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Galveston Island — A Changing Environment

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Texas Engineering Experiment Station

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ABSTRACT

Galveston is the only major U.S. city built on an island fronting on the Gulf of Mexico. This setting provides Galveston with obvious advantages but less obvious problems. Probably chief among the latter is threat of hurricanes. Like all barrier islands along the western half of the Gulf of Mexico, Galveston often lies in or near the path of tropical storms. Unlike other barrier islands, this one is densely populated.

The hurricane of September 1900, with its 120 mile-per-hour winds and its 14-foot storm tide, resulted in thousands of lives lost as well as destruction of most of the buildings on the island. A seawall was built soon thereafter and the land behind it was elevated. This undoubtedly reduced casualties and property loss from several subsequent hurricanes which have hit the island. However, suburban expansion during a recent quiescent period has produced major housing developments on low ground well beyond the protection of the seawall. Much of the island's population is now housed in areas which are terribly vulnerable to the onslaught of future storms.

Direct hits by major hurricanes are not the only threat to the island. Strong waves set up by ordinary winter and spring storms, as well as those originating from tropical storms which skirt the island by some distance, often set up destructive longshore currents. The combination of longshore current scour and direct wave attack results in high periodic erosion of beaches. The flow of beach replenishment material, reduced during recent times by a combination of factors, is now effectively blocked by the presence of the Galveston channel jetties. The net result of high erosion and inadequate replenishment is a higher-than-normal erosion rate along much of Galveston Island.

The combination of high rates of erosion and great vulnerability to storm attack is threatening significant early loss of public and private property. One example is the highway approach to the bridge over San Luis Pass: if present erosion rates continue, washout of the approach road will occur by about 1986 even if the island is not hit by another major hurricane.

The first line of defense against storms and against wave and longshore current attack is the island's natural, vegetated dune structure. Despite this, the dunes and bluffs are routinely leveled or their vegetation decimated by beachfront construction or by vehicular passage from bluff to beach.

Most of the non-urban, non-beach land on the island is either developed for housing or else grazed--and it would appear that much of the presently grazed land is being held for development speculation. Construction and grazing are both detrimental to the natural ecology of the island: construction because it eliminates the productivity of the meadows and wetlands on which the housing is built; grazing because it almost invariably leads to overgrazing, which in turn destroys the deep-rooted perennial grasses which literally hold the island together.

Solution of some of these problems is possible but difficult. Little can be done about hurricane impact or about the mechanisms causing rapid erosion. Protection of the approach to the San Luis Pass bridge, by whatever means, will require, quite soon, a major decision and a major commitment by local government. Regulation of across-the-dune beach access is hampered by tradition and by a state law insuring open beaches--a law which is often interpreted to mean assurance of unlimited beach access. Regulation of construction and overgrazing runs afoul of the historic privileges of private ownership and the current groundswell of protest against government regulation of private activity. In the particular case of construction, the builders and the lenders have a significant vested interest in continuance of the present housing boom on the island and, no doubt, a substantial influence on the local governmental decision process.

The good life on Galveston Island is not without its drawbacks.

ACKNOWLEDGEMENTS

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INTRODUCTION

This is the final report of a one-year remote sensing study of baseline conditions at Galveston Island, Texas. It will describe the varied activities which took place during the gathering of the project data and the numerous insights which were gained enroute to formation of conclusions. These insights include not only an awareness of the appearance and condition of the island, the physical processes which affect it, and the natural and man-caused stresses now ongoing, but some of the institutional constraints which may well inhibit solution of problems now pressing in on the island and its population.

Background

The purpose of the project was to provide the City of Galveston with environmental documentation needed to guide the future development of the island. Commercial developers had been building on the marshes and dunes of the southwest half of the island. Strong opposition had been developing from environmentalists and from fishermen who viewed the prospect of continued construction as destructive to that environmentally sensitive area. Lacking a data base on which to establish a planning rationale, the city government had been unable to come up with a management plan which reconciles the conflicting considerations of development and conservation.

In particular, the planners require an understanding of the relationship between past practices and present conditions on the island. They need to know which types and levels of activities might be carried out without causing permanent damage to the dune and marsh habitat. They also need a well-documented record of the present baseline condition of the island. Only if these factors are known can valid tradeoff analyses be made a part of the planning process.

Project Area

Galveston Island is a barrier beach, nearly 30 miles (48 km) in length by about 3 miles (4.8 km) at its widest, which fronts on the Gulf of Mexico some 50 miles (80 km) southwest of Houston. Galveston, the island's only city, was an active port by the end of the 18th Century; however, it was not charted, nor did any significant growth occur, until the latter part of the 19th Century (See Figure 1).

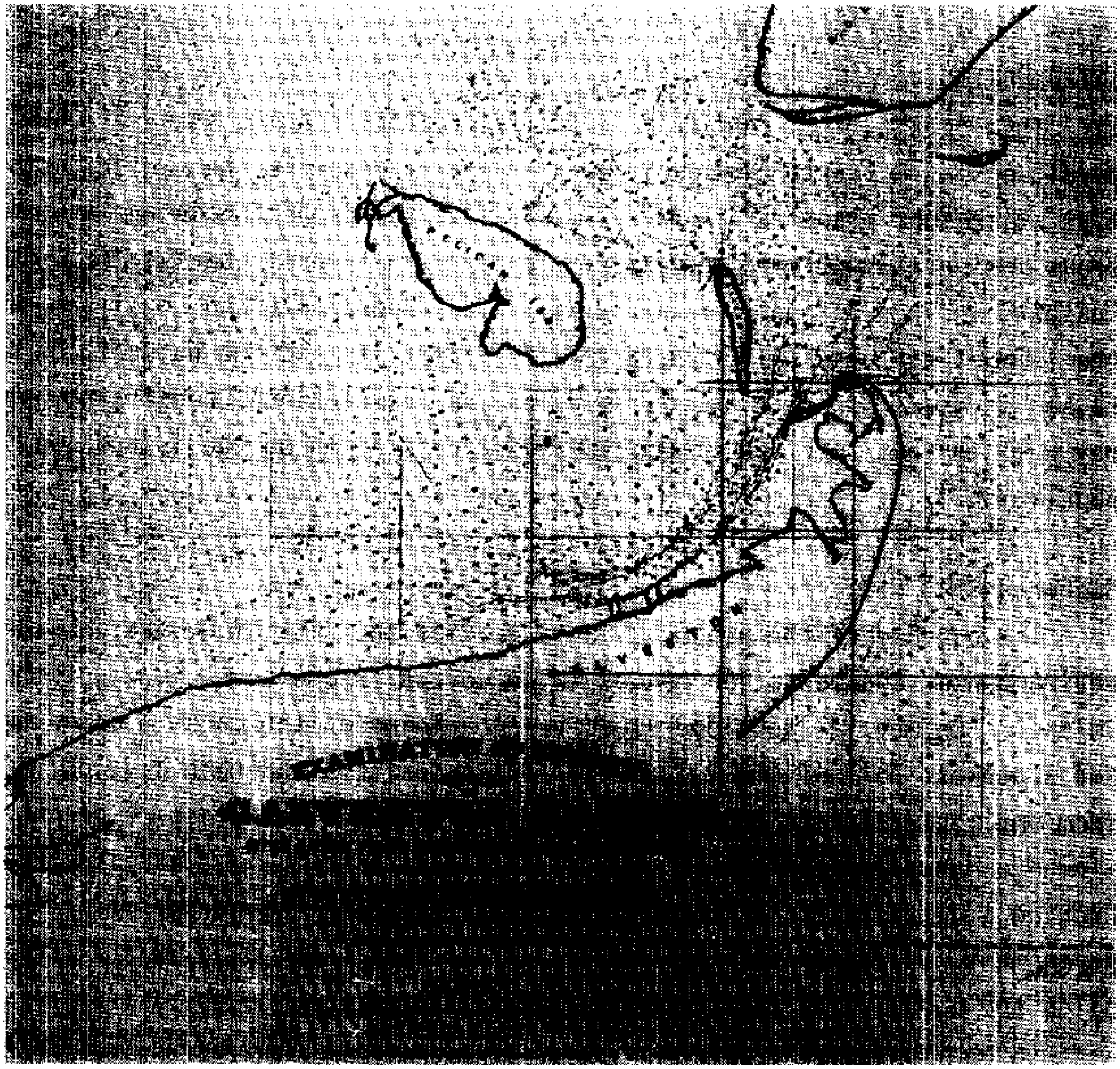

Figure 1. Galveston in 1867, from an early Corps of Engineers survey. A natural deepwater channel, the port city's reason for existence, enters the bay from the Gulf of Mexico at upper right and passes close by the island's north shore at center.

Galveston has had, quite literally, a stormy history. Of the 44 hurricanes affecting the coast of Texas since 1900, 10 have produced storm tides high enough to cause very significant erosion of island beaches. The hurricane of September 1900 was the most destructive on record at Galveston, producing winds of 120 miles per hour (195 km/hr) and storm tides of 14.5 feet (4.4 km) above mean sea level [7]. A 17-foot (5.2-m) high seawall was subsequently built to afford protection from future storms. In addition, dredge material was obtained from nearby waters and used to raise the grade behind the seawall some 10 to 17 feet (3.0-4.4 m) above the old dune tops; i.e., to present elevations exceeding 20 feet (6 m) in many areas [11].

Despite the damage and loss of life from the 1900 hurricane, Galveston has continued to grow. The urban area now covers the northeastern third of the island. Beyond that, housing developments, both large and small, are scattered along the remaining length of the island; some front on the Gulf, others are built on the bayside marshes, a very few span the distance from Gulf to bay. Vacationers and residents alike seem to come for a respite from big-city living. However, the result of the recent suburban growth on the island has been an increase in population and a resultant decline in those qualities of life so many came to the island to enjoy.

Much of the still-undeveloped part of the island is pastoral, with many cattle grazing the dunes and meadows. Part of the grazed area near the island's center, inclusive of meadows and intertidal wetlands, has been set aside as a state nature park. Most areas are not protected. Vehicular traffic, at the time the project began, was relatively unrestricted in the still-open areas of the island, particularly along the beaches themselves. The impact on the beaches, and on the vegetation bordering the beaches, was predictable.

It is within this context that the need had arisen for a baseline study of the island, one which would be descriptive of its current condition and of the nature and extent of the changes which have been going on.

Project Scope

The extent of most studies is usually a function of economics--a compromise between what an investigator would like to do and how much of it can be funded. Thus, this project was originally to have been a 24-month, two-phase study of Galveston Island which would include a year-long remote sensing investigation of the 1977 baseline condition of the island (Phase I) followed by a study of archival data which would trace the development of Galveston and Galveston Island since the mid-1800's (Phase II).

As it turned out, funding was barely sufficient to provide a reasonable shot at Phase I, the baseline study. Even so, a modicum of archival data was bootlegged into the analysis, providing some of the project's more surprising and controversial findings.

Although the investigators had become reconciled to providing what is essentially a thorough baseline study backed up by vegetation and land use maps of the island, the availability of seasonal and other-year data gave strong evidence concerning mid- to long-term trends which transcended the single-year concept. Thus, the study results encompass a significantly greater body of information than might normally have been anticipated from this sort of an effort.

Remote Sensing of Coastal Wetlands

Remote sensing--in this case, color infrared aerial photography--has some rather significant advantages over classic ground surveys for environmental studies of areas of appreciable size. As the area of interest increases, so also does the number of data points which must be investigated, sampled, measured, or what-have-you. If, concurrent with large-area analysis, there remains a requirement for synopticity of measurement, ordinary ground techniques would require a multitude of data takers. Aerial photography obviously provides the needed synoptic sampling since the aerial camera can document large areas within an exceptionally brief time span. The other requirement is for accuracy of measurement of whatever parameters are of interest to the investigator.

Black and white photography, particularly over relatively flat terrain, provides a map-like portrayal of the location and extent of cultural features, physical boundaries, and of broad classifications of vegetation. The use of color infrared photography, used for camouflage detection during the Second World War, provides essentially the same metric properties as black and white photography, but in addition it allows for vegetation species discrimination and for detection of plant stress as well. It is, it turns out, a good all-round environmental monitoring and mapping tool. The Remote Sensing Center of Texas A&M University has expanded the capabilities of color infrared film by using it seasonally, thus providing an even more accurate record of vegetation systems from youth through maturity and senescence. These added photographic sequences have been found to add relatively little to the overall cost of a project, yet they provide invaluable additional evidence with respect to species identity, species dominance, and the relative health of the various plant communities within the area of investigation.

