DECLINE OF SUBMERGED VEGETATION IN THE GALVESTON BAY SYSTEM: CHRONOLOGY AND RELATIONSHIPS TO PHYSICAL PROCESSES

by

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INTRODUCTION

The Galveston Bay complex of Texas ranks as the 7th largest estuary in the USA, including 143,000 ha (about 554,000 acres) of open water and approximately 93,000 ha (230,000 acres) of wetlands (Diener 1975), of which about 48,000 ha (about 118,000 acres) are 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 (Avg. 3.6 million pounds), 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 its inherent natural resource value, Galveston Bay has been heavily impacted by shoreline industrial and municipal development, excess inputs of pollutants and wastewater discharges, channelization, dredging projects, subsidence, and alterations in bay-water circulation dynamics. Degradation of the bay-system's water quality has increased to the point that over 38 billion gallons a day of waste effluents are discharged into the bay and its tributaries (NOAA 1989).

A decline of approximately 90 percent in bay submerged vascular vegetation (SV) since 1956 (when aerial photographs indicate approximately 2,070 ha -- 5,120 acres; Fisher et al. 1972) is an alarming environmental impact (NOAA 1989) because of the loss in fisheries nursery habitat. The disappearance of this valuable subtidal habitat has received widespread attention with the recent designation of Galveston Bay as a national estuary by the EPA National Estuary Program (NOAA 1989). Review of the chronological sequence of SV habitat loss has been recommended to help determine critical factors threatening estuarine habitats and to design management solutions for restoration of impacted SV habitat.

We have completed a study, which examines major regions of Galveston Bay where submerged halophytes have declined since the 1950's and compares them with nearby remaining sites where plants still persist. The approach involved compilation and analysis of active processes and hydrologic data, which could affect distribution and abundance of rooted estuarine plants. After the SV distribution at different time periods was mapped, physical and hydrologic factors were analyzed in an attempt to establish the processes contributing to impacts on SV habitats.

This report is part of a study funded by the Texas Parks and Wildlife Department and Texas Water Development Board with funds allocated by the Texas Legislature for comprehensive studies of the effects of freshwater inflows on the bays and estuaries of Texas.*

MATERIALS AND METHODS

Study Sites

Extant locations of SV, with a minimum of 1/8 acre, were determined for the Galveston Bay system from 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 (Fig. 1): 1) Ruppia along the northern and eastern shores of the upper bay (Trinity Bay), and 2) seagrasses in the Christmas-Drum Bay area of the lower (West Bay) system. This late 1980's distribution contrasts with historic occurrences at nearby locations in the upper bay along the Clear Lake-Seabrook shoreline, and in lower West Bay along the Galveston Island shoreline. Former occurrence of SV in these areas was established from project reports of TPWD biologists (Pullen 1960, 1961, West 1973), interviews with knowledgeable field biologists and fishermen, and review of archived aerial photographs. This investigation documented the chronology of SV decline from the late 1950's.

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* **In response to House Bill 2 (1985) and Senate Bill 683 (1987), as enacted by the Texas Legislature, the Texas Parks and Wildlife Department and the Texas Water Development Board must maintain a continuous data collection and analytical study program on the effects of and needs for freshwater inflow to the State's bays and estuaries. As part of the mandated study program, this research project was funded through the Board's Water Research and Planning Fund, Authorized under Texas Water Code Sections 15.402 and 16.058 (e), and administered by the Department under interagency cooperative contracts No. IAC (86-87)1590, IAC(88-89)0821 and IAC(88-89)1457.**

