Decline of Submerged Vegetation in the Galveston Bay System: Chronology and Relationships to Physical Processes

Warren M. Pulich* and William A. White*

'Texas Parks and Wildlife
Department
4200 Smith School Road
Austin, TX 78744, U.S.A.

'Bureau of Economic Geology
University of Texas at Austin
University Station, Box X
Austin, TX 78713, U.S.A.

ABSTRACT


Changes in submerged vascular plant distribution since the 1950's were documented for the Galveston Bay system (excluding the Trinity River delta proper) using aerial photographs and substantiated field reports. Two major regions where seagrasses have declined extensively were compared with nearby sites where vegetation persists. Along the upper bay shoreline, evidence is presented for involvement of Hurricane Carla (1961) and a relative rise in sea level due to subsidence, which resulted in the disappearance of Ruppia maritima beds between 1960 and 1962. In the lower bay (West Bay), mixed beds of R. maritima and Halodule wrightii declined steadily from the 1950's and disappeared by the early 1980's. This area contrasts with Christmas Bay, a secondary protected bay 5 to 7 km south that still contains extensive beds of H. wrightii and small patches of Thalassia testudinum and Halophila engelmannii. In West Bay, urban development, wastewater discharges, chemical spills, and dredging activities, rather than subsidence and Hurricane Carla, are suspected as the principal deleterious agents. Similarities between submerged vegetation declines in Galveston and other bay systems are discussed.

ADDITIONAL INDEX WORDS: Erosion, Galveston Bay, habitat loss, hurricane Carla, seagrasses, submerged vegetation, subsidence, water quality.

INTRODUCTION

The Galveston Bay system of Texas ranks as the 7th largest estuary in the USA, with 143,000 ha (about 354,000 acres) of open water (DIENER, 1975) and about 48,000 ha (about 118,000 acres) of marshes and swamps (FISHER et al., 1972). These habitats support finfish and shellfish populations which annually account for 28 percent of the total Texas commercial bay fisheries landings, 67 percent of the Texas oyster harvest, and 30 percent of blue crab and shrimp harvests (NOAA, 1989). This production is sustained by a combination of high freshwater inflows from the Trinity-San Jacinto Rivers, nutrient cycling dynamics of bay wetlands, and nursery grounds afforded by shallow-water habitats. Despite this resource value, Galveston Bay has been heavily impacted by shoreline industrial and municipal development, discharge of pollutants and wastewater effluents, channelization and dredging projects, subsidence, and alterations in bay-water circulation dynamics.

In 1956, there were approximately 2,070 ha (5,120 acres) of open bay submerged vascular vegetation (SV) in the Galveston Bay system (FISHER et al., 1972). The loss of most SV by 1979 (WHITE et al., 1985) represents an alarming degree of environmental degradation. This disappearance of valuable fisheries habitat has received widespread attention with the recent designation of Galveston Bay as a national estuary by the EPA National Estuary Program (NOAA, 1989). Program scientists have recommended analysis of critical factors threatening estuarine habitats in order to design restoration procedures and projects for impacted SV areas. The first step in formulating resource management policies, however, is a historical analysis of changes in SV habitat in relation to physical changes in the bay environment.

90119 received 28 September 1990; accepted in revision 21 March 1991.
This paper examines the regions of Galveston Bay (excluding the Trinity River delta) where submerged halophytes have declined since the 1950's and compares them with nearby sites where plants persist. After the SV distribution at different time periods was mapped, physical and hydrographic factors that could affect distribution and abundance of rooted estuarine plants were analyzed in an attempt to establish the processes contributing to impacts on SV habitats.

**MATERIALS AND METHODS**

**Study Sites**

Extant locations of SV, with a minimum of 0.05 ha (0.125 acre), were determined for the Galveston Bay system using November 1987 NASA-Ames color-IR aerial photographs, scale 1:65,000, and corroborated by field surveys in 1988–89. Submerged vegetation was delineated in two regions of the Bay (Figure 1): (1) *Ruppia maritima* L. along the northern and eastern shores of the upper bay (Trinity Bay), and (2) seagrasses in the Christmas-Drum Bay area of the lower bay system. This late 1980's distribution contrasts with the 1956 occurrences at nearby locations in the upper bay along the Clear Lake-Seabrook shoreline, and in lower West Bay along the Galveston Island shoreline (Figure 1). Former occurrence of SV in these areas was established from project reports of Texas Parks and Wildlife Department (TPWD) biologists, interviews with knowledgeable field biologists and fishermen, and review of archived aerial photographs.