There has been ample precedent for aerial photographic investigations in the coastal zone as well as in freshwater wetlands. An earlier study by Herbich and Hales [7] used old charts along with black and white aerial photographs to trace the changes in shoreline configuration of the southwest tip of Galveston Island over a period of many decades. Black and white aerial photography has its strengths and limitations: although such features as roads, buildings, beaches, marshes and even dune lines are usually identifiable, it is often difficult to tell where the land ends and the wetlands begin; in addition, determination of the species and condition of wetlands vegetation is simply not feasible. Color infrared film, which became available in the mid-1960's, made it possible to discriminate and delineate plant communities in the dunes and wetlands.

Reimold, et al. [14] used color infrared film over the Georgia coastal wetland to delineate marsh vegetation communities and to estimate plant biomass, an index of wetlands condition. Guss [6], also working in Georgia, was able to determine the relative water depth in various wetland areas by discriminating species in terms of their preferred depth habitat. Guss was also able to identify dune crests from recognition of typical dune species on color infrared film. Anderson and Wobber [2] used color infrared photographic techniques in the New Jersey marshes to aid the State of New Jersey in developing a wetlands management plan. Similar work has also been done in Delaware by Klemas, et al. [9].

Recent studies at Texas A&M University used seasonal color infrared photography to better define and map the extent, condition, and species makeup of the plant communities comprising the ecological environment of the immediate coastal zone [3]. That project also used color infrared film to detect estuarine physical processes and correlate them with the extent and condition of marsh communities in specific ecological habitats. The present project is an outgrowth of that earlier work.

EQUIPMENT AND METHODS

The project was helped immeasurably by the almost-constant availability of a Cessna TU-206 photo aircraft and Wild RC-8 and RC-9 camera equipment. Photography was scheduled at approximate 3-month intervals from mid-March through mid-December of 1977, the actual flight dates being dependent on photographic weather. The film was Kodak Aerochrome Infrared, Type 2443, used in conjunction with anti-vignetting 500-nm filters. The 6-inch (152-mm) focal length RC-8 camera, because of its reduced vignetting properties, was used whenever atmospheric haze was not a factor. The 3 1/2-inch (89-mm) focal length RC-9 camera was used when it was necessary to fly lower to escape a portion of the haze layer. The selected scale for all project photography was 1:32,000, for an RC-8 flight altitude of 16,000 feet (4875 m) or an RC-9 flight altitude of 9350 feet (2850 m). Because of the problems with sun reflection off the water, a relatively high photo overlap of 70 percent was chosen in order to insure total, glint-free coverage of all wetland areas. For comparison purposes, the same picture centers were repeated on all flights.

Photographic flights were made on 28 March 1977, 3 July 1977, 15 September 1977 and 14 December 1977, providing photography at about the beginning of each of the four seasons. The film was developed commercially, to film positives, usually within 72 hours of the flight. On receipt of the developed film, preliminary photoanalysis was done on a Richards viewing table equipped with zoom binocular microscope optics.

After in-house processing of Cibachrome color contact prints, the ground truth team would leave for a 2-day field verification trip. The field team included a photo-cartographer and a plant taxonomist, both of whom were familiar with photointerpretation techniques. Field notes were inked directly on the color prints in order to insure correct identification on the imagery of field-verified features.

Along with the original film positives, the annotated field prints were used for subsequent photoanalysis and for compilation of planimetric maps. Photocompilation was done with a Kargl Reflecting Projector and a Bausch & Lomb ZTS. Map scale was 1:24,000, a three-map series covering the island. Cartographic products include base maps, seasonal composites of the island's vegetation, and land use maps based on Level II of the U. S. Geological Survey Classification System.

STUDY RESULTS

The most significant difference between this project and most remote sensing studies in the coastal zone has been the availability of seasonal aerial photography of the study area. Instead of having a single look at Galveston Island at a not-necessarily-opportune point in time, it has been possible to observe seasonal trends in plant growth, construction activities and coastal processes. The 1977 sequential photography, supplemented by access to historic charts and earlier photography of the area, has allowed significant insight into how the existing set of conditions has come about as well as what sorts of changes are now going on. These multiple aspects of coastal zone description are discussed separately further on.

Since a number of things will be inferred from analysis of the 1977 data, it would be well to consider whether it was a representative year. If it were not, one would be inclined to arrive at erroneous conclusions concerning what was observed. However, this seems not to have been the case. Housing construction went on as usual. Dredging and filling, associated with what is known as "development", continued in 1977 just as it had obviously occurred in years previous. Cattle grazing, as will be discussed later, continued as before. With perhaps one exception, coastal erosion continued its methodical, seasonal inroads on the beaches.

The exception was Hurricane Anita, which crossed the Mexican coast 120 miles (190 km) south of the U. S. border on 2 September 1977. Since the hurricane passed some 400 miles (640 km) southwest of Galveston, the winds at Galveston should not have been exceedingly high nor the seas extraordinarily heavy. National Ocean Survey records showed that the storm-associated rise in sea level along the Galveston beachfront was barely 2 feet (0.6 km) above normal. Nevertheless, as will be discussed further along, significantly more erosion occurred between the 3 July 1977 and 15 September 1977 flights that would have usually in late summer--no more, however, than would result from a normal series of winter storms.

General Appearance of Galveston Island

The recent history of Galveston Island is fairly apparent from even a cursory examination of the imagery. Black and white copies of selected examples of the original color infrared photography of 15 September 1977 are provided to illustrate, in part, the 1977 condition of the island. Each photography is of a square area roughly 24,000 feet (about 7300 m) on a side.

Figure 2 shows the northeastern tip of the island with the Gulf of Mexico at the lower right. The end of the seawall meets the South Jetty just below and left of photo center and runs upward and left toward the beach. Pelican Island, at the upper right, is composed almost entirely of dredge material from channel maintenance. The channel side of the seawall is also a spoil depository. The area seaward of the seawall is mostly natural sediment accumulated from seasonal longshore sediment transport and trapped

Figure 2. Northeast end of Galveston Island, 15 September 1977.

by the South Jetty. The land appendage intruding into the channel below and left of center is composed of sediment which was driven across the top of the jetty by wave action. The North Jetty is seen at botton right. The beach area in this photo is East Beach, a public beach which was vehicle-accessible at the time the photograph was taken.

Figure 3, a photograph of the area immediately southwest of Figure 2, shows the central commercial and residential section of Galveston. The original townsite lies approximately at photo center. The area immediately behind and along the seawall (left) is significantly higher in elevation

Figure 3. Downtown Galveston, 15 September 1977.

than the rest of the city. Note the multiple groins jutting out from the seawall. These were designed to limit erosion of beach material.

Figure 4 shows the adjacent area to the southwest, the main railroad and highway bridges to the mainland appearing at the right. The seawall ends near the top of the photo and the beachfront highway is seen to diverge inland. The dark, parallel ground features in the upper third of the photo are between-the-dune depressions left over from an earlier era when the shoreline was advancing, new dunes forming seaward of the previous dune line. The depressions between these relict dunes are wetter than the dune tops

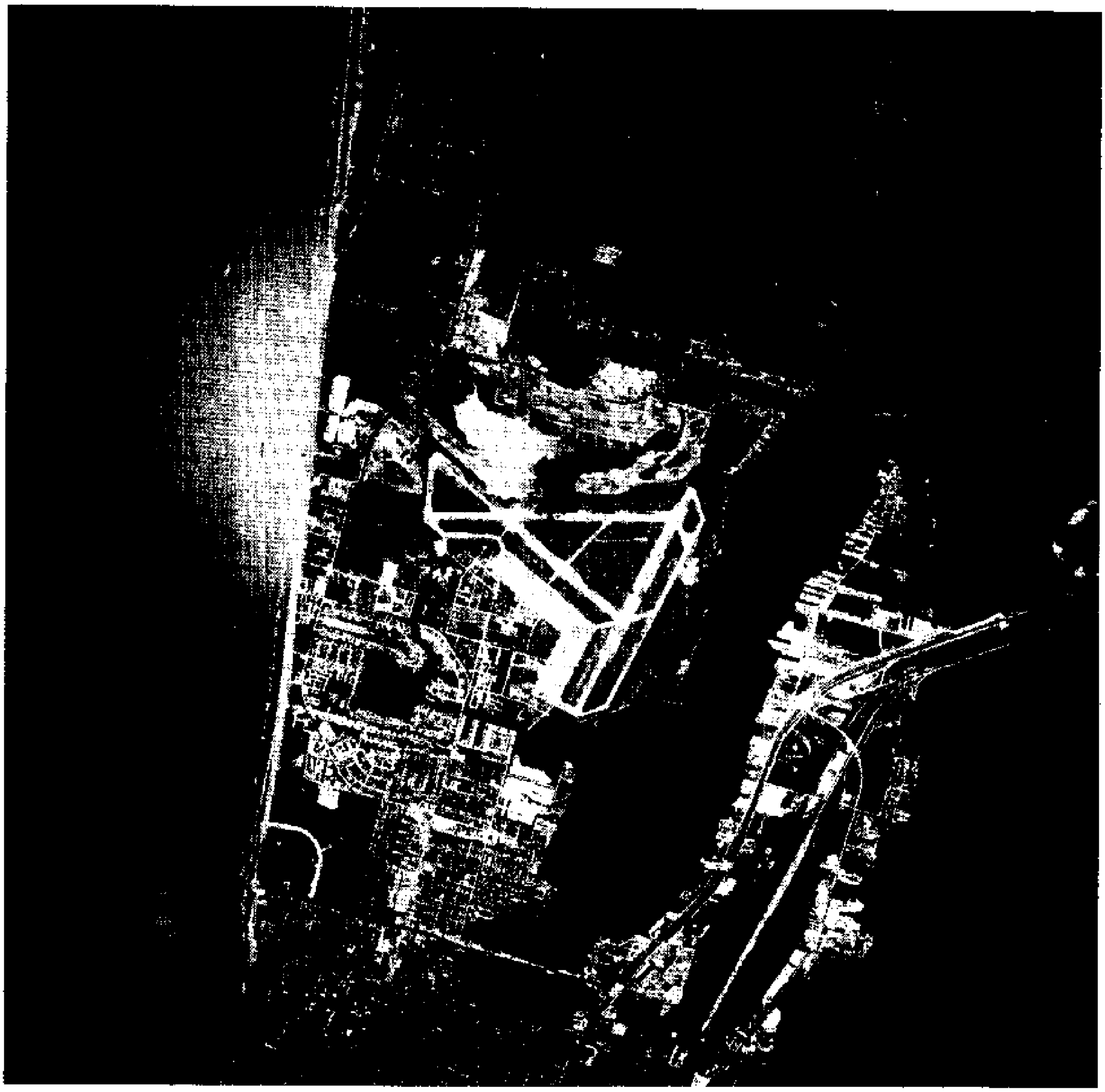

Figure 4. Galveston Airport and vicinity, 15 September 1977.

and a different group of species--discriminable on color infrared film--is supported there. This parallel banding is quite typical of Texas barrier islands.