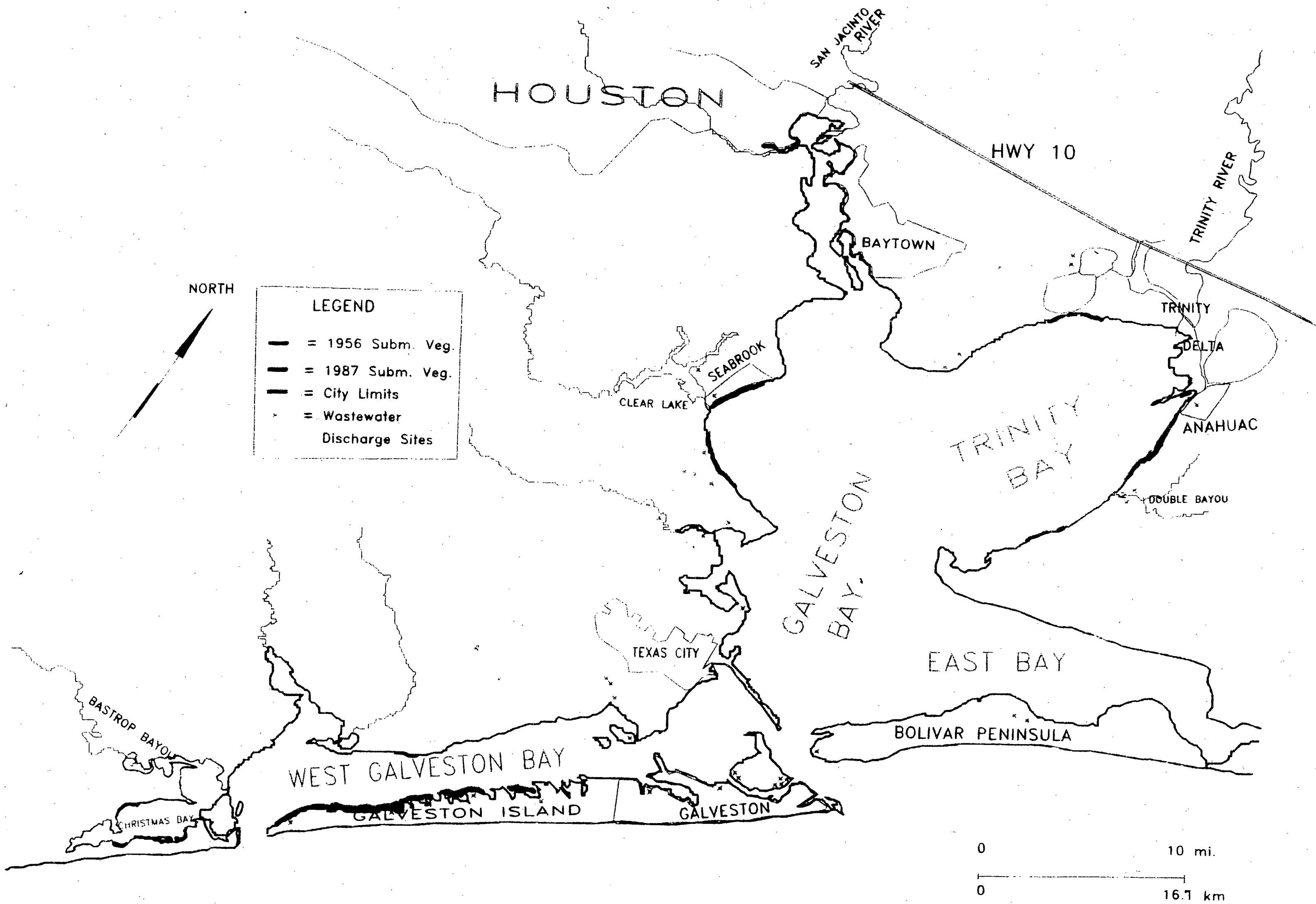

Figure 1. Map of the Galveston Bay system comparing 1956 and 1987 locations of submerged vegetation. Wastewater discharge sites compiled from 1988 records in Texas Water Commission permits section.

SV 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 and for the years 1956, 1965, 1975, and 1987 in the lower bay area. 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 Factor Analysis

Historic data on various physical/hydrologic processes affecting the bay environment were compiled and analyzed for the defined SV sites. Included in the analysis were the following processes known to affect growth of SV: Shoreline erosion and relative sea-level rise associated with compactional subsidence; hurricane and other climatic events; physical alterations related to channel dredging and residential developments; and degradation in selected water quality conditions. A number of 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); TPWD water quality monitoring data (Fisheries Division); and Texas Water Commission (TWC) wastewater discharge permits records.