**HISTORICAL ANALYSIS**

This investigation documented the chronology of SV decline from the mid-1950's. Submerged vegetation acreage was mapped at a scale of 1:24,000 on USGS quadrangle sheets. Changes in SV acreage were calculated from 1:24,000 base map overlays for the years 1956 and 1962 for Seabrook in upper Trinity Bay, for the years 1956, 1965, 1975, and 1987 in lower West Bay, and for 1975 and 1987 in Christmas Bay. Disturbance features, e.g. residential developments, dredged channels, boat marinas, etc., were also mapped in portions of West Bay. The sources of historical photographs were: 1956, black and white photomosaics from Edger Tobin Aerial Surveys, San Antonio, Texas; 1962 and 1965, black and white photographs from the US Coast and Geodetic Survey; and 1975, color-IR photographs from NASA-JSC.

**PHYSICAL FACTORS**

Historic data on the following physical/hydrographic processes were compiled and analyzed for the defined SV sites: shoreline erosion and relative sea-level rise associated with subsidence; hurricane and other climatic events; physical alterations related to channel dredging and onshore developments; and degradation in selected water quality conditions. Various Texas state agency data bases were examined: Bureau of Economic Geology (BEG) coastal erosion data (PAINE and MORTON, 1986); TPWD fish kill/pollution monitoring reports (Resource Protection Division, Austin, Texas); TPWD water quality monitoring data (Fisheries Division, Austin, Texas); and Texas Water Commission (TWC, Austin, Texas) wastewater discharge permits and water quality monitoring network databases. Statistical analysis was performed using Sigma Plot Software (Jandel Scientific, Corte Madera, California).

**RESULTS**

**Changes in Submerged Vegetation Distribution**

**Upper Galveston Bay (Galveston and Trinity Bays)**

SV distribution along the Trinity Bay shoreline in 1987 (exclusive of the Trinity River delta proper) is compared with that in 1956 for the Seabrook shoreline on the west side of the bay in Figure 1. *Ruppia maritima* has been the only species to occur at these sites. The areal extent of *R. maritima* in the Seabrook area in 1956 and east Trinity Bay in 1987 is compared in Table 1.

Aerial photographs taken in 1956 show that submerged vegetation in the Seabrook area occurred in a shore-parallel belt about 0.3 km (0.12 mi) wide and approximately 86 ha (212 acres) in total area. The extent of submerged vegetation in 1956 may have been partly related to climatic factors. The most extreme
decline of submerged vegetation in Galveston Bay

EXPLANATION

1956 submerged vegetation
1987 submerged vegetation
Wastewater discharge site

Figure 1. Map of the Galveston Bay system comparing 1956 and 1987 locations of submerged vegetation. Wastewater discharge sites compiled from 1988 records in Texas Water Commission permits section.

Table 1. Areal extent of submerged vegetation in selected regions of the Galveston Bay system, 1956 to 1987. (N.D. = no data)

<table>
<thead>
<tr>
<th>Region</th>
<th>1956</th>
<th>1965</th>
<th>1975</th>
<th>1987</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinity Bay (East Shore)</td>
<td>N.D.</td>
<td>N.D.</td>
<td>N.D.</td>
<td>60</td>
</tr>
<tr>
<td>Galveston Bay (Seabrook Shore)</td>
<td>86</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>West Bay (Western Half)</td>
<td>458</td>
<td>117</td>
<td>37</td>
<td>0</td>
</tr>
<tr>
<td>Christmas Bay</td>
<td>N.D.</td>
<td>N.D.</td>
<td>97</td>
<td>77</td>
</tr>
</tbody>
</table>

drought in recorded history occurred in Texas in the 1950's and climaxed in 1956 (Riggo et al., 1987). Tide gauge records at Galveston reflected the drought, which produced lower average sea-levels. Furthermore, reduced streamflow and runoff from coastal upland areas during the drought probably resulted in lower turbidities. These conditions may have allowed submerged vegetation to reach maximum distribution in 1956.