Figure 5 is near the center of the island, showing two of the recent major housing developments, one of which extends from the Gulf to the bay. Note that the right half of the upper development is built directly on the intertidal and subtidal wetlands, while the one on the bottom tends to conform to the boundaries of a natural inlet. Galveston Island State Park, established in a former grazed area as a wetlands preserve, lies between the

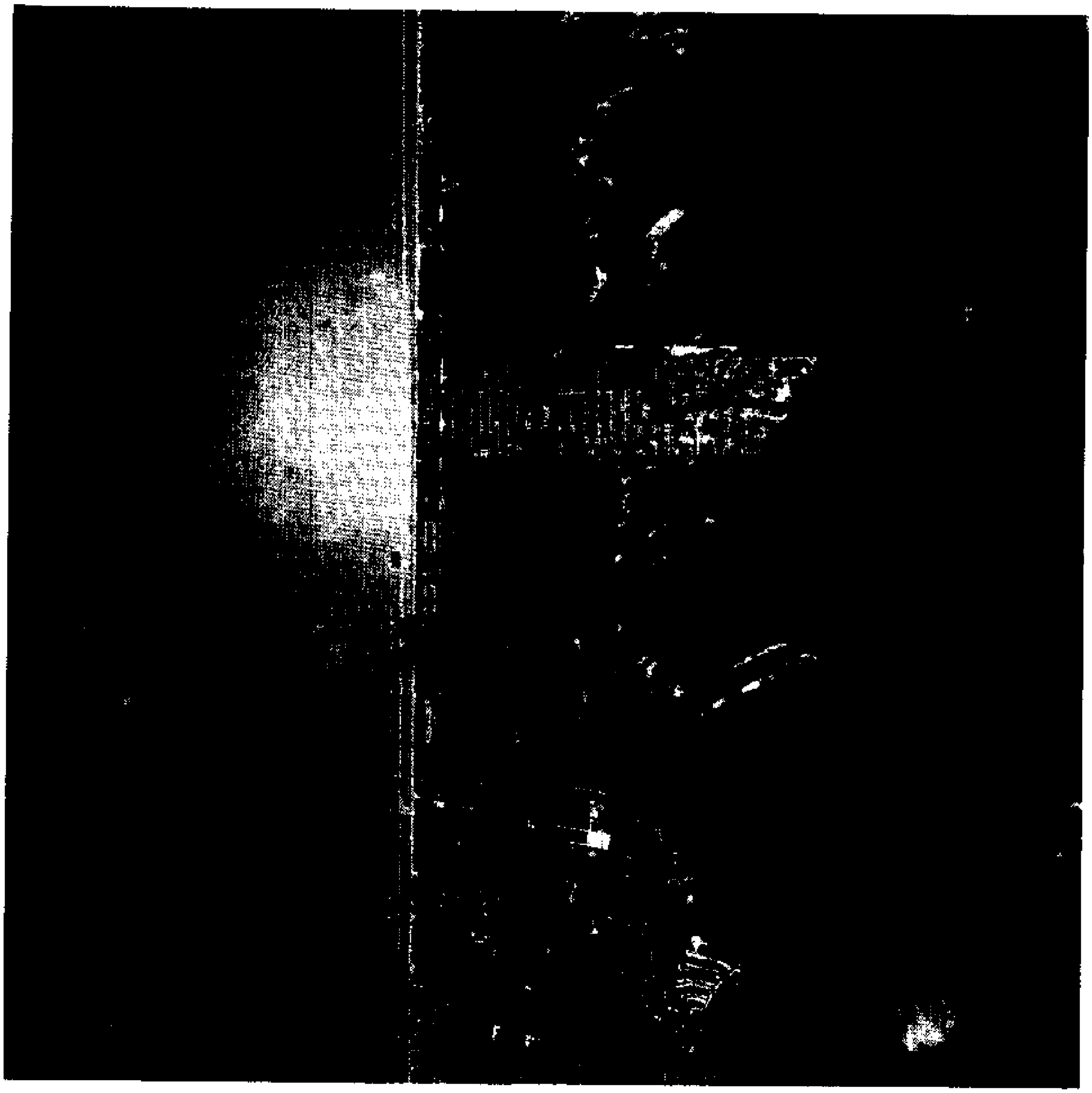

Figure 5. Galveston Island State Park, 15 September 1977.

two developments. Note also that many homes are built directly on the dunes. Beach erosion already extends landward of many of the residences, protective structures having been built in the attempt to avert, or at least delay, the eventual property loss. The intermittent clusters of houses along the beach at the top typify the sort of development seen at the west end of the island.

Figure 6, near the southwest tip of the island, is of interest because it shows a heavily grazed meadow as well as a rapidly eroding shoreline area. The meadows above the developed area are typified by cattle trails and by a good deal of bare ground where one would normally find dense native grasses

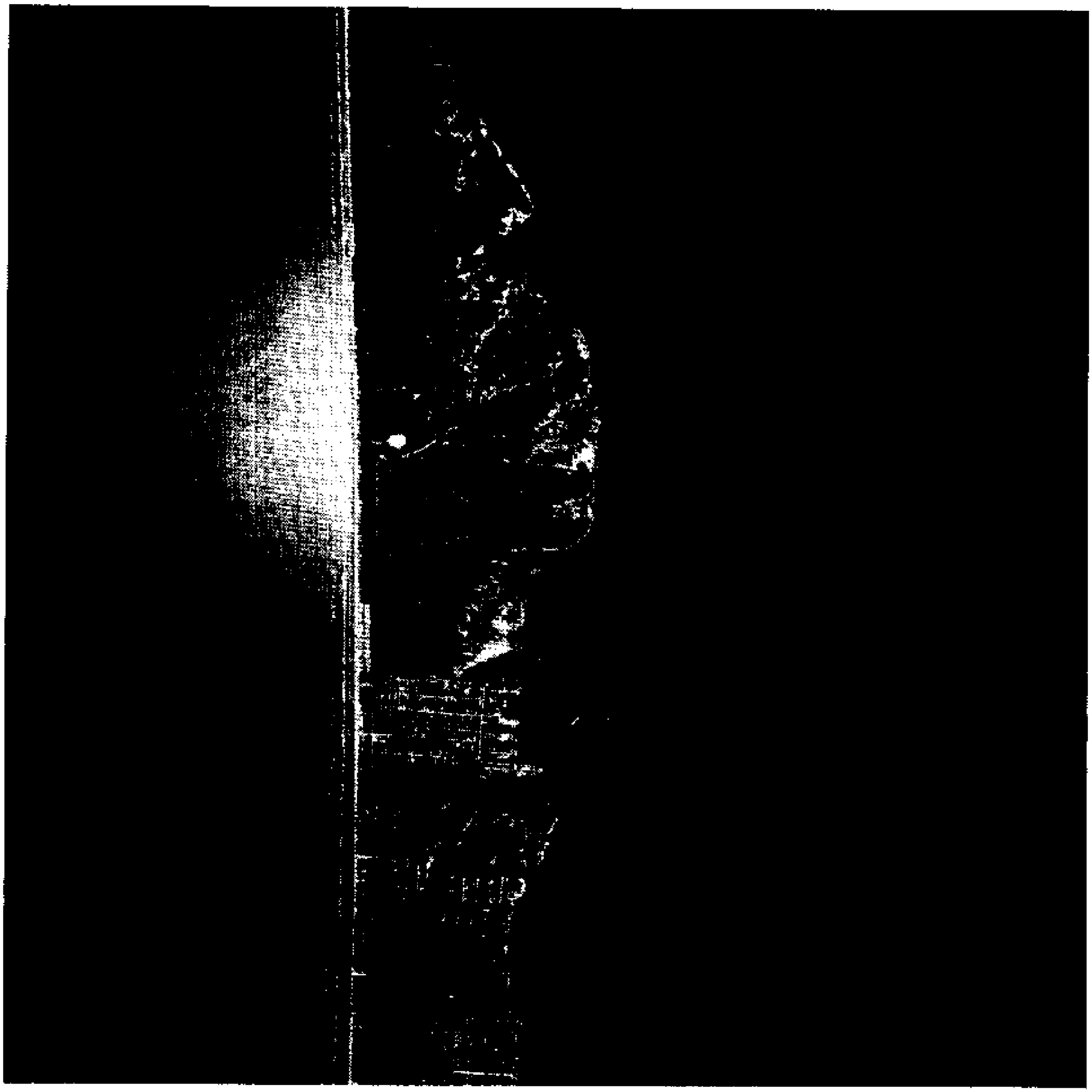

Figure 6. Grazing areas near the southwest end, 15 September 1977.

on less-modified barrier islands. Note the dark line of healthy vegetation bordering the Gulf beach just above photo center; a fence line running between the road and the beach keeps cattle off that section. The beach area above the fence line terminus is a heavily used public beach (West Beach) which is now washing away quite rapidly, as will be discussed further along.

San Luis Pass and the southwest tip of Galveston Island are shown in Figure 7. The bridge connecting Galveston Island with the northeast tip of Follets Island was built around 1966. The toll plaza is seen on the Galveston Island side, next to which a T-shaped small-boat inlet has been dredged

Figure 7. Southwest tip of Galveston Island, 15 September 1977.

and a boat ramp built. The area below the bridge on the Follets Island side was the subject of an earlier study [7] which showed that the winter-to-summer movement of the shoreline was on the order of 900 feet (275 m) seaward and which concluded that the long-term trend was toward erosion rather than accretion.

The foregoing discussion has been descriptive chiefly of the present general appearance and condition of Galveston Island as determined from the analysis of seasonal imagery. The following section deals with the study findings of the island's vegetation, acquired from seasonal field verification as well as from the imagery.

Vegetation Systems

An important aspect of the study has been the provision of two sets of 1977 baseline maps of Galveston and Pelican Islands at 1:24,000 scale: a land-use/land-cover series and another series showing the extent and identity of the major plant communities. The two sets are closely related. The land-use/land-cover series is classified to Level II, and in some cases to Level III, of a recently published U. S. Geological Survey system [1]. Those Level II and Level III classifications which pertain to wetlands vegetation are further broken down, in the vegetation map series, into nine separate vegetative categories with respect to species makeup.

This section is a synthesis of the detailed ground verification work needed for compilation of the vegetation series. It deals in narrative fashion with the plant species and species mixes found on Galveston and Pelican Islands, with their habitat, and with the apparent species succession now ongoing in some areas. Each of the major sites where problems exist or seem imminent is discussed in detail from the standpoint of plant communities, phenology, ecology, photographic appearance, and, to the extent feasible, the ongoing physical and biological processes. Those areas which offer unspoiled, natural beauty to Galvestonians are also described. The section will begin with a general overview of the island as a plant habitat.

Overview of Plant Communities

In general, natural dune areas on barrier islands along the central Texas coast tend to be dominated by stabilizing grasses such as *Spartina patens* (Marshhay Cordgrass), *Panicum amarum* (Bitter Panicum), and *Uniola* paniculata (Sea-oats). The interior meadows are usually dominated by the grasses S. patens, Distichlis spicata (Saltgrass) and occasionally Cynodon dactylon (Bermudagrass). Higher elevations within the meadows are often marked by Spartina spartinae (Gulf Cordgrass). In fact, S. patens and S. spartinae are so prevalent on the Texas barrier islands that these areas are usually typified on color infrared imagery by the color signatures of those plants. Juncus spp. (rushes) often fill the depressions between relict dunes. On the vegetated tidal flats are usually found dominants such as Batis maritima (Maritime Saltwort), Salicornia virginica (Virginia Glasswort), and a Monanthochloe littoralis (Shoregrass), with Spartina alterniflora (Smooth Cordgrass) forming a border community at about the low water line. Beyond, in deeper water, are often found submerged Ruppia maritima (Widgeongrass) and Halodule beaudettei. [3]

The dune areas along the coast of Galveston Island (labeled with the numeral "6" on the vegetation maps) are dominated by Panicum amarum, which is atypical for barrier islands of the Texas Gulf Coast. Spartina patens, Distichlis spicata, and occasionally Uniola paniculata are scattered along the dunes. Uniola, rather than being a dominant, is quite rare in Galveston Island. Also usually present in varying amounts and somewhat seasonally are Hydrocotyle bonariensis (Largeleaf Pennywort), Croton punctatus (Gulf Croton), Heterotheca subaxillaris (Camphor Weed), Scirpus americanus (American Bulrush), Ipomoea pes-caprae (Sailbird Morningglory), and Fimbristylis castanea (Fimbry). Borrichia frutescens (Bush Sea-oxeye) is frequently scattered along the dunes and, in spring, Cakile fusiformis (Sea Rocket) may be abundant.

The meadows behind the dunes (labeled "5" on the maps) are dominated by the grasses Spartina patens, Andropogon virginicus (Broomsedge Bluestem), Andropogon glomeratus (Bushy Beardgrass), Schizachyrium scoparium var. littoralis (Seacoast Bluestem), Distichlis spicata, Sporobolus virginicus (Seashore Dropseed), and Cynodon dactylon. Hydrocotyle bonariensis usually occurs in these meadows along with numerous Juncus spp., Scirpus sppl, and Fimbristylis castanea.

Depressions between relict dunes occur across the entire island except where man and erosion have leveled and/or removed the land. In these depressions, wetland plants such as Juncus spp., Scirpus spp., Carex spp., Cyperus spp., Eleocharis spp., Fimbristylis spp., Rynchospora spp., Scleria spp., Typha spp. and Phragmites australis occur frequently and usually abundantly. Many of the depressions have standing water, and they are often ringed by Sesbania drummondii, especially if they are in overgrazed pastures.

