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Effects of Perturbations on South Padre Island

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Padre Island is one of the world's longest barrier islands. It extends 182 km along the Gulf Coast of Texas from Corpus Christi on the north to Brazos-Santiago Pass at Port Isabel on the south. The types, extents, and durations of perturbations affecting the ecological zones of South Padre Island are assessed. Emphasis is placed on providing the environmental documentation necessary for coastal zone managers and planners to make informed decisions about future development. Recommendations are made concerning location of construction, vehicular traffic and pedestrian traffic. A program to revegetate existing dunes and to encourage growth of eroded dunes is needed. The northern third of the island should be maintained in an undeveloped state.

Introduction

The future of the coastal region of Texas is of major public interest and various proposed uses by a variety of industries from aquaculture to recreation have stimulated much controversy in the Legislature, in the local press and national magazines, and at public hearings. Unfortunately, much of the information needed for making management decisions is lacking.

The predominant land form along the Gulf Coast of Texas consists of a series of five barrier islands enclosing several shallow bays (14, 18). These coastal barrier islands encompass 155,202 ha and they provide significant protection to the Texas mainland against high water from the Gulf of Mexico during tropical storms and hurricanes. The barrier islands also protect habitats in the bays from the effects of waves and currents. Similar barrier islands occur off the coast of Mexico to Altamira, Tamaulipas, Mexico, 402 km south of Brownsville, Texas. Thus, the islands provide an avenue of northward dispersal for numerous organisms (18).

Padre Island is the longest of these barrier islands. It extends approximately 182 km from Corpus Christi on the north to the Brazos-Santiago Pass at Port Isabel on the south (Fig. 1). The island varies from about 467 m to 4.8 km in width and is separated from the mainland by the Laguna Madre, a shallow bay with a maximum width of about 16 km (13). South Padre Island is separated from the northern two-thirds of the island by the Mansfield Channel; thus, "South Padre Island" is both a geographical description and the name of an incorporated town.

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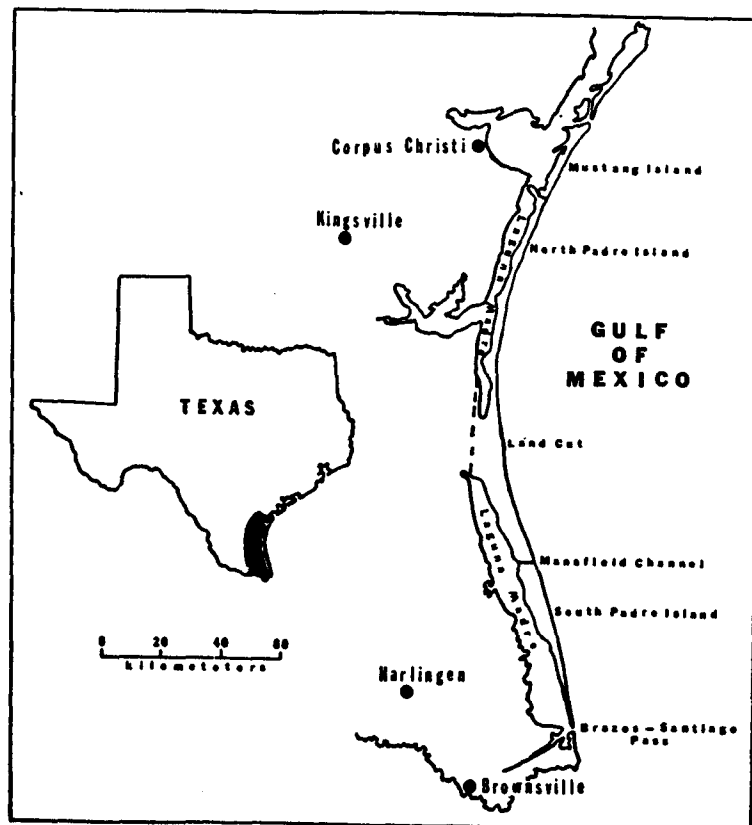