Subsequently, TPWD biologists documented the chronology of Ruppia maritima decline and disappearance in the Seabrook area (Renfro, 1959; Pullen, 1960, 1961). Pullen (1961) observed variations in R. maritima and salt-marsh abundance between 1959–1961, and specifically effects of Hurricane Carla in 1961. He noted extensive damage from the hurricane to SV on both sides of the upper bay. Grassbeds on the east shore appeared washed over and buried by mud from surrounding spoil banks, while Seabrook grasses were extensively uprooted and washed ashore as wrack. Physical destruction along the Seabrook shoreline was confirmed from conversations with TPWD personnel, Charles Wilkes and Robert Hofstetter, who worked in Seabrook during the late 1950's, and

early 1960's. Both sources stated that all SV in the Seabrook area disappeared by the winter of 1961 and did not return in 1962. Hofstetter felt that turbidity and water quality factors may have contributed to the inability of the SV to reestablish in 1962. PULLEN (1961) specifically suggested that turbidity may have been higher on the Seabrook side of the bay compared to the east side. However, no quantitative turbidity or water clarity data could be located for this time period for inclusion in our analysis. Submerged vegetation on the east side of the bay recovered, as documented in later (e.g. 1987) photographs.

**Lower Galveston Bay (West Bay and Christmas Bay)**

The Lower Bay has typically polyhaline waters (salinity range 15–32 ppt) and has historically supported beds of true seagrasses. As of the 1987 survey date, major seagrass beds were no longer present in West Bay; Christmas Bay contained the only significant SV habitat (Figure 1). *Halodule wrightii* Ascherson (Shoalgrass) had been the dominant species (by percent cover) in West Bay and remains so in Christmas Bay. West Bay also had significant amounts of *Ruppia maritima* and *Thalassia testudinum* L. (Turtle grass). Substantial amounts of *R. maritima* during spring months, *Halodule wrightii* and a few small patches (about 0.1 ha or 0.25 acre) of *T. testudinum* still occur in Christmas Bay. Seagrass acreage in Christmas Bay during the fall season of 1975 and 1987 is shown in Table 1, with 100 ha (240 acres) in 1975 compared to 79 ha (190 acres) in 1987.

Analysis of aerial photographs from 1956, 1965, 1975, and 1987 substantiates the progression of seagrass loss for West Bay (Figure 2). Reports by WEST (1973), GILMORE and TRENT (1974) and area scientists (Sammy Ray, Texas A&M University at Galveston; Kirk Strawn, Texas A&M University; Roger Zimmerman, National Marine Fisheries Service, Galveston; personal communications) further corroborate the occurrence and decline of *Halodule wrightii* and *Thalassia testudinum* from West Bay. After a dramatic decrease in seagrasses from approximately 458 to 125 ha (1,100 to 300 acres) between 1956 and 1965, the remainder of the reduction appears to have occurred gradually (Figure 2). Final disappearance of these major grassbeds from West Bay probably occurred between 1982 and 1985.

**Impacts of Physical Processes on Submerged Vegetation**

**Upper Galveston Bay (Galveston and Trinity Bays)**

The loss of SV in the Seabrook area was correlated with several interactive processes and events, including subsidence, shoreline erosion, and Hurricane Carla.

**Subsidence.** Land-surface subsidence, due primarily to the withdrawal of large amounts of groundwater, has been an ongoing process in the Houston area over the past several decades (GABRYSch, 1984). A map prepared by GABRYSch and Bonnet (1975) shows that a relatively large subsidence bowl, with a center of maximum subsidence located east of Houston, encompasses much of upper Galveston Bay (Figure 3). Between 1943 and 1978, land-surface subsidence reached a magnitude of almost 3 m (10 ft) (GABRYSch, 1984). The amount of subsidence decreases away from upper Galveston Bay toward the lower bay.