The inland areas of higher ground are the sites of the herbaceous and the mixed rangelands. These areas may have been very similar to, or the same as, the meadows behind the dunes had they not been so heavily grazed for such a long period of time. At any rate, they are now quite different from natural upper meadows on barrier islands. Herbaceous rangeland that is not overgrazed usually has a good stand of Spartina patens, some Distichlis spicata, Cynodon dactylon, Andropogon glomeratus, A. virginicus and Schizachyrium scoparium. Scattered Stenotaphrum secundatum (St. Augustinegrass) and Spartina spartinae occur as well as Hydrocotyle bonariensis, Croton capitatus (Wooly Croton), Sesbania drummondii (Rattlebush), Sesbania vesicaria (Bladder Pod) and Ambrosia spp. (Ragweed). The extent of overgrazing determines the density of not only the grasses but also weeds: Croton, Sesbania, Ambrosia, Opuntia, Iva and Baptisia.

In some rangeland sites overgrazing has continued until invasions by shrubs and brush have occurred. When the deep-rooted perennial grasses are removed by overgrazing, competition for the shrubs and bushes is removed. Also, if pastures are overgrazed and grazing pressure subsequently removed, the shrubs can take over. Thus the mixed rangelands become established. Baccharis halimifolia (Eastern Baccharis), Tamarix gallica (Saltcedar), Iva frutescens (Bigleaf Sumpweed), Rosa bracteata (Macartney Rose), Zanthoxylum fagara (Lime Pricklyash), Opuntia spp., and the grasses and forbs of the herbaceous rangelands make up the dominants in the mixed rangelands.

In the transition zones of the nonforested wetlands, species dominants include Monanthochloe littoralis, Salicornia virginica, Salicornia bigelovii (Bigelow Glasswort), Batis maritima, Borrichia frutescens, Spartina patens, S. spartinae, Distichlis spicata, Scirpus spp., Juncus spp. and Sporobolus virginicus.

The mud flats which are generally adjacent to the transition zones are vegetated with scattered Spartina alterniflora, Salicornia spp., Batis maritima and Sesuvium portulacastrum (Sea Purslane). Adjacent to the mud flats and extending into the West Bay are the Spartina alterniflora tidal marshes. These fertile wetlands still exist where men and cattle have allowed them to.

However, many have been removed for urban and suburban development, many are suffering from pollution, and many are declining for unknown reasons; although, in the last case, the decline could be due to overgrazing and the resultant reduction of detrital nutrient flow from the meadows to the tidal wetlands.

Some Halodule beaudettei has been found in the open waters of West Bay; however, unlike the other barrier islands along the central Texas coast, no Ruppia maritima was found.

The spoil disposal areas such as Pelican Island and a number of diked areas on Galveston Island vary in vegetation density from extremely dense and lush to barren mud flats. However, the dredge material does not have to be deposited too long before it begins to revegetate. The older deposits with well-established vegetation include dense intermingled stands of Distichlis spicata, Cynodon dactylon, Sorghum halapense (Johnsongrass), Andropogon glomeratus, Elymus virginicus (Virginia Wildrye), Leptochloa dubia (Green Sprangletop), Aster spinosus (Devilweed), Sonchus asper (Prickly Sowthistle), Tamarix gallica, Baccharis halimifolia, Iva frutescens, Suaeda linearis (Annual Seepweed) and Lantana horrida. The vegetated mud flats have Borrichia frutescens, Lycium carolinianum (Carolina Wolfberry), Salicornia virginica, S. bigelovii, Batis maritima, Sesuvium portulacastrum, Distichlis spicata, Spartina patens, Avicennia germinans (Blackmangrove), Iva frutescens and juvenile Baccharis halimifolia. The more recent deposits are first invaded by Salicornia virginica, S. bigelovii, Batis maritima and Suaeda linearis. Helianthus annuus (Common Sunflower) is scattered among the other vegetation in summer and fall.

In the following section there are discussions of specific portions of the general study area, beginning with the east end of Galveston Island and working through the west end at San Luis Pass.

Extreme Northeast Galveston Island

On the channel side of the South Jetty is an anomalous land area which was formed from the blow-over of material from East Beach. This land area consists of low-lying sand beach backed up by vegetated dunes. The primary dunes appear as a blue and white reticulation in the aerial infrared imagery. These sparsely vegetated dunes have been cut by numerous dune-buggy and trail-bike paths. A large amount of litter has accumulated and/or been dumped in this area.

The dominant species in the East Beach dunes are Panicum amarum, Croton punctatus, Heterotheca subaxillaris, Hydrocotyle bonariensis and Spartina patens. Behind this line of dunes is a meadow dominated by Spartina patens, Andropogon glomeratus and Croton punctatus. Some Distichlis spicata, Scirpus spp., Juncus spp. and Fimbristylis castanea are also present. In areas near standing water Borrichia frutescens and Batis maritima occur and Spartina alterniflora is a dominant along the margins of the pools.

Looking southward down the beach, it is quite obvious from the aerial photography that off-the-road vehicular triffic has kept the vegetation line back. The blockade, which certainly reduced and supposedly eliminated traffic to the beach during the period of study, had a gap wide enough to allow passage of what Detroit has euphemistically called "full-sized" cars. Tire tracks have almost always-during field verification trips--been visible in the sand along the beach of this vehicle-restricted area. It is evident on the aerial imagery, however, that the blockade had kept vehicular traffic to a minimum so that vegetation has substantially increased down the beach toward the high-water line from the dunes. On the other hand, the dunes, which are quite large in this area, have had a roadway cut along their tops the entire length of East Beach--the result of unrestricted traffic.

The ungrazed meadows behind these dunes have tall, dense stands of Spartina patens, Panicum amarum, Distichlis spicata, Andropogon virginicus and Hydrocotyle bonariensis. Some Scirpus and Juncus is present as is Borrichia frutescens. These grasses are as much as three feet (a meter) tall. The grasses in the meadow across (north of) the road are never as tall as those immediately behind the large dunes.

The line of darker blue on the imagery (especially in December 1977) marking the northeastern tip of this meadow area is reflected in the vegetation by the loss of Solidago spp., Baptista spp. and Hydrocotyle bonariensis. The darker blue area is dominated by Spartina patens, Juncus spp. and Scirpus spp. Apparently the whole area is slightly depressed and, as a result, retains more water. Bare ground can also be seen in this area as opposed to the light blue area adjoining to the south. The area under discussion is in Figure 2, unfortunately a black and white copy of the color infrared originals.

The lagoon area fronting the seawall is a marsh community with dense vegetation growing in standing water. The dominant plants include Distichlis spicata, Juncus spp., Spartina alterniflora, Typha spp., Sesbania drummondii, Zizaniopsis miliacea and Phragmites australis.

Westward along the beach, adjacent to a prominent condominium, is a disturbed beach area with a dense stand of vegetation. Included are Cynodon dactylon, Panicum amarum, Distichlis spicata, Ambrosia psilostachya, Hydrocotyle bonariensis, Cacalia lanceolata and various grasses. These vigorous plants apparently invaded and proliferated as a result of the disturbance created by the nearby construction.

A densely vegetated area behind Stewart Beach and adjacent to a water slide has rather different dominants which include Panicum repens, Fimbristylis castanea and Scirpus americanus. Panicum repens was not found in such abundance at any other place on the island.

Fort San Jacinto

The area north of Seawall Boulevard, old Fort San Jacinto, is apparently occasionally mowed, or at least in part. The vegetation which gives a bright pink return on the early-spring infrared imagery is Medicago hispada (Burclover) and Melilotus sp. (Sweetclover).

Pelican Island

Pelican Island is composed almost entirely of dredge material from channel maintenance, much of it of recent origin. Because of the long history of deposition, the average elevation is equivalent to that of the upper meadow area on barrier islands. Thus it would be expected that the climax vegetation would be mostly Spartina patens and S. spartinae. S. patens and Cynodon dactylon are found in abundance along the older regions of the island--i.e., southeast of the highway as well as some northwest areas--along with scattered, and sometimes dense, stands of Baccharis halimifolia, Tamarix gallica, Borrichia frutescens, Iva frutescens and Distichlis spicata. Along the dike on the northeast side are outcroppings of Sonchus asper, Spartina patens, Tamarix gallica, Borrrichia frutescens, Distichlis spicata, Batis maritima, Elymus virginicus, Avicennia germinans, Lonicera japonica, Lycium carolinianum and Baccharis halimifolia. Scattered plants of Machaeranthera phyllocephala add bright splashes of yellow flowers to the January landscape. Juvenile stands of Baccharis halimifolia are becoming established on the southeast side of the dike across from the large, dense mound of B. halimifolia which gives a dark magenta circular return on the imagery northwest of the end of the dike.

Scattered Borrichia, dense stands of Salicornia spp., Suaeda linearis and Batis maritima are the dominants of northwest Pelican Island. Dumping of trash seem as popular here as drilling for oil. The newer spoil deposits in the center of the island seem to first be invaded by dense stands of Salicornia spp.; then Suaeda spp. dominates before Borrichia, Distichlis, Batis and other of the above-named species move in.

It appears, then, that the presence of ordinary dredge material does not substantially inhibit vegetation, and that the tendency is toward an ultimate sucession to Spartina spp., Distichlis, Baccharis and associated plants. This confirms similar findings in an earlier study [3].

Galveston City

The central commercial and residential section of Galveston boasts numerous plantings of Quercus virginiana (Live Oak), Nerium oleander (Oleander), Cycas revoluta, Sapium sebiferum (Chinese Tallow), Tamarix gallica and many genera and species of palms.

The areas north of the airport runways and east of the channel connecting Offatt Bayou with Lake Madeline were visited. Old plantings of Nerium oleander some 10-15 feet (3-4.5 m) tall border the streets and give a lush appearance to the area. A large dump has been allowed to accumulate in this area, resulting in decreased maintenance and the intermingling of species such as Schizachyrium scoparium var. littoralis, Sorghum halapense, Panicum amarum, Distichlis spicata, Baccharis halimifolia, Cynodon dactylon, Sesbania drummondii, Typha spp. and Hydrocotyle bonariensis with the abandoned junk. North of the east-west runway is a sparse wetland area with some Spartina alterniflora.

Just north of the point where Seawall Boulevard leaves the seawall, pink areas on the December 1977 imagery proved to be heavily grazed fields of Cynodon dactylon, Hydrocotyle bonariensis, Ambrosia psilostachya and Meliotus indicus. The extent of the overgrazing allowed the new winter growth of the above-named plants to appear on the imagery. Most pasture and rangeland areas on the island are grossly overgrazed. Only two large ranches, one off Eightmile Road and bounded on the north by Sweetwater Lake, and one inland from Maggies Cove and north of Termini Road, appear to utilize range management practices of any kind. Even on these ranches, range conditions are poor except for cultivated areas of Oats and Coastal Bermuda. Some pastures are overgrazed to the extent that much bare ground is visible, with grazing even of the small, germinating annual and perennial forbs. Most grazed areas have many cattle in rather small pastures. Although many pastures looked like feedlots because of the large numbers of cattle confined in small areas, only one true feedlot was seen.

In an overgrazed pasture at the end of Sweetwater Lake north of the junction of Stewart Road and Eightmile Road is a good stand of Rosa bracteata, Sesbania drummondii and Croton capitatus, all of which are indicators of the overgrazed condition. Three of four grazed pastures in the area had dense stands of Coastal Bermuda, one intermixed with St. Augustinegrass.

The end of the seawall was photographed on the ground to illustrate erosion at that critical point. No dunes are present at that end of the seawall, although small dunes do occur further down the beach. The distance from the vertical outside seawall to the average high-water mark on 15 March 1978 was 200 feet (60 m). Wave action at the foot of the seawall was observed and photographed on that date. It would appear that waves from winter and spring storms are frequently of sufficient intensity, and from the appropriate direction, to generate longshore currents moving from northeast to southwest. The disassembled bulkheading further down West Beach from the end of the seawall gives mute testimony that such scouring has taken place in the past. Access barriers to the section of the beach immediately west of the seawall have been bypassed and vehicular traffic was, at the time of the study, still obvious along this badly eroded stretch of beach from the end of the seawall to Eightmile Road.

The dark, parallel ground features so prominent on the imagery of this area (see Fugure 4), beginning at the southeasternmost tip of Sweetwater Lake and occurring all the way back to West Bay, are between-the-dune depressions left over from an earlier era when the shoreline was advancing; new dunes successively forming as much as 1200 feet (360 m) seaward of the previous dune line. The depressions between these old dunes are wetter than the dune tops, often with standing water, and thus support wetland vegetation; i.e., vegetation that requires saturated soil conditions for growth and reproduction. This distinctive vegetation, including _Juncus_ spp., _Scirpus_ spp., _Carex_ spp. and _Phragmites australis_, has a definitive signature on the aerial color infrared imagery.