Fig. 1. - Map of South Padre Island

South Padre Island is approximately 55 km long and has a total area of about 16,200 ha. The town of South Padre Island currently occupies the southernmost 8 km of the island. Development is tourist-oriented, featuring hotels, motels, condominiums, vacation homes, restaurants, and fast-food emporiums. The diversity of developed and undeveloped landscapes is an attraction to visitors to the island (5). The southern end offers resort accommodations and commercial attractions while the northern two-thirds offers visitors more primitive experiences. Most projections forecast further growth and development for South Padre Island (5, 9). Several strategies are possible, but the major question resolves to-- "Will the island become a highly developed coastal resort emphasizing cultural attractions or will the island retain much of its natural character and emphasize environmental recreational opportunities?" Coastal zone managers and planners need to understand the relationships between past practices, present conditions and likely effects of future plans to select the "best" development strategy. Herein we provide a

review of the types, extents, and durations of perturbations that affect the ecological zones of South Padre Island. Emphasis is placed on providing the environmental documentation necessary to guide the future development of the island.

Climate

The climate may be characterized as subtropical in the sense that the seasons are poorly differentiated and winters are short and mild. Winter lasts from December through February. January is the coldest month with daily minimums averaging 10 to 11° C. Frequently an entire winter will pass without freezing temperatures, but damaging cold may occur. For example, a cold front on 24 December 1983 dropped temperatures to -8.8° C and maintained temperature below freezing for 53 hours. Summer is long and hot. It begins in May and extends through September. Temperatures range from 32 to 35° C during the day and 23 to 25° C at night. Winds are predominately from the southeast and they are strong. The annual average is 9.6 km/h (29). Occasionally, strong northerly winds accompany southward moving cold fronts.

The climate has also been characterized as semiarid (31). The average annual rainfall of 60.9 cm is poorly distributed with a peak in September and October. Secondary maxima occur in late May or June. November through March are usually the driest months. Precipitation usually occurs as a result of thunderstorm activity and often a single storm will provide an entire month's rainfall. Many days are foggy and relative humidity is high due to the proximity of the Gulf of Mexico and Laguna Madre. Generally, tides are less than 1.0 m and waves along the beach are normally 0.5 to 1.0 m in height (24). However, during storms and hurricanes, waves may be 3 to 5 m high and tides may be 5 m above average sea level.

Substrate

The beaches and dunes of South Padre Island are composed of fine sands that are well sorted (8, 11, 16). Judd et al. (13) reported that particle size and pore space were similar in all the topographic zones. Approximately 95% or more of the sand grains were in the 0.25 to 0.125 mm range. The soil is extremely variable in salt content and has varying amounts of shell and organic matter. The highest percent organic matter in beach sands was 0.1 percent (3).

Ecological Zones

The flora and vegetation of South Padre Island is relatively well known compared to other areas of the Texas barrier island chain (3, 13, 14, 17, 18, 19). Furthermore, Judd and Sides (14) have presented data on the effects of a hurricane to the near-shore vegetation. Judd et al. (13) provided information on the pattern of vegetation in relation to topography and reported that the vegetation occurs in distinct zones that correspond closely to topographic facets. They recognized six major topographic zones (Fig. 2), but pointed out that certain of the zones might be absent or narrow in one place and exceptionally conspicuous, broad or well developed in another. An idealized profile would include:

(1) a bare foreshore zone, (2) a backshore zone with a belt of *Sesuvium portulacastrum* nearest the gulf and a landward zone dominated by *Uniola paniculata*, (3) a primary dune ridge supporting *Ipomoea stolonifera* and *Uniola paniculata* as dominants, (4) a zone of either secondary dunes or vegetated flats or a mosaic of both in which *Schizachyrium scoparium* is dominant, and (5) a tidal flat zone that is largely bare, but which supports typical halophytic vegetation in a narrow zone bordering the vegetated flats. Washovers (6) are transverse features which cut across the other topographic zones. They are distinct in the primary dune zone and secondary dune and vegetated flats zone, but washovers grade imperceptibly into the tidal flats. Most of the area is bare, but scattered clumps of *Sesuvium portulacastrum* may be found on these windswept flats. Occasionally, tide pools of considerable size may be present.