The SV area affected most by subsidence is on the west side of Galveston Bay near Seabrook (Figure 3). Historical trends in subsidence in the Seabrook area indicate that rates increased after 1943 and reached a maximum of about 6 cm/yr (2.4 inches/yr) for the period 1964–1973 (Figure 4). Subsidence in the Seabrook area between 1943 and 1973 was approximately 0.9 m (3 ft), and from 1943 to 1978 it exceeded 1.2 m (3.9 ft) (GABRYSch, 1984). Water depths near shore possibly increased 30 to 60 cm (1 to 2 ft) between 1968 and 1977 (MORTon and MCgowen, 1980). The amount of subsidence in other SV areas has been considerably lower than in the Seabrook area, ranging from less than 0.5 m (1.6 ft) in upper Trinity Bay and 0.4 m (1.3 ft) in West Bay, to 0.2 m (0.7 ft) in Christmas Bay for the period 1943 to 1973 (Figure 3). During the period 1943 to 1978, subsidence in these areas was less than 0.3 m (0.1 ft) (GABRYSch, 1984).

**Erosion.** The western margin of upper Galveston Bay is characterized by increasing rates of erosion since the mid-1800's (PAINE and MOR-
The Galveston Bay shoreline (which includes Seabrook) is one of two areas (the other being West Bay) where a significant increase in the rate of erosion occurred during the more recent period. Average rates increased from 0.67 to 1.32 m (2.2 to 4.4 ft/yr). Shorelines in other areas of the upper bay, however, eroded at a slower rate (east and west Trinity Bay) or accreted (Trinity delta) (Table 2).

Hurricane Carla. On September 11, 1961, Hurricane Carla, one of the greatest storms in this century (USACE, 1962), made landfall along the Texas coast 200 km (120 mi) southwest of Galveston. Surge heights reached 4.3 m (14.2 ft) at Clear Lake in the Seabrook area (USACE, 1962). Winds in the Galveston Bay system during the Hurricane were primarily from (1) the east with average speeds at 82 km/hr (51 mi/hr), and (2) the southeast with peak gusts reaching 180 km/hr (112 mi/hr) (USACE, 1962). These wind directions, aided by a fetch across the Galveston-Trinity Bay system of approximately 25 km (15 mi), would generate waves and currents having their greatest impact on the western shoreline of Galveston Bay including the Seabrook area. Bulkheads and other erosion control measures along the shoreline may have intensified the erosive effect in nearshore areas by reflecting much of the wave energy (MORTON, 1988).

The impact of Hurricane Carla on submerged vegetation in the Seabrook area was pro-
SV to become re-established in the Seabrook area after Hurricane Carla is probably due in large part to human-induced subsidence, which along with shoreline erosion and associated shoreline development, had substantially modified the morphology of the bay-margin environments in the Seabrook area. Across Trinity Bay, along the eastern shore, the impact of Hurricane Carla on submerged vegetation was less severe because hurricane winds were offshore rather than onshore. Also, SV had not been affected by subsidence so recovery after the storm was not as severe a problem as in the Seabrook area.

Lower Bay (West Bay and Christmas Bay)

Although subsidence, erosion, and Hurricane Carla may have contributed to the loss of sub-
Decline of Submerged Vegetation in Galveston Bay

Table 2. Average rates of shoreline change in the Galveston Bay system, 1850-52 to 1982. (From Paine and Morton, 1986).

<table>
<thead>
<tr>
<th></th>
<th>1850-52 to 1930 (Historical)</th>
<th>1930 to 1982 (Recent)</th>
<th>Ratio of Erosion Rates (Recent/Historical)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of stations</td>
<td>Rate (ft/yr)</td>
<td>No. of stations</td>
</tr>
<tr>
<td>Trinity Bay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Trinity Bay</td>
<td>26</td>
<td>-3</td>
<td>25</td>
</tr>
<tr>
<td>Trinity delta</td>
<td>10</td>
<td>3.9</td>
<td>9</td>
</tr>
<tr>
<td>W. Trinity Bay</td>
<td>21</td>
<td>-2.6</td>
<td>20</td>
</tr>
<tr>
<td>Galveston Bay</td>
<td>57</td>
<td>-2.2</td>
<td>55</td>
</tr>
<tr>
<td>West Bay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galveston Is.</td>
<td>34</td>
<td>-0.8</td>
<td>40</td>
</tr>
<tr>
<td>Christmas Bay area</td>
<td>30</td>
<td>-1.3</td>
<td>29</td>
</tr>
</tbody>
</table>

merged vegetation in West Bay, impact from another major factor was more pronounced—that of waterfront development along the bay margin of Galveston Island.