Sportsmans Road at West Bay

These areas of mixed low salt marsh and tidal salt marsh are in relatively good condition. The bay front area has been filled in and houses built on the fill. Portions of the marsh are used for dumping. At the end of Sportsmans Road is an area of new development where shell has been hauled in recently to extend the dry land; small lots here have been marked off with surveyor's stakes. Construction in this location would result in closing off and destroying a valuable wetland resource--the extensive _Spartina alterniflora_ marsh to the east of Sportsmans Road.

Area between Oxen Bayou and Mensell Bayou

The outer _Spartina alterniflora_ wetland is relatively healthy, but numerous cattle trails crisscross the marsh. The herbaceous rangeland behind this wetland has been moderately overgrazed, however, a portion of the rangeland immediately below Oxen Bayou is severely overgrazed. The bright pink return on the September imagery, noted in most of the island's rangelands, is a result of healthy seasonal growth of weedy fall annuals such as _Croton_, _Heterotheca_, _Conyza_, _Eupatorium_, _Astranthium_, _Aster_, etc., the native perennial grasses having been removed by overgrazing.

Eightmile Road South to Bermuda Beach

The area enclosed by Termini Road and Eightmile Road is a fairly typecal mixed rangeland bordered by wetland meadow. A stand of _Tamarix_ occurs near Eightmile Road and _Baccharis_ is scattered through the area. There is a road of sorts extending behind the very small dunes from Eightmile Road to Spanish Grant. These dunes have _Panicum amarum_ as a dominant grass but are otherwise covered with meadow vegetation rather than dune vegetation. Numerous dune-buggy and trail-bike trails and roads crisscross these dunes, ending at the Spanish Grant subdivision where houses have been built virtually on the beach; or, conversely, where the high-water line is approaching the houses. Several houses in the Bermuda Beach subdivision regularly have high tides coming under them. Cattle are grazed between Termini Road and the houses of Bermuda Beach.

Eckert Bayou - Lake Como - Pirate's Cove

Eckert Bayou is one of the few unspoiled bayous left where citizens can fish, boat and enjoy nature. The cutting of a channel into the Bayou from Delehide Cove has, however, introduced a large amount of silt which has covvered some of the oyster beds. Erosion along the banks of this channel is occurring at a rapid rate and will continue to do so until the channel can accomodate the volume of water being moved into and out of the bayou as the tides change. The deposition of spoil from the channel has eliminated some of the wetlands and erosion of the spoil dikes is covering the Spartina alterniflora with sand and silt, causing the demise of large patches of this important wetland grass.

The wooded area on the southwest side of Eckert Bayou is undoubtedly the most beautiful area on the island. Numerous large Quercus virginiana (Live Oak) trees, Celtis laevigata (Hackberry), Morus rubra (Red Mulberry), Nerium oleander, Quercus incana (Bluejack Oak), Catalpa bignonioides (Catalpa), Rosa bracteata, Zanthoxylum fagara, Bumelia lanuginosa and miscellaneous other trees and shrubs occur in this unique area. The large mulberry trees were loaded with big, delicious mulberries in June and the flowering Oleanders and spring annuals coupled with the exotic songs of hundreds of birds made this seem a veritable paradise. It is most unfortunate that this woodland has been designated to become a residential subdivision. To change one factor in this ecosystem, as in any ecosystem, will change many factors. According to the proposed plan of developemnt, of the existing 20.4 acres (8.3 ha) of trees in this area, 15.8 acres (6.4 ha) acres will be destroyed; this is over three quarters of this unique stand.

Several spoil disposal areas have been developed on the northeast side of Pirate's Cove subdivision. These are completely devoid of vegetation in the central regions but with weedy species coming in on the dikes; i.e., Dichanthelium spp., Eragrostis spp., Sporobolus contractus, Heterotheca subaxillaris, Astranthium integrifolium, Ambrosia spp., etc.

Galveston Island State Park

There are some small secondary dunes as well as primary dunes in the State Park. The dunes are dominated by Panicum amarum--with scattered stands of Uniola paniculata--plus Spartina patens, Distichlis spicata, Hydrocotyle bonariensis, Dichanthelium spp. and Ipomea pes-caprae. Behind the dunes are dense stands of Spartina patens, Baccharis halimifolia, Iva frutescens, Hydrocotyle bonariensis, Spartina spartinae, Distichlis spicata, Baptisia sphaerocarpa, B. leucophaea var. laevicaulis, Cynodon dactylon, Stenotaphrum secundatum, Andropogon glomeratus and Sporobolus virginicus. These meadows are extensive and contain numerous shrubs.

Marsh areas around standing pools are diverse in species composition. Dominant forms include Baccharis, Juncus spp., Sesbania drummondii, Zanthoxylum fagara, Tamarix gallica, Sapium sebiferum and Scirpus spp.

The designated marshland in the State Park is in near-pristine condition. All of the classic wetlands species are present in very representative communities. The dominant species include Spartina alterniflora, S. patens, S. spartinae, Sporobolus virginicus, Monanthochloe littoralis, Salicornia spp., Borrichia frutescens, Batis maritima, Scirpus spp., and Juncus spp.

Jamaica Beach to Sea Isle Subdivision

Southwestward from Galveston Island State Park there is a marked contrast between the vegetation on the beach side of Termini Road and that on the Bay side. On the Gulf side there are areas which have been fenced off, apparently grazed at one time, but no longer grazed. Dunes are small and almost nonexistent in places. Panicum amarum is the dominant, as on all dunes of Galveston Island. A few stands of Uniola paniculata are scattered along West Beach. The meadows behind the dunes are covered by lush stands of Spartina patens, Distichlis spicata, Juncus spp. and Scirpus spp.

The rangelands across the road, on the other hand, are practically all overgrazed. There are some pastures along this stretch with Coastal Bermuda and St. Augustinegrass. Some pastures are so overgrazed that what look like healthy, pink returns on the color infrared imagery are actually reflectance from the new green growth or winter bases of weedy annual and perennial forbs rather than new, fertilized growth of pasture grasses. In these severely overgrazed areas the deep-rooted, perennial, soil-binding native grasses such as Spartina spp., Sporobolus virginicus and Distichlis spicata have died of root starvation, allowing shallow-rooted annual and perennial forbs to become established. The native perennials, being the soil binders they are, virtually hold the island together when they are intact. When they are grazed out, these exposed areas become extremely vulnerable to wind, rain and storm erosion. To completely remove grazing pressure from overgrazed areas is, however, no solution. This allows for further invasion of undesirable species. Range management practices should be undertaken at once to allow regrowth of any remaining native perennial grasses. In some areas, such as the big grazed pasture at the end of Galveston Island, overgrazing has completely eliminated the native grasses. In such areas more drastic corrective measures need to be taken. There are no longer any plants there capable of holding the soil during the onslaught of a hurricane of any intensity.

Even though most of the area under discussion here is overgrazed, the wetlands are still in fairly good condition. There has been noted, however, a direct correlation between overgrazing and wetland condition. This is quite evident from the color infrared aerial photography of this rangeland area between Jamaica Beach and Sea Isle and of the rangeland area at the end of the island southwest of Bay Harbor subdivision. The mid-December photography in particular, which is unaffected by the artifact of phototropism, shows quite clearly that densely vegetated meadows and lush adjacent _Spartina alterniflora_ marshes go hand in hand--and that an overgrazed lower meadow will have a sparse intertidal wetland as a neighbor.

Bay Harbor to San Luis Pass

Like the area described above, this area shows a marked contrast in vegetation due to land use and abuse. A short strip of beachfront just southwest of Bay Harbor was mechnically leveled during 1977 and surveyed into residential lots for sale. No real dunes exist from Bay Harbor to the end of the island. Adjacent to this leveled strip is a longer strip of Gulf frontage with good meadow vegetation. A fence separates this grassy area from a badly overgrazed area to the west--the complete absence of dunes or dunelike structures in the latter area make it appear almost to have been mechanically leveled. At any rate, the beach line at the southwest tip of Galveston Island is obviously being eroded at a high rate--this is evident from the sequential aerial photography as well as the ground verification work which was done subsequent to each flight. Erosion along the beach has exposed long, broad strips of the black root systems of _Spartina patens_ which had previously held these low-lying sea-front bluffs together. High-energy waves, such as those generated by the hurricane of early September

1977, tend to undercut completely these low bluffs and to result in the collapse, directly into the surf swash zone, of Spartina patens turf which had been growing at the edge of the bluff. Close-up photographs taken during the ground verification trip immediately subsequent to the September 1977 aerial photography attest to this particular phenomenon. The key problem at the southwest tip of the island is that, with the dune structure now gone, what remains are low bluffs which were actually behind-the-dunes meadows at the time when the dunes were still present. These bluffs are quite low--only about 3 feet (1 m) high--and offer little resistance to either longshore current scour or to direct wave attack. Thus, because the beach cross-section has relatively little relief, for a given volume of beach material eroded away, a significantly higher landward erosion takes place at the west tip of Galveston Island today than would have been the case a few years ago when the dunes were still there. In this latter respect, there seems to be a local understanding that the dunes at the west end were taken away for use as fill material behind the Galveston seawall. Morton [13], on the other hand, states that the limit of such fill "borrow" was 10 to 15 miles from the city of Galveston; i.e., at least 8 miles (13 km) from the southwest tip of the island.

The apparent ongoing rate of erosion will be discussed and illustrated in greater detail further along in this report.

Beach Erosion Factors

As indicated earlier, the original intent of this project was to provide environmental baseline data for Galveston Island. However, because of the strong evidence of extraordinary erosion rates which we uncovered during the course of this study, it would be inappropriate if we did not report these findings. It would seem equally appropriate, then, to preface such discussion with some background on coastal erosion in the western Gulf of Mexico.

Background

Morton [13], in his 1974 study of historical shoreline changes on Galveston Island, states that at the end of the late-Holocene sea level rise there was a period of seaward advance of the island shoreline--and concurrent southwestward movement of the island's southwest tip. At some time subsequent to that beach-building period, probably as a result of climatic change and a reduction in availability of beach mourishment material, a slow and possibly erratic long-term retreat of that shoreline has come about. Mathewson and Minter [10] have postulated the average rate of this retreat--as measured at Sargent Beach, some 35 miles (55 km) southwest of Galveston Island--to be 13 feet (4 m) per year during the latter half of the 19th Century, a rate they labeled the Geologic Recession Rate. They further postulate that the significant increase in the rate of erosion at Sargent Beach since the early 1900's has been man-caused, the result of the building of jetties along the coast, dams along main river tributaries, and flood retention structures in the upper reaches of the watershed.

Mathewson and Minter, who were studying beaches down-drift from the Gulf outlet of the Brazos River, could well discuss the role of dams on the Brazos watershed in reducing sediment availability for those beaches. Morton, on the other hand, whose study concentrated on Galveston Island, points out that the first river updrift from Galveston Island which empties directly into the Gulf is the Mississippi, sand-sized sediments from intervening rivers merely providing for the slow filling of their estuaries. The Mississippi's present delta empties the bulk of the river's sediments over the edge of the continental shelf, however, rather than into the zone of littoral drift. Further, over the past several decades, the Mississippi has been artificially constrained from jumping westward into its now-preferred channel, the present lower drainage of the Atchafalaya River, whose Gulf outlet could once again provide a large and viable sand replenishment source for Gulf beaches to the west.

As indicated by Morton [13], removal of Mississippi sediments from the east-to-west littoral drift pattern has reduced the availability of replenishing sand from that major if not sole source. Consider the fact that little or no sand beach exists between the Mississippi delta and Sabine Pass--and after that the beach is somewhat narrow until one arrives in the vicinity of Bolivar Peninsula. This suggests that the full erosional impact from loss of Mississippi sediments is still working its way westward. After all, a sand particle exiting from the historic Mississippi River outflow into the littoral zone would not have undergone a continuous trip from that point to the shores of Galveston Island. It would have made the move over a very long period of time as a result of a multitude of short, separate jumps, each jump occurring during infrequent periods when longshore currents built up sufficient velocity to pick up and carry a sand particle of that particular size. Thus, because some beach still exists to the east of Galveston Island, there must still be some westward sediment drift toward Galveston, though considerably diminished below what it might be if the Mississippi outflow were once again to be ejected into the zone of littoral drift.