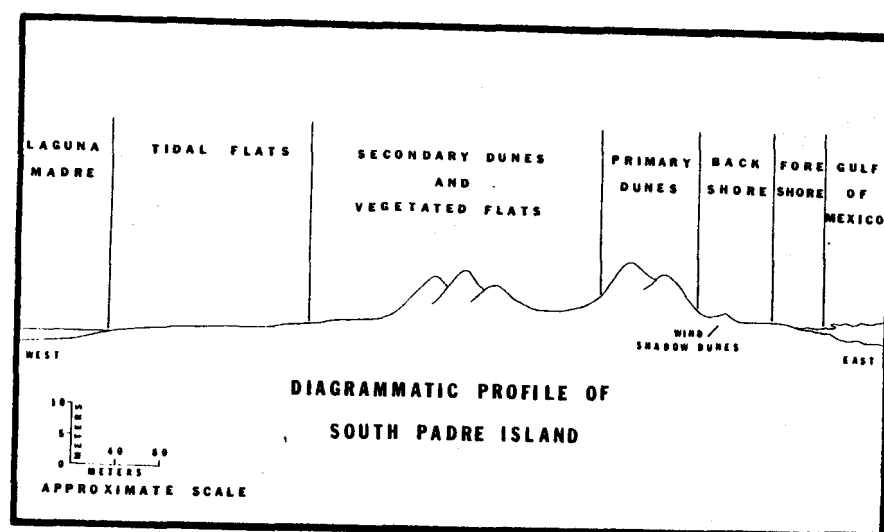


Fig. 2. - Cross sectional profile of South Padre Island showing the five longitudinal ecological zones. A sixth zone termed "Washovers" traverse these zones.

Many of the studies of barrier islands and marine sandy shores have centered on the zonation of the vegetation. Boughey (12), Gooding (10) and Poggie (27) called the shore a "pioneer" zone and Gooding (10) and others have interpreted the vegetation zones as stages in succession. However, many workers (e.g. 1, 2, 21, 26, 27) regard the vegetation of the zones as relatively stable and comprised of species adapted to the existing environmental conditions. Oosting and Billings (26) argued that the zonal distribution of the major species was explainable on the basis of tolerance to wind and salt spray; and that once the zones are developed they are relatively stable unless storms or other disturbances

break the cover and start a new shifting of sand. However, within the various zones there is some evidence that succession takes place. Judd et al. (13) reported that on South Padre Island this is most evident along the margins of washovers in areas adjacent to stabilized dunes or flats. Here succession apparently proceeds to dominance by sea coast bluestem, *Schizachyrium scoparium*.

Traditional succession theory holds that an ecosystem is normally in equilibrium and that disturbances act merely to perturb the system away from a "normal" state. Thus, succession has been thought of as recovery toward equilibrium (33). Data from studies of barrier islands and recent information from a variety of mainland ecosystems, however, suggest that ecosystems may normally be far from equilibrium and that the kinds of disturbances they are exposed to determine their structures. This view holds that vegetation is always in a process of change because of variation in environmental factors. Extreme events that cause a sudden shift in species composition or relative importance are of major concern because such events, even if they occur infrequently, can be major factors in structuring ecosystems (33).

Perturbations

Factors affecting shoreline changes on South Padre Island include sea-level rise, compactional subsidence, a deficit in sediment supply, climate and human activities (25). Storms that generate high winds and tides are the principal natural factors producing vegetation changes on Texas barrier islands. Freezing temperatures may retard growth or prevent establishment. Human generated perturbations include burning, grazing, development (construction of jetties, sea walls, highways, buildings, parking areas, etc.), vehicular and pedestrian traffic, and planting of trees.

Except for the extreme southern tip of the island close to the jetties at Brazos-Santiago Pass, South Padre Island has been undergoing erosion since 1854 (25). There is considerable variation along the length of the island, but overall net erosion ranges from 2.4 to 4.0 m per year. During the 120 years from 1854 to 1974 the average net erosion (absolute) was about 302 m (25). This is due in part to the interaction of sea level rise and compactional subsidence which result in sea level rising about 0.4 to 0.6 m per 100 years. However, the major cause is the construction of jetties at Brazos-Santiago Pass (1935) and construction of Falcon Dam (1955) which has greatly decreased the availability of sediment from the Rio Grande to South Padre Island.