**Subsidence.** The significance of sea-level rise in the 1960's and 1970's due to subsidence was examined by reviewing Figure 3. The north end of Galveston Island showed only a moderate decrease in elevation since 1943 (Figure 3). It appears that subsidence was not a significant factor in the loss of submerged vegetation at the southwestern end of West Bay because subsidence rates were similar to those in Christmas Bay where SV still occurs.

**Erosion.** The Galveston Island shoreline in West Bay is one of two areas where rates of erosion have increased during more recent periods (Table 2). The average rate of erosion during the period 1930 to 1982 is about 2.5 times the average rate during 1850–52 to 1930. Unpublished analysis of shoreline changes over three time periods along Galveston Island indicates that rates of erosion in general were higher during the period from 1956 to 1982 than during earlier periods of 1850–52 to 1930 and 1930 to 1956. This latter period coincides with the time during which submerged vegetation declined and disappeared.

**Hurricane Carla.** Aerial photographs taken in August 1956 reveal a relatively broad, dense expanse of submerged vegetation along the margins of Galveston Island (Figure 2). As described in the Seabrook section, the 1950's drought probably contributed to this extensive occurrence of seagrasses. Rising water levels at the end of the drought in 1957, plus temporary increases in turbidity, phytoplankton, and/or epiphytes associated with increasing streamflow and runoff, may have stressed the submerged vegetation, especially in deeper areas. The storm surge associated with Hurricane Carla in 1961 probably damaged these areas. Although aerial photographs taken in 1964 and 1965 indicate that the seagrasses were still quite extensive toward the western end of Galveston Island near San Luis Pass (a tidal inlet through which storm tides flowed), the width of the vegetated area was substantially reduced (Figure 2). Photographs taken in 1964 indicate a much more patchy appearance in the grassbeds, particularly along the outer margins, compared to their distribution in 1956.

**Waterfront Development.** When the progression of dredged channels, bulkheaded marinas and resort housing is charted from aerial photographs, such areas show substantial increases between 1956–1965 and 1965–1975, as demonstrated in Figure 5. Dredged channels in West Bay physically displaced many acres of seagrasses over the 20 year period. Spoil material from dredging was often disposed of in open water areas, burying adjacent seagrass beds and producing high levels of suspended sediment.

Other effects of development include increased boat traffic, channel maintenance and discharges of toxic materials or other pollutants. Runoff containing high levels of nutrients, herbicides and pesticides from lawn fertilizer, or fuel spilled from boats, is flushed...
out of channels into the bay. Wastewater discharge sites are obvious point sources of excess nutrients. Six major secondary wastewater treatment plants permitted by the Texas Water Commission discharge into West Bay. Two of the earliest plants were discharging into upper West Bay in the early 1960's. The distribution and proximity of these point-source discharges to declining seagrass beds around West Bay is illustrated in Figure 1. Christmas Bay is notable for its lack of discharge sites.

The potential impact of effluent discharges and toxic spills on the West Bay environment can be estimated from reports of fish kills in TPWD files. A total of 61 fish kills was investigated by TPWD biologists in Galveston County during the period January 1980 to July 1984. Twenty-two of the incidents (ca 36%) occurred in West Bay where discharges from channel-front developments and industrial plants emptied into shallow nearshore wetlands. Most kills were associated with low dissolved oxygen conditions, algal blooms, or petrochemical spills. In earlier years (1960's) when water-quality discharge standards were more lenient, or non-existent, compared to current (1986's) standards (George Guillen, Texas Water Commission, personal communication), stagnant, eutrophic conditions were probably more frequent.