The foregoing obligatory discussion of historic beach accretion, recent erosion patterns, and the present-day erosional bias, while perhaps necessary to a general understanding of what was been happening, is not as important as determining what the present-day erosion rates might be, their proximate causes, and what the short- to mid-term impacts might be. What follows is a discussion of factors germane to some specific erosion problems along Galveston Island beaches.

Findings from the Present Study

The 1977 photography and ground truth work gives evidence that over the millenia preceding this study there was indeed a slow, periodic seaward movement of Galveston Island. Photographic evidence of this has also turned up on other Texas barrier islands [3]. Yet there is even stronger evidence from the imagery that the past decade or so has produced a relatively rapid erosion of the Gulf shoreline of Galveston Island. Possible explanations for this erosion are subsidence and jetty construction.

Subsidence would not seem an important factor. The city of Galveston is at the edge of a subsidence zone centered well in toward Houston. Nevertheless, records from the primary tide gage at Galveston show that there has been an anomalous--in comparison to other Gulf of Mexico tide stations--rise in sea level of 0.55 feet (16.7 cm) over the period 1940-1973 [8]. Even so, the nearshore beach profile averages only a 2-to-3 percent grade along the shoreline toward the southwest end of the island [7,13]; thus, the localized 1940-1973 rise in sea level could only account for about a 20-to-30 foot (6-9 m) landward movement of the shoreline during the entire period. This, as will be discussed later, is far less than the one-year erosion experienced in 1977 alone.

Thus, up-current construction is undoubtedly the major cause of recent accelerated erosion. Longshore currents tend to be cyclical in the study area. Records of the National Weather Service and the Naval Oceanographic Office indicate that surf with a northeasterly component (which could generate a northeast-to-southwest longshore current) is as prevalent as surf with a southwesterly component (which could generate a southwest-to-northeast longshore current). Nevertheless, the general consensus, backed up by the characteristic appearance of the ends of the barrier island systems along this part of the coast, seems to indicate that the net longshore sediment transport is from northeast to southwest. Thus the chief sediment sources are the Mississippi River and the diminishing reservoir of beach sand between the Mississippi and Galveston. As discussed earlier, the shrinking of these sources has considerably reduced the sediment load available for beach nourishment. Further, the North Jetty, acting as a sand trap, has caught a considerable amount of the reduced longshore sediment load which had been headed southwest toward Galveston Island beaches. This latter factor is apparent from comparison of old bathymetric records (Figure 1, for example) with present-day charts. The same records also show a similar buildup of a sand wedge on the south side of the South Jetty (Fig. 2). It must be kept in mind that the latter buildup must almost certainly accrue from the occasional reversal of the usual longshore sediment transport direction--and the source of this sand must almost certainly be Galveston Island itself.

This latter point is worth elaborating on. One can readily infer from Morton [13], although he does not so state, that the southwestward littoral drift swings seaward around the Galveston Channel jetties and circles back to become a northeastward littoral drift along East Beach. While this may be occasionally true for silt-size particles, the drift velocity of such an eddy current would be much too low to carry sand-size particles around the end of the jetty or to scour sand from the shoreline west of East Beach and deposit it along East Beach. Further, a later study by Moherek [12], undertaken during the period February through June 1976, concludes that the net sediment drift direction from the area immediately south of the tip of the South Jetty would be offshore or downcoast, though more probably somewhere between the two directions. Thus, one would tend to conclude that the large store of sand along East Beach would have to have arrived from the southwest. This raises the possibility that the Brazos River may occasionally have nourished Galveston Island in the past--and perhaps still does.

Getting vack to the Galveston jetties, it may be assumed that they form a very effective barrier to the transport of sand-sized particles from northeast to southwest. Southwest-bound longshore currents immediately below the South Jetty are probably minimal because of the shadowing effect of the jetty on sea and swell. It would also seem that northeast-bound currents in that same area are infrequent and/or of low velocity. Examination of the groins along the seawall in all of the 1977 photography (see Fig. 3) shows that the buildup of sand against the groin faces is fairly syemmetrical at all times of the year, as opposed to being unidirectional. It would seem, then, that most of the sand transport in this area would depend on periodic storms.

Southwestward of the end of the seawall (Fig. 4), erosion is readily apparent from the 1977 photography, from older photographic imagery, and from local knowledge. The seawall was built to its present terminus in the late 1960's. At that time the shoreline beyond coincided with the waterline at the face of the seawall. Now, some 10 years later, the shoreline is found to have eroded some 120 feet (37 m) landward of the end of the seawall. It must be emphasized that this is a conservative measurement, taken at a less-than-high-water stage and at the end of the summer's beach-building process rather than at the time of the winter erosional maximum. It may thus be assumed that the 10-year erosion rate at this point was *at least* 12 feet (3.7 m) per year. In fact, as mentioned earlier, the March 1978 ground measurement taken at this point was 200 feet (60 m) from the outer face of the seawall to the high water mark landward from the end of the seawall--indicative of a somewhat greater rate of erosion.

With respect to this study's method of comparative measurement of multidate photography for determining erosion rates, the area adjacent to the end of the seawall is an exception to the rule. Elsewhere, measurements are made with respect to the edge of the vegetation line rather than trying to ascertain the position of the mean water line or the high water line. In an erosional situation, the edge of the vegetation line will almost invariably mark the inshore limit of the most recent erosional event. Further, by using the vegetation line, one avoids ambiguities arising from hourly tidal variations or from seasonal advance or retreat of the high-water line. It is suspected that some of the erosion-accretion anomalies which have turned up in earlier studies [13] could have resulted, in part, from attempts to compare high-water lines on multi-year photography which had been taken at different seasons of the year.

Continuing along the beach southwest from the end of the seawall, the apparent rate of erosion decreases significantly, although ground observation of washed-out bulkheading gives mute testimony of continuing erosion in most areas along West Beach. There are, however, in the stretch of beach between the top of Figure 4 and the lower third of Figure 5, a few anomalous points where the vegetation line is advancing slightly. Comparison of earlier aerial photography with same-season 1977 photography shows areas of beachfront homes where vegetation between the houses has actually migrated seaward. In other portions of this same stretch of beach, a slight, but observable general retreat of the vegetation line is seen. This is especially true in areas of older homes where dunes were apparently bulldozed off so houses could be built on a level surface close to the beach. Ground observation of one of these areas shows that the power lines, which run along the front of the homes, now lie in the wave-swash zone at high tode. Since it is improbable that a local utility would deliberately locate its power poles on the beach, one must conclude that the beach has retreated into the utility easement.

Another sign of beachfront erosion, picked up on the imagery and verified on the ground, is the downdrift impact of bulkheading. In practically every case of bulkheaded or rip-rapped homefronts, the unprotected beach immediately to the southwest is seen to be significantly indented with respect to the general trend of the bluffline in that area.

Southwestward from Figure 5, the more recent relict dunes are seen in the imagery to converge on the present shoreline, an indication that an earlier bowed-out configuration has been eroded away by increasingly higher rates of erosion toward the southwest end of the island.

Note the fenced-off area on the Gulf side of Termini Road in Figure 6; this is seen as a dark area extending upward from left center on the photo. As is the case with all of the west-end beachfront, this area ia being eaten rapidly away. The fence line and bluff area supporting it (seen in the photo to converge on the beach) extended some 1200 feet (360 m) further southwest less than three months before this photograph was taken. This lateral loss of fenceline was accompanied by a 50-foot (15 m) shoreward erosion during that same period and a 100-foot (30-m) shoreward erosion during the March through December 1977 period. Another half mile (800 m) further on, vehicular trails which were 50 feet (15 m) in from the edge of the bluff in March of 1977 had sloughed off into the eroding beach by September.

The greatest rate of erosion is occurring near the toll plaza at the southwest tip of the island. A color aerial photograph taken in January of 1970 (Figure 8) showed the bluff line to lie about 940 feet (285 m) seaward of the toll area. As of December 1977 the bluff line was seen on color infrared imagery (Figure 9) to be only 440 feet (135 m) away. Furthermore,

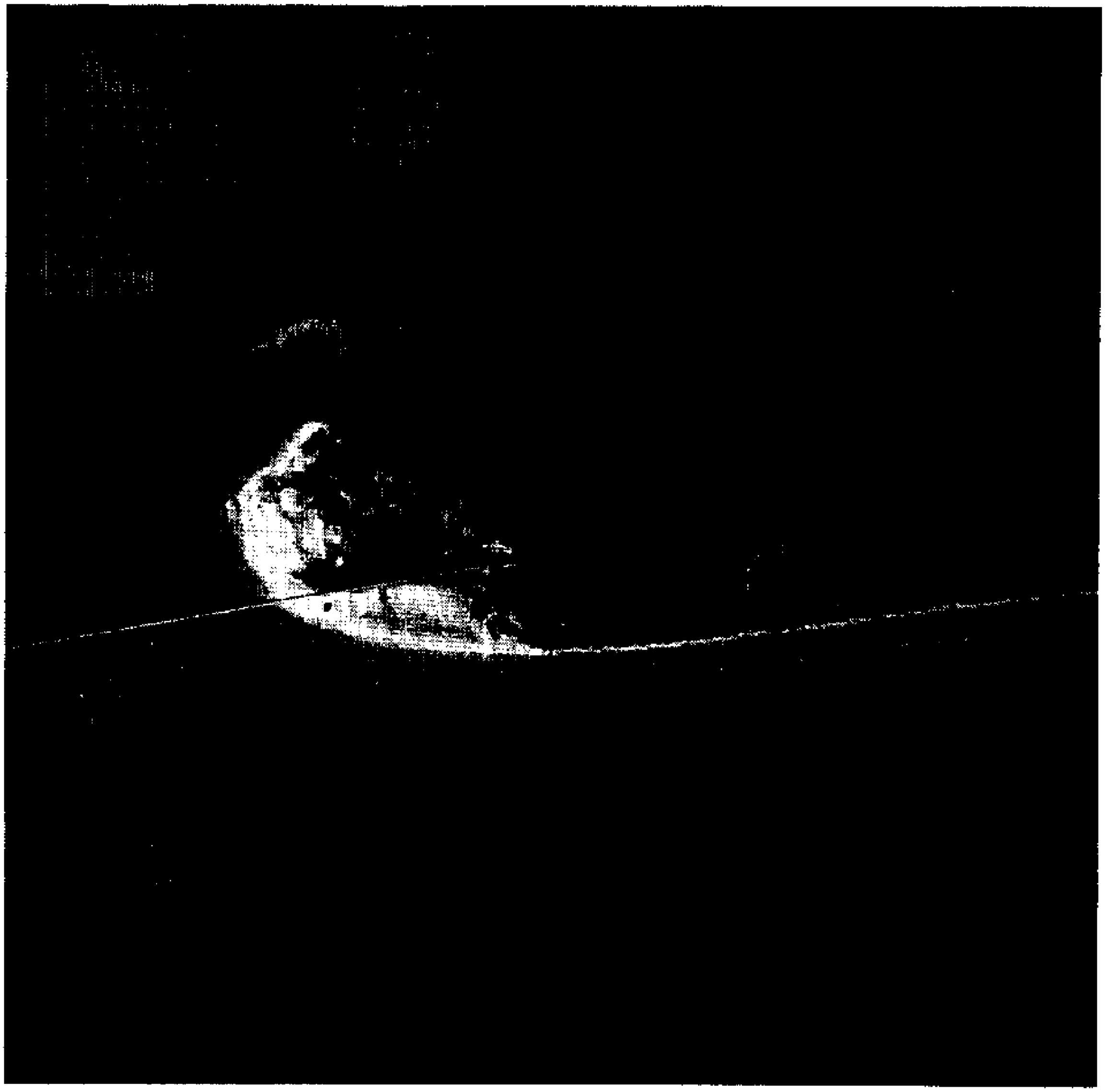

Figure 8. Southwest tip of Galveston Island, January 1970. NASA photograph.