Johnson (12) identified the major sources of sediment along coasts as major streams and onshore movement of shelf sand by wave action. Morton and Pieper (25) report that the shelf sediment in the area off South Padre Island are primarily muds. Consequently, they provide very little sand for the nourishment of the barrier island. Sediment supplied by major streams is transported alongshore by littoral currents. South Padre Island is oriented on a North-South axis and the prevailing winds are onshore from the southeast. Consequently, the longshore currents flow northward. The Rio Grande is the only major river supplying sediments to South Padre Island. Construction of Falcon Dam on the Rio Grande in

1955 reduced the sediment transported from more than 10,000 acre-feet (12,336,190 cu. m) per year to less than 1,000 acre-feet (1,233,619 cu. m) per year (25). Furthermore, the jetties at Brazos-Santiago Pass intercept much of the sediment transported by long shore currents. Consequently, the only area on the island that has accreted is the area adjacent to the north jetty.

Winds and storm-generated tides are important factors in producing changes in both the physical environment and the vegetation. The strong onshore winds move significant amounts of sand from the backshore and primary dunes across the island and into the Laguna Madre. However, hurricanes produce the major changes on barrier islands (4). These tropical storms have winds that exceed 120 km/h and they cover large areas. During hurricanes, the storm surge or overwash moves large volumes of sand from the beach, foredunes, primary dunes and offshore areas to the interior and bay tidal flats and into the Laguna Madre. Passes cut by hurricanes usually close by sand deposition resulting from the normal tidal cycle within a few weeks, but the washover areas remain low and are commonly reopened by subsequent storms (14). During overwash events large expanses of vegetation are denuded or covered.

Major hurricanes have occurred at South Padre Island six times since 1844. The most recent was Hurricane Allen on August 10, 1980. Peak water surge during Hurricane Allen was estimated at 2.7 m above mean sea level (7). Simpson and Lawrence (30) conducted a study of the probability of storms striking 80 km segments of the Texas coast during any given year. The 80 km segment that includes South Padre Island has a 9 percent probability of experiencing a tropical storm, an 8 percent probability of experiencing a hurricane, and a 2 percent probability of experiencing a great hurricane.

After a hurricane, during periods of calmer weather, low energy waves gradually move sand from offshore sandbars back onto the beaches. Onshore winds then move the sand across the beach. Dunes form where vegetation and other obstacles such as drift lines cause deposition of windblown sand. Pioneer species colonizing these dunes are tolerant of scouring, salt spray, and of being covered with sand. Furthermore, they are able to grow more rapidly than the rate of sand deposition. Once established, the vegetated dunes provide protection in their lee to communities comprised of species less tolerant of salt spray, sand scouring, and sand deposition. In areas where stabilizing vegetation has been damaged or destroyed by human disturbance (clearing, grazing, or heavy pedestrian or vehicular traffic) sand dunes continue to migrate toward the mainland under the influence of the prevailing winds (29). Ultimately, this windblown sand fills in the margins of the Laguna Madre.

Droughts affect vegetation directly and the physical environment indirectly. Droughts reduce the abundance of vegetation and because dunes are stabilized by vegetation, sparse vegetation resulting from droughts offers less resistance to wind and wave attack. Similarly, freezing temperatures can kill vegetation and make dunes more susceptible to erosion by wind and water. Most human perturbations are detrimental or inhibitory. Burning, grazing, vehicular traffic, trampling and removal

of vegetation for construction all render dunes more susceptible to erosion due to reduction or obliteration of vegetative cover. Conversely, some human perturbations may be stimulatory (e.g. irrigation, nutrient enrichment, and plantings).

Ecological Zones

Foreshore.--The foreshore is that portion of the shore over which the waterline migrates as the tide changes. The inner margin of this zone is usually marked by a line of shells and debris deposited at high tide. It is devoid of vegetation and the sand is usually damp.

Driving is permitted on beaches in Texas and vehicular traffic is largely limited to the foreshore on South Padre Island. A local ordinance prohibits vehicular traffic on the beaches in the town of South Padre Island and in Isla Blanca County Park. The foreshore is also the portion of the beach attracting the greatest density of people. McAtee and Drawe (22) found that heavy vehicular traffic on the foreshore of North Padre Island resulted in greatly decreased elevation. Compaction of sand due to the traffic also may adversely affect burrowing animals occupying this zone such as ghost crabs, *Ocypoda albicans*. Because of the absence of vegetation the human perturbations in this zone are slight compared to the effects in other ecological zones.

