plant communities.
5. The main process of dune succession is facilitation, in which populations constituting a particular sucessional stage modify the environment in such a way as to facilitate the arrival of other species at a later sucessional stage. In wet swales, inhibition processes plays an important role, preventing later successional stages. More thorough research must be done on floral community dynamics and ecosystem functioning.
6. Coastal species show numerous adaptive forms reflecting the overall conditions in these ecosystems. They react correspondingly at different stages of germination, settlement, growth etc. There are many species whose ecology and physiology is unknown but that are key to the functioning of the ecosystem.
7. Coastal beaches and dunes provide an important environmental service to human society by acting as a buffer zone between the sea, land and atmosphere: they protect the coastal zone during storms and hurricanes, trap sand, filter water and provide specialized habitats for flora and fauna.
8. Today these ecosystems are among those most affected by human activities. Productive activities, mainly the construction of rows of buildings for tourism, or the transformation of areas into fields for extensive cattle rising, have transformed the geomorphology and plant cover.
9. They are extremely fragile ecosystems and, for this reason, activities such as trampling, groundwater extraction and invasion of exotic species, among others, have caused severe deterioration. Mexican legislation does not include laws for management of these ecosystems.
10. Mainly the beaches, but also the dunes, are extremely vulnerable to global climatic changes and rising sea levels.
11. In Mexico, no evaluation has been carried out concerning the degree of beach erosion and what this implies to projects of costal tourist development.
12. The current situation requires that strong measures are taken to conserve their ecosystem function and biodiversity such as: creation of new protected areas; laws governing management and use of these systems; redefinition of the terrestrial federal maritime zone and seaward land growth, based on geomorphological and ecological criteria specific to the different regions of the country and their coastal delimitation; identification of areas that are vulnerable and at risk; and support for environmental impact assessments in the coastal zone based on conservation of coastal dynamics.

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