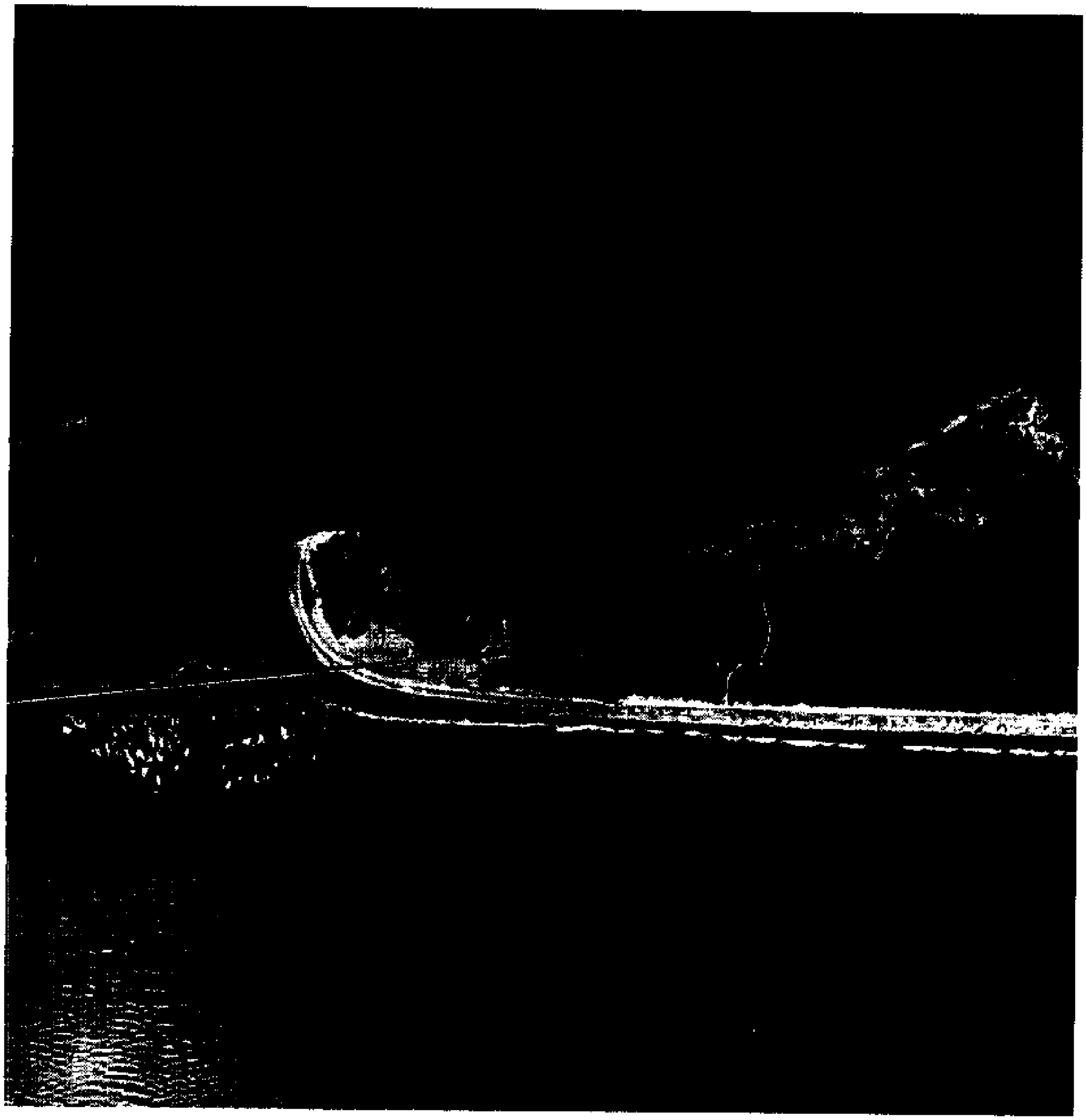

Figure 9. Southwest tip of Galveston Island, 14 December 1977.

100 feet (30 m) of this erosion took place between March and December 1977--50 feet (15 m) of that resulting from the hurricane which crossed the coast of Mexico 120 miles (190 km) south of the Rio Grande on 2 September 1977.

Thus, the average rate of erosion over the eight-year period between January 1970 and December 1977 was over 60 feet (18 m) per year. For those who might wish to make their own measurements, the scale of Figures 8 and 9 is 1:27,000, or 1 inch equals 2250 feet (1 cm = 270 m).

Erosion at the west end is apparently aggravated by vehicular traffic. Earlier erosion patterns, as seen on 1952 black and white photography [7], showed an even, regular bluff line which closely paralleled the waterline. All of the 1977 photography, on the other hand, showed the bluff line to be quite irregular, with auto and motorcycle ruts cutting randomly through the bluff to the beach. Ground truth verified the photoanalysis and also showed that a great deal of picnic trash routinely shows up on the bluffs along with the vehicle ruts. Superimposition of this recreation-based erosion factor on top of longshore current scouring and direct wave attack seems certain to accelerate the rate of loss of beach material.

As indicated earlier, the southwestern end of the island no longer contains a regular dune structure, although there was one at one time (compare, for example, the multiple dune ridges seen in the rather blurred blowup in Figure 8 against the sharp imagery in Figure 9 in which no such ridges are seen). Beginning about 3 miles (5 km) up the beach from San Luis Pass, the beach bluffs are quite low-lying. The bluff frontage, instead of rising toward a dune structure further in, drops gently along what would usually be considered a characteristic behind-the-dunes meadow. In spite of the rapid rate of erosion and the low elevations in this part of the West Beach area, residential development continues apace. These activities are discussed in the next section.

Construction Impacts

In the fall of 1900 Galveston was recovering from a devastating hurricane which destroyed most of the buildings on the island and caused great loss of life. The seawall was built soon thereafter to limit future damage. Most commercial and residential construction during the first several decades of this century took place behind the comforting presence of the seawall. As the seawall was extended southwesterly to its present length of 10 miles (16 km), the city moved along with it. Because people eventually forget, suburban development since the 1950's has taken place beyond the end of the seawall and on lower elevations. Today, as a monument to optimism, a high-rise condominium stands seaward of the seawall on East Beach (the small, dark rectangle just above center on Figure 2 is the shadow of the building).

Low-lying areas are particularly vulnerable to storm tides and storm waves. The 1900 hurricane inundated the city for seven hours and reached a height of 14.5 feet (4.4 m) above mean sea level. Since then, storm tides at Galveston have topped 9 feet (2.7 m) twice and 6 feet (1.8 m) seven times. Tides from Hurricane Carla in September of 1961 reached 9.3 feet (2.8 m) above mean sea level and flooded the entire portion of Galveston Island lying southwest of the city [7]. It is of interest that the largest suburban developments on the island have sprung up in that same area since Carla.

Examination of the 1977 photography shows a continuation of this trend in construction. The development at Lake Como (lower right in Figure 5) had grown during the course of the study year, with new fill appearing at the subtidal marsh boundary. At the upper left in Figure 5 is a new waterfront trailer park which was completed and occupied during 1977. Just off the bottom edge of Figure 6, ten to twelve waterfront dwellings were built during the spring and summer of 1977. In the center of the beachfront area in Figure 6 (the light, rectangular area), around 1400 feet (430 m) of bluff vegetation was bulldozed away during mid-1977 in preparation for additional waterfront construction.

There is a tendency to think of hurricane impact as a function of the concurrent rise in mean water level. Morton [13], however, brings up the effect of hurricane waves breaking near the beach with a substantial amount of their deep-water energy remaining. Since hurricane waves, even within the confines of the Gulf, can in deep water exceed 40 feet (12 m) in height, and can be expected to do so on the average of once every 20 years [13], one must also consider the effect of this level of wave energy being dissipated against whatever mad-made structures might lie in the storm path.

A study of the imagery and a visit to the West Beach building sites clearly shows their terrible vulnerability to storm waves and storm tides. It would seem that the *chutzpah* of the developers and the *caveat emptor* attitude of the lenders is exceeded only by the incredible optimism and short memories of the purchasers.

Facilitation of Mapping

The avialability of seasonal and other-year photography has been of very significant value for providing insights into past and present activities and processes in the coastal zone. From a workaday standpoint, the multi-date photography has considerably expedited the cartographic compilation process as well.

The primary cartographic products from this project are vegetation maps. The optimum photography for delineation and discrimination of plant communities is that taken at the time of maturity, when the image color density is at its greatest and the image texture and color signature are the most characteristic for a given species or species mix. Since barrier island species mature at the higher elevations first and in the submerged areas last, accurate analysis of the condition and extent of the upper, mesic and hydric communities, as well as their accurate delineation, requires seasonal photography [3]. Many questions arising during the early stages of map compilation are readily resolved on arrival of imagery from the next aerial photographic sequence.

CONCLUSIONS

Two distinct barrier island regimes are now being threatened by natural forces and by currently unrestricted human activities. The wetlands system, which includes all of the areas bayward of the dune creast, is being both diminished and stressed by overgrazing and by construction. The beach areas, running from dune top to the shoreline, are under the combined attack of coastal erosion, vehicular traffic and beachfront construction.

Wetlands

It is surprising that an activity as innocuous-seeming as grazing could be harmful to the wetlands habitat. However, where grazing occurs, the possibility of overgrazing must exist. Given a plant cover dominated by the stabilizing natural grasses, continuous over-utilization reduces leaf area and results in root starvation. Thus, these deep-rooted perennial grasses eventually die, to be replaced by shallow-rooted annual grasses and forbs. Further heavy grazing pressure can denude the soil, allowing wind and water erosion of the topsoil. Many of these things have already happened. Grazing in wetlands areas should, therefore, be carefully managed so as not to destroy the deep-rooted perennial grasses which, in essence, hold the island together.

From an ecological standpoint, overgrazing of the island meadows significantly decreases the flow of detrital nutrients into the lower wetlands where primary productivity of algae and the emersed and submersed plants is essential for the continuation of the first trophic level of the food chain.

The relative diminution of those wetlands lying below overgrazed meadows is quite visible in the 1977 imagery.

Galveston Island State Park is an area in which grazing at one time was going on. Its present excellent condition, in both the meadow and lower wetlands, shows that detrimental effects of grazing are reversible.

The impact of housing construction in the wetlands is, of course, quite obvious; the wetlands simply vanish. For every piece of bay frontage that is thus developed, that much productive wetland is lost. It is doubtful that there is an ecologically correct method of developing barrier island wetlands. Even if such construction were limited to the meadows, possibly with narrow, dredged channels leading to the bay--and at least one of the newer developments seems to be taking this tack--loss of the meadow would in itself substantially affect the viability of the emersed and submersed wetlands adjacent.

Island Beaches

The conditions which have brought about the ongoing shoreline accretion at the northeast end of the island and continuing erosion along the southwestern shoreline are not readily modified. Increase in the sand wedge at East Beach (Figure 2) and decrease in beach frontage at the end of West Beach (Figures 6, 7, 8 and 9) will undoubtedly continue until a new equilibrium shoreline establishes itself. Added sand at East Beach is no great envirnomental threat. The key problem is erosion along the southwest 60 percent of Galveston Island, most particularly near the southwest tip. Barring initiation of a modifying artifact such as artificial beach replenishment, one could look to the dune and bluff vegetation as the primary means of limiting the rate of erosion. Unlimited access to the beach, dune and bluff areas is a recreational luxury which can no longer be tolerated on Galveston Island--and by mid-1978 the local government had taken steps to limit such access (see Epilogue). In the absence of the previous unrestricted traffic on the bluffs, as well as that from the bluffs to the beach, a fair amount of natural, beneficial revegetation should now take place.

Purchase of a beachfront home in a low-lying, high-risk area is a chancy business, but an individual decision. However, when the beachfront development process brings about the depletion or loss of the deep-rooted perennial grasses which stabilize the dunes, a private activity becomes a public concern. It would seem, then, that consideration might be given to the protection of dune and bluff vegetation, and that this might be achieved by restricting both the public and private use of still-undeveloped beachfront. To do otherwise would simply hasten the day of its eventual loss.

Study Procedures

This project was not only a study of the processes and activities affecting Galveston Island; it was also a test of, and a cost model for, the concept of sequential photography as a better way of doing coastal zone mapping and monitoring. The method's advantages have already been discussed in fair detail. The manager and the mapper of the coastal zone are much better off with mutli-date imagery showing coastal condition, processes and activities than they would be with photography from a single overflight. The remaining consideration is cost.

A project of this magnitude takes a year or more to bring off, whether multi-date photography is obtained or not. A great deal of seasonal field work must still be done in order to arrive at definitive results. However, with photography, less field work is actually required per field trip. The added cost for this project, at most, has been simply the cost of the three additional flights, inclusive of additional film and processing. Based on actual 1977 expenditures, these combined costs add up to only six percent of the total project funding.