Backshore.--The backshore extends from the high tide line to the seaward base of the primary dunes. This zone is usually not subject to inundation except during high spring tides or storm tides and therefore it is vegetated. Prior to Hurricane Allen (1980) sea oats, *Uniola paniculata*, and sea purslane *Sesuvium portulacastrum*, were of almost equal importance in the backshore zone and constituted the dominant species (Table 1). However, these species occurred in two distinct belts (13). Nearest to the high tide line the vegetation consisted of isolated patches of *Sesuvium portulacastrum* which usually occupied the

Table 1. - Comparison of the relative importance of species occurring in the backshore zone before and after Hurricane Allen in 1980.

Species	Pre-Hurricane			Post-Hurricane		
	Freq.	% Cover	Importance value	Freq.	% Cover	Importance value
<i>Uniola paniculata</i>	20.7	2.1	71.9	4.2	0.5	145.5
<i>Sesuvium portulacastrum</i>	32.2	1.3	70.0			
<i>Ipomoea stolonifera</i>	10.7	0.4	22.6			
<i>Panicum amarulum</i>	2.5	0.4	11.8			
<i>Ipomoea pes-caprae</i>	3.3	0.3	10.7			
<i>Fimbristylis castanea</i>	3.3	0.1	6.4	2.1	<0.1	39.8
<i>Schizachyrium scoparium</i>	1.7	<0.1	2.9			
<i>Croton punctatus</i>	1.7	<0.1	2.6			
<i>Sporobolus virginicus</i>				1.0	<0.1	14.7
Total Cover		4.7			0.5	

tops of small dunes. Westward these embryonic dunes graded into taller foredunes which supported growths of Uniola paniculata and beach morning glory, Ipomoea stolonifera. At infrequent locales railroad vine, I. pes-caprae, was present instead of I. stolonifera. A total of eight species were present in the backshore zone and total cover was 4.7% (Table 1). After Hurricane Allen, only three species were present and total cover was only about 0.5% (Table 1). The most striking feature was the absence of the Sesuvium belt (14). Also, Ipomoea stolonifera, which ranked third in importance prior to the hurricane, was absent. Both Sesuvium portulacastrum and I. stolonifera are low-growing and shallow-rooted. Apparently, these species were either swept away by the water surge and/or covered by transported sand (14). In the process, much Uniola paniculata and Fimbristylis castanea were covered, but because these species are relatively tall, many stems remained emergent.

In the four years since Hurricane Allen, the Sesuvium portulacastrum belt has not been re-established and foredunes are still largely absent. This has made the driving of vehicles easier in the backshore zone and traffic has been a primary factor in retarding the development of dunes. McAtee and Drawe (22, 23) monitored the effects of vehicular and pedestrian traffic in the backshore zone of North Padre Island. They also found that embryo dune formation was prevented and that vegetative growth was prohibited. Furthermore, the microclimate of the backshore was drastically altered. Vehicular and pedestrian traffic caused a decrease in foredune elevations and increases in average wind speed, evaporation, atmospheric salinity, soil salinity, temperature range, mean soil temperature, soil bulk density, and soil water content.

Freezing temperatures have a minor impact on the vegetation of the backshore zone. Leaves of the subtropical Ipomoea stolonifera are killed by light frosts, but stolons and fibrous roots are not usually damaged. Conversely, the closely related species, I. pes-caprae, acts essentially as an annual and dies back during winter months. Thus, episodic freezing events facilitate wind and wave erosion of the backshore during winter months because of the decrease in plant cover.

Primary Dunes.--The primary dunes form a ridge extending parallel to the long axis of the island. Maximum height of the primary dunes is about 10 m. Primary dunes are absent in washover areas; thus, the ridge is discontinuous. When these dunes are present they afford significant protection leeward. For example, Judd et al. (13) found that the leeward side of the primary dunes supported about twice the number of species found on the windward slopes. Furthermore, percent cover was three times greater on the leeward side of the primaries.