**Water Quality.** An increase in bay water turbidity caused by increased suspended material from agricultural runoff, shoreline erosion, channel dredging, and boat traffic has been postulated by some scientists (NOAA, 1989). Higher turbidities could result in increased light attenuation at depths which previously supported SV. Although this mechanism could contribute to decline in SV in deeper water, it is unlikely that all SV in the shallow water would be completely deprived of light above the ecological compensation point. Moreover, TPWD data files for 1977–1987 document that turbidity levels in West Bay and Christmas Bay water were not appreciably different over this time period. When bimonthly means were compared (Figure 6), the two areas showed similar turbidity regimes by independent t-test (West Bay mean 37.95 ± 20.25 JTU vs. Christmas Bay mean 44.59 ± 35.05, p = 0.262). The current SV sites on the east shore of Trinity Bay also serve as controls for the lower bay turbidity regimes. Although this area experiences significantly higher (p = 0.07) turbidities than the lower bay areas, due to freshwater inflows from the Trinity River, *Ruppia maritima* still grows well (Trinity Bay mean 64.89 ± 49.81).

Since turbidity measurements (based on JTU's) do not account for all light attenuation in the water column, analysis of other light absorption factors is necessary to fully evaluate light reduction stress on SV. This includes, specifically, chlorophyll levels and other pigmented material originating from phytoplankton blooms, overgrowths of epiphytes, or from effluent discharges. However, historical records on water transparency conditions other than turbidity are fragmentary.

Limited data available in the TWC water quality database illustrate the complex relationships between suspended particulate material and chlorophyll levels in Galveston Bay waters. Total suspended solids, the major contributor to turbidity measurements, were examined for the 1972–80 period of record from three sampling stations in West Bay and one in Christmas Bay (Figure 7). When compared to Christmas Bay, TSS in West Bay showed no significant difference by t-test (Christmas Bay mean 58.69 ± 41.91 milligrams/liter vs. West Bay mean 46.67 ± 37.62, p = 0.217). Corresponding chlorophyll records over this time period indicated a contrasting situation (Figure 8). Christmas Bay had significantly lower (p = 0.044) seasonal chlorophyll levels (Christ-
mas Bay mean 7.89 ± 7.64 micrograms/liter, n = 20) than West Bay, especially in earlier years, 1972–77 (West Bay mean 13.35 ± 9.80, n = 28).

Mean salinities in West, Christmas, and Trinity Bays are compared in Figure 9. There is no evidence to suggest that salinity regimes have contributed to a decline in SV areas. Salinities in Christmas Bay, where seagrasses are relatively abundant, were similar to salinities in West Bay where seagrasses disappeared.
Figure 8. Particulate chlorophyll a for West and Christmas Bays, 1972–1980. Based on quarterly samples from the Texas Water Commission.

Figure 9. Bimonthly mean salinities in areas of submerged vegetation in Christmas, West, and Trinity Bays.

DISCUSSION AND CONCLUSIONS

This paper has reviewed the chronological sequence of SV losses in the upper and lower Galveston Bay system since 1956 and described corresponding changes in physical and hydrographic factors possibly related to the declines. When the results are integrated, the SV declines are attributable to different processes in the two parts of Galveston Bay.
The upper bay near Seabrook has experienced major geomorphic modifications from land subsidence and associated erosion. Hurricane Carla physically removed the majority of the *Ruppia maritima* late in the annual growth cycle (mid September 1961). This allowed for increased erosion to occur during the ensuing winter and spring when the area is normally subjected to the full force of north and northeasterly winds associated with frontal passage. Increased nearshore water depth caused by subsidence may have reduced the amount of light reaching bay bottom and submerged vegetation, thus eliminating suitable SV habitat along the Seabrook shoreline. A few areas here that do have shallow depths are in the exposed, high-wave energy zones where SV was not found in the 1950's. This hypothesis is supported when the Seabrook area is compared to the eastern shoreline of Trinity Bay. Protected areas on this opposite shoreline with suitable depths still support substantial *R. maritima* beds during the proper season.