EPILOGUE

A somewhat condensed and less accurate version of this Final Report, written as a paper for a March 1978 professional society symposium, was presented to Galveston officials at separate meetings in February and April of 1978. Events what have transpired subsequent to those presentations seem worthy of mention.

The "Benton Report" and the Coastal Society Report

In mid-1977, well before any of the study's more interesting findings had turned up, an abstract for a paper on the Galveston project was accepted by the American Society of Civil Engineers for presentation at its Coastal Zone '78 symposium in March 1978. The final paper [4], completed in December 1977, contained a number of early conclusions on beach erosion and on the apparent environmental impacts of such disparate activities as housing construction, grazing and vehicular traffic to and from the beach. The paper was presented to the Galveston Marine Affairs Council in February 1978 and to a rather larger general audience of interested Galvestonians in April 1978. Local reaction to the paper was so strong, and it became so widely read, that it picked up the *sobriquet* "Benton Report" instead of its more staid title "Seasonal Aerial Photogtrahic Mapping of Galveston Island."

General response was quite mixed. Local people who had read or heard of the report seemed to be either in strong agreement or strong disagreement with its various findings. Few, apparently, were taking a neutral stand. The hue and cry over what would normally have remained an obscure academic paper prompted yet another paper, this one on the public reaction to the first paper. In October of 1978 one of the authors of the "Benton Report" presented the follow-up paper at the Coastal Society's annual meeting in Toronto [5]. Interestingly enough, an entire session had been given over to the phenomenon of local civic response to reports containing unnerving environmental news in the coastal zone. At best, this is indicative of increasing grass-roots interest in environmental concerns--at worst, one recalls the old days when they used to kill the bearer of bad tidings.

The Coastal Society paper [5] chronicled in some detail the variety of reactions to the "Benton Report". The following section contains quotes and condensations of the Coastal Society paper's content.

Vehicle Ban

Just two days after viewing a presentation of the "Benton Report", in which accelerated bluff erosion in vehicle-access areas of West Beach was contrasted with the advancing vegetation line in a barricaded area of East Beach, the Galveston City Council announced an ordinance which would limit vehicular traffic on West Beach. This was a subject which had been under consideration for some time, but the "Benton Report" may well have provided the impetus for action. Announcement of the ban had a number of repercussions because Texas has had an open beach law for some twenty years which guarantees free ingress and egress to all space between the vegetation line and the water line. Television talk shows picked up on the subject, public forums were held, state senators made speeches, debates were held before the City Council, and people on the beach were interviewed for news reports [5].

The ban, which went into effect on 21 June 1978, is a seasonal one which is lifted during the winter months. The City of Galveston has provided twelve vehicle access routes to the beach from the beachfront road and has also provided over 6000 off-street parking places, a third of which were free. Many public and privately owned parking lots charge a fee of a dollar a car. A group of West Beach property owners, concerned that the concentration of cars directly in front of their homes would create unsightly and hazardous conditions, took the law into their own hands and barricaded a beach access road. After talking with the mayor and city planning director, a property-owners' association withdrew their earlier support of the barricading. However, official barricades, in the form of rows of posts with chained openings, were placed across newly banned access roads to the beach. Some of these were promptly dismantled by disgruntled beach-goers who continued to disregard the ordinance. [5]

Overgrazing

Reaction to the "Benton Report's" discussion of overgrazing problems was limited. One of the persons involved in dairying on the island wrote a very lengthy letter, read at a Galveston public forum on wetlands management, which advanced the novel theory that the grazing of cattle is actually beneficial to the land because of the fertilizer produced by running the grass through the animals. Several more-serious-minded landowners in overgrazed areas have requested information from the study team on their land erosion problems. [5]

Shoreline Erosion

On 26 June 1978, at the request of the Galveston Marine Affairs Council, Col. Jon C. Vanden Bosch, District Engineer, Galveston District, U. S. Army Corps of Engineers, presented the Corps' position on shoreline erosion. The Council considered it important to hear the Corps' view in light of the information developed in the Benton study. On 13 July 1978 the office of the director of planning for the City of Galveston forwarded to the Galveston Marine Affairs Council a critique of what it termed the "Benton Beach Erosion Report." In its memorandum, it was clear that the planning office had serious reservations concerning the accuracy of the erosion estimates in that study. [5]

Residential Construction

Construction of single-family dwellings continued in the West Beach area in 1978 with increased activity in spring and summer. Although relatively little response had arisen from builders concerning the "Benton Report" and its allegations about building practices on the island, data from the report was used in a court suit involving a proposed subdivision addition in the Lake Como area. The proposed development would require extensive dredging and filling in a 190-acre (73-ha) tract adjacent to a large natural inlet and would destroy a naturally forested area as well as a significant acreage of Spartina alterniflora wetlands. A Houston attorney who also happened to be a Galveston resident took it upon himself to try to block the permit for the development until such time that a full environmental impact study had been made. [5]

On 5 September 1978, Civil Action G-78-188 was begun in the Galveston Division of the United States District Court, naming both the developer and the Corps of Engineers (which had issued an earlier permit for development in this same area) as defendants. The thrust of the hearing was to seek a declaration by the Court that the granting, by the Corps of Engineers to the developer, of a permit to dredge a connecting canal, loop canals and finger canals, and to erect piers, bulkheads and boat-launching ramps in Eckert Bayou, was in violation of the law. After many days of testimony--which included a good deal of data from this study--the judge interrupted the examination of one of the witnesses in order to enter a preliminary injunction. The Court found that "irreversible and irretrievable damage" had been done by the dredging of an existing canal which, he stated, was improperly designed. The Court also enjoined the developer from (1) moving any heavy equipment of any kind, in, around, or on the proposed subdivision, and (2) cutting any trees or shrubs, even for surveying purposes. He further ordered that the hearing would be recessed until a later date, at which time the final hearing would be on the merits of the case. The manner in which the case is finally settled will quite likely have a good deal of influence on future development of the west end of Galveston Island. [5]

Galveston City Planning Office Report

On 16 November 1978 it was reported in the Houston Post that the City of Galveston's planning office had undertaken its own study and determined that erosion rates near San Luis Pass are only 20 feet (6 m) per year. The authors of this Final Report have not seen the planning office study, but according to the Post's article the study stated that "if the maximum rates of erosion continue, the main east-west road on the west end could be washed away and the eastern base of the San Luis Pass Bridge at the extreme west end of the island could be threatened within the next 20 years."

The authors of this Report concur with this reported statement, but with the proviso that the approach to the San Luis Pass bridge will be threatened *well within* that 20-year time frame. The imagery shown in Figures 8 and 9 gives clear evidence of an eight-year average erosion rate of 60 feet (16 m) per year at the San Luis Pass bridge approach. The seasonal imagery from the 1977 study, augmented by additional photography from flights of March and May of 1978, shows that the full-year 1977 rate was quite close to the eight-year average--discounting the single-event impact of Hurricane Anita in early September 1977. Analysis of tropical storm records between January 1970 and December 1977, and comparison with pre-1970 records, shows that the eight-year period is rather typical in terms of wave impact at Galveston.

December 1978 photography, flown just as this report was being finished, shows continued loss at the bridge approach during 1978 (a relatively quiet year) from 440 feet (135 m) down to 400 feet (122 m). One can, then, conclude that loss of the remaining 400 feet (122 m) of intervening bluff between bridge approach and beach could well occur within seven years.

Given the urgency of the situation, and considering the unavoidable time lag between decision and action, a decision on the specific problem of the bridge approach must come soon. Time is running out.

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APPENDIX

DOMINANT PLANT SPECIES

Ambrosia psilostachya DC.	Western Ragweed
Ambrosia spp.	Ragweed
Andropogon glomeratus (Walt.) B.S.P.	Bushy Beardgrass
Andropogon virginicus L.	Broomsedge Bluestem
Aster spinosus Benth.	Devilweed
Aster spp.	Aster
Astranthium integrifolium (Michx.) Nutt. var. trifolium (Raf.) Shinners	Western Daisy
Avicennia germinans (L.) Stern.	Blackmangrove
Baccharis halimifolia L.	Eastern Baccharis
Baptisia leucophaea Nutt. var. var. laevicaulis Canby	Plains Wildindigo
Baptisia sphaerocarpa Nutt.	Roundfruit Wildindigo
Batis maritima L.	Maritime Saltwort
Borrichia frutescens (L.) DC.	Bushy Sea-oxeye
Bumelia lanuginosa (Michx.) Pers.	Bumelia
Cacalia lanceolata Nutt.	Lanceleaf Indianplantain
Cakile fusiformis Green	Sea Rocket
Carex spp.	Sedge
Catalpa bignonioides Walt.	Common Catalpa
Celtis laevigata Willd.	Hackberry
Conyza canadensis (L.) Cronq.	Horseweed
Croton punctatus Jacq.	Gulf Croton
Cycas revoluta	
Cynodon dactylon (L.) Pers.	Bermudagrass
Dichanthelium spp.	Dichanthelium
Distichlis spicata (L.) Green	Saltgrass
Eleocharis spp.	Spikesedge
Elymus virginicus L.	Virginia Wildrye
Eragrostis spp.	Lovegrass
Eupatorium compositifolium Walt.	Yankeeweed
Fimbristylis castanea (Michx.) Vahl.	Fimbry
Halodule beaudettei (den Hartog) den Hartog	Halodule

Helianthus annuus L.	Common Sunflower
Heterotheca subaxillaris (Lam.) Britt. & Rusby	Camphor Weed
Hydrocotyle bonariensis Lam.	Largeleaf Pennywort
Ipomoea pes-caprae (L.) Sweet	Soilbind Morningglory
Iva frutescens L.	Bigleaf Sumpweed
Juncus spp.	Rush
Lantana horrida K.B.K.	Common Lantana
Lonicera japonica Thunb.	Japanese Honeysuckle
Lycium carolinianum Walt.	Carolina Wolfberry
Machaeranthera phyllocephala (DC) Shinners	Machaeranthera
Medicago hispida Gaertn.	Burclover
Melilotus indicus (L.) All.	Annual Yellow Sweetclover
Melilotus sp.	Sweetclover
Monanthocloe littoralis Engelm.	Shoregrass
Morus rubra L.	Red Mulberry
Nerium oleander L.	Common Oleander
Opuntia lindheimeri Engelm.	Texas Pricklypear
Opuntia stricta Haw	Erect Pricklypear
Panicum amarum Ell.	Bitter Panicum
Panicum repens L.	Porpedograss
Phragmites australis (Cav.) Trin. ex. Steud.	Common Reed
Quercus incana Bartr.	Bluejack Oak
Quercus virginiana Mill.	Live Oak
Rosa bracteata Wendl.	Mccartney Rose
Ruppia maritima L.	Widgeongrass
Rynchospora spp.	Beakrush
Salicornia bigelovii Torr.	Bigelow Glasswort
Salicornia virginica L.	Virginia Glasswort
Sapium sebiferum (L.) Roxb.	Chinese Tallow
Schizachyrium scoparium (Michx.) Nash var. littoralis (Nash) Gould	Seacoast Bluestem
Scirpus americanus Pers.	American Bulrush
Scirpus spp.	Sedge
Scleria spp.	Nutrush

Sesbania drummondii (Rydb.) Cory	Rattlebush
Sesbania vesicaria (Jacq.) Ell.	Bagpod Sesbania
Sesuvium portulacastrum L.	Sea Purslane
Solidago sp.	Goldenrod
Sonchus asper (L.) Hill	Prickly Sowthistle
Sorghum halapense (L.) Pers.	Johnsongrass
Spartina alterniflora Loisel.	Smooth Cordgrass
Spartina patens (Ait.) Muhl.	Marshhay Cordgrass
Spartina spartinae (Trin.) Merr.	Gulf Cordgrass
Sporobolus contractus Hitchc.	Spike Dropseed
Sporobolus virginicus (L.) Kunth.	Seashore Dropseed
Stenotaphrum secondatum (Walt.) Kuntze	St. Augustinegrass
Suaeda linearis (Ell.) Moq.	Annual Seepweed
Tamarix gallica L.	Saltcedar
Typha domingensis Pers.	Narrowleaf Cattail
Typha latifolia L.	Common Cattail
Uniola paniculata L.	Seaoats
Zanthoxylum fagara (L.) Sarg.	Lime Pricklyash
Zizaniopsis miliacea (Michx.) Doell & Aschers	Marshmillet