Judd and Sides (14) found that vegetation on the primary dunes was not greatly disturbed by Hurricane Allen (at least on the dunes that were left after the hurricane). There was no decrease in species richness on either the windward or leeward sides of the primary dunes and a decrease in cover was found only on the leeward slopes (Table 2). Judd and Sides (14) suggested that the lower cover values were due to the covering of Ipomoea stolonifera and I. pes-caprae by sand transported over the tops of the primary dunes. They also suggested that higher percent cover values for the windward slopes was due to variables introduced by their

sampling approach. An alternative explanation is that increased cover after the storm was due to nutrient enhancement introduced by the storm tides. Judd and Sides (14) reported that Oenothera drummondii was represented by a large number of small individuals on the windward slopes after the hurricane. Kachi and Hirose (15) demonstrated growth enhancement of O. erythrosepala on coastal sand dunes in Japan following addition of small amounts of aqueous nitrogen solution. Furthermore, Woodhouse (32) showed that moderate applications of nitrogen successfully maintained growth and vigor of Uniola paniculata on eroding dune ridges. Thus, storm tides may have carried nutrients onto the windward slopes of the primary dunes where, otherwise, waters do not reach.

Table 2. - Comparison of the vegetation of the windward and leeward slopes of the primary dunes before and after Hurricane Allen in 1980.

Species	Pre-Hurricane			Post-Hurricane		
	Freq.	% Cover	Importance value	Freq.	% Cover	Importance value
Windward Slope of Primary Dune						
<u>Ipomoea stolonifera</u>	45.7	3.5	92.5	24.4	1.0	31.9
<u>Uniola paniculata</u>	34.3	2.6	69.0	41.5	4.3	83.8
<u>Croton punctatus</u>	14.3	0.5	20.6	12.2	0.7	18.0
<u>Schizachyrium scoparium</u>	5.7	0.2	8.2	9.8	0.5	13.9
<u>Heterotheca subaxillaris</u>	2.9	0.3	6.9	2.4	0.2	4.6
<u>Panicum amarulum</u>	2.9	<0.1	3.0	2.4	<0.1	2.0
<u>Oenothera drummondii</u>				12.2	1.2	24.3
<u>Ipomoea pes-caprae</u>				9.8	0.6	14.6
<u>Sporobolus virginicus</u>				2.4	<0.1	2.7
<u>Rhynchosia minima</u>				2.4	<0.1	2.1
<u>Eragrostis oxylepis</u>				2.4	<0.1	2.0
Total Cover		7.1			8.6	
Leeward Slope of Primary Dune						
<u>Ipomoea stolonifera</u>	81.5	9.7	81.0	33.3	2.1	28.5
<u>Uniola paniculata</u>	44.4	2.6	31.6	38.1	3.9	41.8
<u>Schizachyrium scoparium</u>	25.9	4.0	30.1	42.9	6.4	59.2
<u>Croton punctatus</u>	29.6	2.3	23.7	19.0	1.3	17.1
<u>Cassia fasciculata</u>	7.4	1.2	8.8	4.8	0.6	6.0
<u>Heterotheca subaxillaris</u>	7.4	1.0	7.9			
<u>Oenothera drummondii</u>	11.1	0.2	5.7	14.3	0.6	10.3
<u>Rhynchosia minima</u>	7.4	0.2	4.1	9.5	<0.1	4.9
<u>Paspalum monostachyum</u>	7.4	0.1	3.7			
<u>Panicum amarulum</u>	3.7	<0.1	1.7	4.8	<0.1	2.8
<u>Fimbristylis castanea</u>	3.7	<0.1	1.6	4.8	0.3	3.9
<u>Ipomoea pes-caprae</u>				33.3	1.2	23.1
Unknown				4.8	<0.1	2.4
Total Cover		21.3			16.4	

Extensive vehicular and pedestrian traffic on the southernmost 19.5 km of the island have destroyed the vegetation on many of the primary dunes. Dune buggies, all-terrain vehicles, and four-wheel drive vehicles that are driven on or across the primary dunes are responsible for most of the damage. Destruction of the vegetation causes "blowouts" and exacerbates wind and wave scouring. Wind-eroded primary dune ridges produce "tongues" which consist of masses of bare sand oriented in a southeast to northwest axis extending into the secondary dunes and vegetated flats zone and occasionally into the tidal flats. These tongues of bare sand cover vegetation in the secondary dunes and vegetated flats zone.