The shoreline in the Seabrook area is predominantly an erosional one, and there is evidence that erosion has increased during recent times (Table 1, Galveston Bay). Although loss of grasses may contribute to higher rates of erosion (Orth and Moore, 1983), rates can also be accelerated as a result of human activities (Paine and Morton, 1986). The Galveston Bay shoreline has been artificially stabilized in many areas by bulkheads, riprap, and other erosion control measures (Paine and Morton, 1986). In areas of rapid subsidence such as the Seabrook area, however, these stabilizing features also contribute to deeper-water conditions near shore by inhibiting the natural development of a broad, shallow, and gently-sloping subaqueous bay-margin profile that would likely develop along an unmodified, retreating shoreline. Water depths of approximately 1 m (3 ft) at bulkheads were measured during a survey of the Seabrook shoreline in 1988.

The severe drought climaxing in 1956 may have caused SV to become more extensive than usual due to lower water levels in the bay. The end of the drought in 1957 was marked by soaking rains in February, and heavier rainfall in March and April (Riggo et al., 1987). Tide-gauge records at Galveston suggest that bay water levels rose about 15 cm (0.5 ft) in the late 1950's, probably from the increasing freshwater inflows. The turbid freshwater inflows, added to the ongoing processes of subsidence, erosion, and shoreline disturbance, are likely to have placed *Ruppia maritima* in the Seabrook area under considerable stress, which made it vulnerable to destruction by Hurricane Carla.

Periodic exposure to high wave action or high currents can cause erosion foci to develop in seagrass beds. "Patchy" distribution and "blow-outs" have been documented in seagrass beds subjected to these hydrologic conditions in the Caribbean (Patriquin, 1975) and in Mississippi Sound (Eleuterius and Miller, 1976). Eleuterius and Miller (1976) reported a 33 percent reduction in seagrass beds in Mississippi Sound as a result of erosion and sedimentation during Hurricane Camille and subsequent reductions in salinities due to aftermath flooding. Conner et al. (1989) emphasized that hurricanes are normal episodic events in the climatic regime of the Gulf Coast and generally contribute to the development and maintenance of coastal ecosystems. Nevertheless, these storms can have long-term adverse impacts in areas altered by man (Eleuterius, 1987; Conner et al., 1989).

A different scenario for West Bay emerges from compilation of available data. Although Hurricane Carla apparently impacted the seagrass beds in West Bay in 1961, the major decline of SV along upper Galveston Island between 1956 and 1965 suggests a stronger correlation with increases in residential and commercial waterfront development. Many construction projects represented classical examples of "dredging and filling" of wetlands. Subsequent stress involved erosion and redistribution of dredged sediments, excessive nutrient loading from wastewater discharges, nonpoint source runoff, and toxic spills from shipping and industry. In many respects, this explanation invokes the mechanism proposed for the decline of SV in Chesapeake Bay (Kemp et al., 1983), Cockburn Sound, Australia (Cambridge and McComb, 1984), Tampa Bay, Florida (Lewis et al., 1985), and Apalachee Bay, Florida (Livingston, 1984). These cases document, particularly, the serious damage to SV from various agents that reduced water column light penetration.

The major difference between Galveston Bay and these other bay systems appears to be the degree to which increased turbidity, toxic discharges, or eutrophic conditions have contrib-
uted to the SV problem. Excessive nutrient or organic loading is known to stress SV populations by stimulating growth of planktonic and epiphytic algae, as well as causing premature senescence (PHILLIPS et al., 1978; KEMP et al., 1983). Evidence of this stress is suggested by the observations that particulate chlorophyll comprised a higher percentage of the suspended material in West Bay compared to Christmas Bay during years when SV was actually declining. Heavy growths of epiphytes or phytoplankton inhibit SV photosynthesis by reducing the light available for absorption by SV leaves (PENHALL, 1977; SAND-JENSEN, 1977). In addition, phytoplankton/bacterial blooms associated with storm or sewage runoff often cause anoxic events. Anoxia poses a lethal stress to SV due to sulfide production from decomposition processes, especially during warm weather and calm water conditions (NIENHUIS, 1983). Senescence, and then plant death, would quickly result if these highly toxic conditions occurred during historical low-dissolved oxygen events in West Bay. In an analogous situation, ELEUTERIUS (1987) has attributed recent decline of seagrasses in Mississippi Sound to anthropogenic impacts such as altered freshwater diversion from the Mississippi River, intensive shrimp trawling and dredging activities, and pollutant input (sewage and toxins) to this system.