RESULTS

Changes in Submerged Vegetation Distribution

Upper Galveston Bay (Galveston-Trinity Bay System)

SV distribution along the Trinity Bay shoreline (exclusive of the Trinity River Delta proper from Anahuac to Old River Pass) is compared with that along the Seabrook shoreline on the west side of the bay in Figure 1. The Seabrook area was mapped from 1956 photographs, while the Trinity Bay area represents 1987 distribution. Both sites contain only Ruppia maritima. The areal extent of SV in the Seabrook area in 1956 and east Trinity Bay in 1987 are given in Table 1.

Texas Parks and Wildlife Department biologists have documented the chronology of Ruppia decline and disappearance in the Seabrook area (Pullen 1960, 1961). Pullen (1961) observed variations in Ruppia and saltmarsh occurrence and abundance between years, and specifically the effect of Hurricane Carla in 1961. He noted extensive damage from the hurricane to SV in both upper bay areas. Grassbeds on the east side of the bay 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 during the winter after the hurricane. Hofstetter felt that turbidity may have contributed to the inability of the SV to reestablish in 1962. Pullen (1961) specifically mentioned turbidity as a major limiting factor to SV; he suggested it may have been higher on the Seabrook side of the bay compared to the east side.

Lower Galveston Bay (West Bay and Christmas Bay)

The Lower Bay system constitutes typically polyhaline waters and has historically supported beds of true seagrasses. As of the 1987 survey date, Christmas Bay in the southernmost part contained the only remaining SV habitat (Fig. 1). Halodule wrightii (shoalgrass) is the dominant species, but significant Ruppia occurs during spring months. Substantial amounts of Halophila engelmanni and a few small patches (about 1/4 acre) of Thalassia testudinum (turtle grass) also co-occur. The area of seagrasses in Christmas Bay during the fall season of 1975 and 1987 is shown in Table 1; there were 240 acres in 1975 compared to 190 acres in 1987.

Analysis of aerial photographs from 1956, 1965, 1975, and 1987 substantiates the progression of seagrass loss for Lower West Bay (Fig. 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; personnel

Table 1. Areal extent of submerged vegetation in selected regions of the Galveston Bay system, 1956 to 1987.

	Areal Extent in Acres for Specified Years			
	1956	**1965**	**1975**	**1987**
Trinity Bay (East Shore)				148
Galveston Bay (Seabrook Shore)	213			
West Bay (Western Half)	1131	288	91	0
Christmas Bay			240	191