Secondary Dunes and Vegetated Flats.---This zone occurs west of the primary dunes. Width ranges from 600 to 700 m; thus, it is the broadest ecological zone. In some places this area is virtually flat, but usually dunes of lower elevation than the primaries are present. Since the area is lower in elevation and in the lee of the primary dunes, it is less exposed to environmental stresses. Consequently, the dunes are partially to completely stabilized. Sea coast bluestem, Schizachyrium scoparium is the dominant in this zone (13). However, in areas where surface elevation is sufficiently low and the drainage configuration so arranged as to produce saturated soil conditions, dense meadows of fresh marsh communities occur. Most of these are composed of several species, but some relatively simple combinations recur frequently. The most common is a combination of Fimbristylis castanea and Eleocharis obtusa. Other combinations include Scirpus americanus and Spartina patens, and S. patens and E. obtusa. In some places virtually closed stands of Dichromena colorata and E. obtusa occur.

The most serious detrimental impact to this zone is development due to an expanding island population. Virtually all of the hotels, motels, vacation homes, roads, and businesses are located in this zone. The development destroys almost all the native vegetation and dunes are leveled to provide a flat surface for construction. Because much of the area is covered with buildings, cement, or asphalt, rains often cause flooding in the developed portions of the zone. Presently development (except for Park Road 100 which extends 11.5 km farther north) is limited to the southernmost 8 km of the island because of absence of utilities north of Andy Bowie County Park.

Hurricanes cause great damage to developments in this zone, but do not greatly affect the vegetation of the undeveloped areas (14). The main effect is destruction of vegetation and dunes on the margins of washovers as washovers are re-opened and widened by the storm surge. Lightning-initiated and human-set fires have been a problem on North Padre Island (6). Fires have periodically denuded areas ranging from 10 to 100 ha. Fires have not been a problem on South Padre Island. A primary contributing factor is that camps are usually established in the backshore zone or on the margins of washovers. The occasional freezing conditions that occur on South Padre Island apparently cause little damage to the plants of this zone. The woody shrub Sophora tomentosa suffered freeze damage to the base of the stems during the severe freeze of December 1983. However, individuals of this species recovered slowly from rhizomatous bases and initiated a flowering

response by late November 1984.

Park Road 100 extends north of the developed southern section of the island for a distance of 11.5 km. It is 8.0 m wide and a 2.8 m wide paved shoulder is provided on each side of the driving lanes. Vehicles leave the highway at washovers and drive east toward the Gulf of Mexico or west toward the Laguna Madre. Camps are often established in these washover areas. The vehicle and pedestrian traffic inhibits the recovery of vegetation on the margins of washovers and retards the re-establishment of primary and secondary dunes in these areas.

Oil and gas drilling operations are occasionally established north of the terminus of Park Road 100. Trucks hauling drilling equipment reach the secondary dunes and vegetated flats via wooden pontoon roads established across the backshore and primary dunes. Otherwise, there is relatively little vehicular traffic in the secondary dunes and vegetated flats north of the end of Park Road 100.

Tidal Flats.---The tidal flats are flooded by waters of the Laguna Madre following high tides or heavy rains. This zone is largely bare, but includes a number of sparsely distributed salt-tolerant species, many of which occur in a narrow zone bordering the vegetated flats or along the low tide line of the bayshore edge (13). On the bare, wind-swept flats, a few widely scattered clumps of Sesuvium portulacastrum can be found growing on the crests of small accretion dunes. Near the southern end of the island black mangrove, Avicennia germinans, occurs in discontinuous stands. Mangroves are most abundant along the bayshore between the old and new causeways in heavy clay soil. Most of this population was severely damaged by the December 1983 freeze (20). Seedling re-establishment has not occurred yet, but many of the plants are recovering at their bases.

Hurricane damage to the vegetation of the tidal flats has not been quantitatively determined, but there is little doubt that transported sand covers vegetation adjacent to washovers. In the developed portion of the island, owners often place bulkheads along the bayshore of their property. Some also dredge channels up to their property so as to be able to get motorboats up to the bulkhead for mooring. Vehicular traffic is largely limited to washover margins as fishermen drive as closely as possible to the bayshore before they begin wade-fishing. Traffic loosens the crust that forms on the barren tidal flats and exacerbates wind transport of sand into the Laguna Madre.

Washovers.---Washovers are transverse features which cut across the other ecological zones. They are distinct in the primary dune zone and secondary dune and vegetated flats zone, but westward, washovers grade imperceptibly into the tidal flats. Most of the area is bare. Occasionally, tide pools of considerable size may be present. Scattered clumps of Sesuvium portulacastrum may be found on these windswept flats (13).