While impacts from individual factors are difficult to separate and quantify from this analysis, the evidence is compelling that cumulative impacts of dredging, subsidence, erosion, effluent discharges, and toxic spills have been deleterious to SV in the Galveston Bay System. Before restoration of SV habitat in this bay system can be practically proposed, concerted efforts must be made to control or eliminate these specific environmental stresses.

ACKNOWLEDGMENTS

Funding for this study was provided by the Texas Parks and Wildlife Department and Water Development Board through the Board’s Water Research and Planning Fund, authorized under Texas Water Code Sections 15.402 and 16.058 (e), and administered (1) by the Department under interagency cooperative contract No. IAC(88-89)1457, and (2) by the Texas Parks and Wildlife Department under IAC(88-89)1423.

Special thanks go to Rick Edson (Computer Programmer), Bureau of Economic Geology, for assistance in determining the areal extent of submerged vegetation in the Galveston Bay system, to Drs. Wen Y. Lee and Rita H. Wellens, Texas Parks and Wildlife Department, for assistance with analyses of turbidity and salinity data, and to Jeff Kirkpatrick and David Petrick, Texas Water Commission, for supplying water quality data.

LITERATURE CITED


On possèdes des informations sur les modifications dans la distribution des plantes vasculaires depuis les années 1950 pour la baie de Galveston (à l’exception du delta de la Trinity River), grâce à des photographies aériennes et d’importants rapports de mises de terrain. On a comparé deux zones où les herbiers ont décliné en extension avec des sites proches où la végétation a persisté. Pour le rivage de la “haute” baie, le fort niveau de la mer cause par la subsidence sont impliqués dans la disparition de Ruppia maritima entre 1960 et 1962 dans la “base” baie (West Bay), et le fort déclin des lits mixtes de R. maritima et Halodule wrightii des années 1950 puis de leur disparition au début des années 1980. Cette zone contraste fortement avec Christmas Bay, anse secondaire protégée située à 5 à 7 km plus au Nord, qui possède encore des lits étendus de H. wrightii et de petits lits de Thalassia testudinum et de Halophila engelmanni. Dans West Bay, le développement urbain, les rejets d’eaux usées, les épanchements chimiques et les dragages sont, plus qu’une subsidence et le hurricaine Carla suspectés d’être les principaux agents de destruction. Des similitudes entre le déclin de la végétation submergée à Galveston et les autres baies sont discutées.—Catherine Boussard-Bressolier, Laboratoire de Géomorphologie EPHE, Montrouge, France.


RESUMEN

Se ha utilizado fotografía aérea e información comprobada de campo para documentar los cambios desde los 1950 de la distribución de plantas vasculares sumergidas en el sistema de la Bahía de Galveston (excluyendo el propio delta del Trinity River). Se ha comparado un área donde las hierbas marinas han disminuido extensamente con otras áreas cercanas donde persiste la vegetación. A lo largo de la línea de costa de la parte superior de la bahía se presenta la evidencia del paso del huracán Carla (1961) y un ascenso relativo del nivel del mar debido a subsidencia, que ha producido la desaparición de los lechos de Ruppie maritima entre 1960 y 1962. En la parte baja de la bahía (West Bay) los lechos mixtos de R. maritima y Halodule wrightii han disminuido constantemente desde la década de 1950 y desaparecido al inicio de los 80. Este área contrasta con la de Christmas Bay, una bahía secundaria protegida situada 5 a 7 km al Sur que contiene todavía extensos lechos de H. wrightii y pequeños campos de Thalassia testudinum y Halophila eugelmanni. En West Bay, el desarrollo urbano, descargas de aguas residuales, vertidos de industrias químicas y actividades de dragado son más sospechosos de ser los principales agentes deletéreos que la subsidencia o el huracán Carla. Se analiza asimismo las similitudes con disminuciones de vegetación sumergida en Galveston y otros sistemas de bahía.—Department of Water Sciences, University of Cantabria, Santander, Spain.