Prior to Hurricane Allen in 1980, there were 26 washovers on South Padre Island and the mean width of the washovers was 238 m (13). After Hurricane Allen, there were 23 washovers and mean width was 434 m (14).

Apparently, overwashes in 1980 followed the old washover channels formed during Hurricane Beulah (September 20, 1967). The greater widths of washovers in 1980 suggest that the margins of the primary dunes were eroded and that dunes which had formed in the interior of old washovers were eroded completely. Consequently, there were slightly fewer, but much wider washovers (14).

Vehicular traffic is the major human perturbation in washovers. Driving retards dune establishment and drastically reduces growth of vegetation into the bare areas.

Conclusions and Recommendations

Land use patterns on South Padre Island have evolved from the low impact subsistence based livelihood of prehistoric Indians, to cattle ranching, to recreational development (9). The activities of Indians did not alter the ecology of the island very much. Ranching was the major use of the island for approximately 160 years. Price and Gunter (28) suggested that during the late 1800's and early 1900's much of the vegetation was destroyed by overgrazing and droughts resulting in migration of dunes toward the Laguna Madre. The remoteness of the island restricted major development until 1954 when the first Queen Isabella Causeway was built. The causeway provided automobile access to South Padre Island for the first time, but development was slow until 1971, when legislation provided hurricane insurance (5). Construction of a new Queen Isabella Causeway in 1974 improved accessibility and tourist visitation to the island because it eliminated traffic back-ups caused by the swing-bridge across the ship channel at the entrance to the old causeway. Since 1974 development has been rapid. Except for small holdings at the northern and southern ends, South Padre Island is under private ownership and except for Park Road 100, development is currently limited to the southern 8 km of the island because of the absence of utilities north of this point. Park Road 100 extends 11.5 km north of the current northern limit of development.

Existing development is "island wide", i.e. it extends across all the island except for the foreshore and backshore. Because South Padre Island is largely privately owned and because of its geographic location and subtropical climate, predictions call for intensive development (5, 9). For example, Ditton et al. (5) predict that utilities and Park Road 100 will be extended the full length of the island by the year 2000. Furthermore, they suggest that the development will proceed as a series of successive northward annexations. As the island becomes more intensively developed emphasis will shift from environmental recreation to cultural attractions as the character of the barrier island is lost to development. Currently, more than 80% of the island remains undeveloped, thus there is opportunity to make informed decisions about whether or not further development takes place and if it does occur, the strategy of development employed.

It is clear that the shoreline of South Padre Island has been retreating landward since at least the middle 1800's as a consequence of the combined effects of decreased and interrupted sediment supply, relative sea level rise, and hurricanes (25). All available evidence

suggests that this long-range trend of erosion will continue. Thus, it is important that construction occur well back of the primary dune ridge and that every effort be extended to maintain the foredunes and primary dunes. Steps should be taken to revegetate existing dunes and to encourage the growth of eroded dunes. Vehicular traffic should be eliminated from all dunes and limited to Park Road 100, city streets, beach accesses, and the foreshore. It will be difficult and expensive to police the traffic, but well worth the time and money in the long term, for the alternative is catastrophic erosion and destruction during storms. Dahl et al. (3) have shown that sea oats, *Uniola paniculata*, and bitter panicum, *Panicum amarum*, can be transplanted to construct and stabilize foredunes. A transplant program should be established and work initiated soon. Pedestrian access to the beach should be encouraged by providing parking facilities at several locations along Park Road 100. Paths should be provided through old washover channels.

Planning and zoning should ensure that future development is accomplished in a manner so that the essential character of the secondary dunes and vegetated flats is maintained. Marshes should not be filled to build up land for development. Buildings should be placed on pilings to allow overwash to pass under the principal structures. Owners should not be permitted to enclose the lower level (which defeats the purpose of placing structures on pilings).

A large portion of the island, preferably the northern third, should be maintained in an undeveloped state. This will likely require purchase by a governmental entity, i.e. county, state, or federal. Maintenance of an undeveloped area will serve as a major attraction to the area, for it will allow visitors to enjoy a greater variety of recreational opportunities.

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