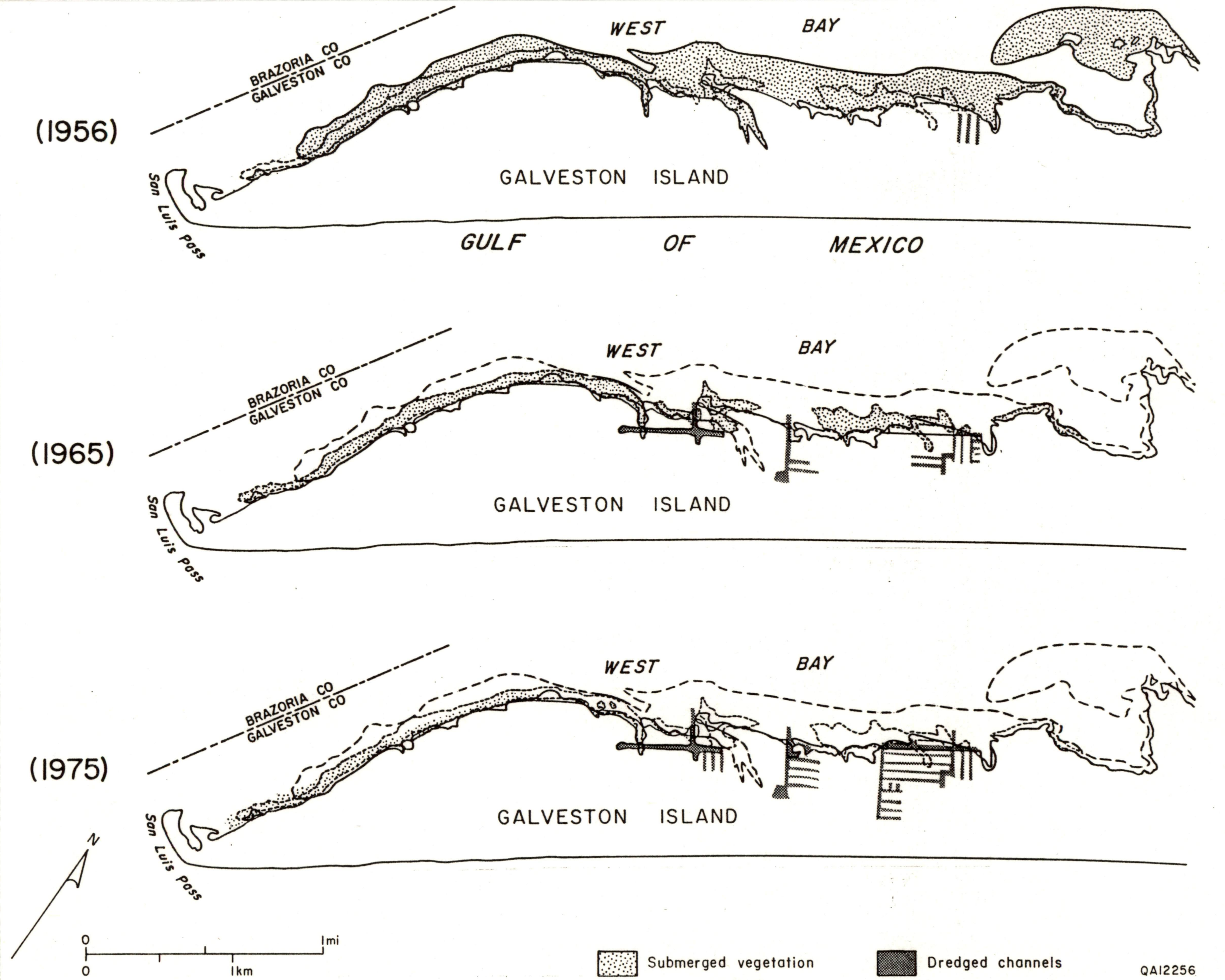

Figure 2. Historical changes in the distribution of seagrasss and dredged channels along the western half of Galveston Island, West Bay.

communication) further corroborate the occurrence and decline of Halodule from the West Bay area. After a dramatic decrease in seagrasses from approximately 1,100 to 300 acres between 1956 and 1965, the remainder of the reduction appears to have occurred gradually (Fig. 2).

Impacts of Physical Processes on Submerged Vegetation

Upper Galveston Bay (Galveston-Trinity Bay System)

The loss of SV in the Seabrook area was correlated with several interactive processes and events, including subsidence, shoreline erosion, Hurricane Carla, and the severe drought of the 1950's. 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 (Fig. 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 (Fig. 3). Historical trends in subsidence in the Seabrook area indicate that rates increased after 1943 and reached a maximum of about 6 cm/yr for the period 1964-1973 (Fig. 4). Subsidence in the Seabrook area between 1943 and 1973 was approximately 0.9 m, and from 1943 to 1978 it exceeded 1.2 m (Gabrysch, 1984). Water depths near shore possibly increased by as much as 30 to 60 cm between 1968 and 1977 (Morton and McGowen, 1980). The amount of subsidence in other SV areas is considerably lower than in the Seabrook area, ranging from less than 0.5 m in upper Trinity Bay to less than 0.4 m in West Bay and 0.2 m in Christmas Bay for the period 1943 to 1973 (Fig. 3). In the eastern part of Trinity Bay and in the southwest part of West Bay, subsidence during the period 1943 to 1978 was less than 0.3 m (Gabrysch, 1984).

The western margin of upper Galveston Bay is characterized by increasing rates of erosion since the mid-1800's (Paine and Morton, 1986). Table 2 compares the average rates of erosion

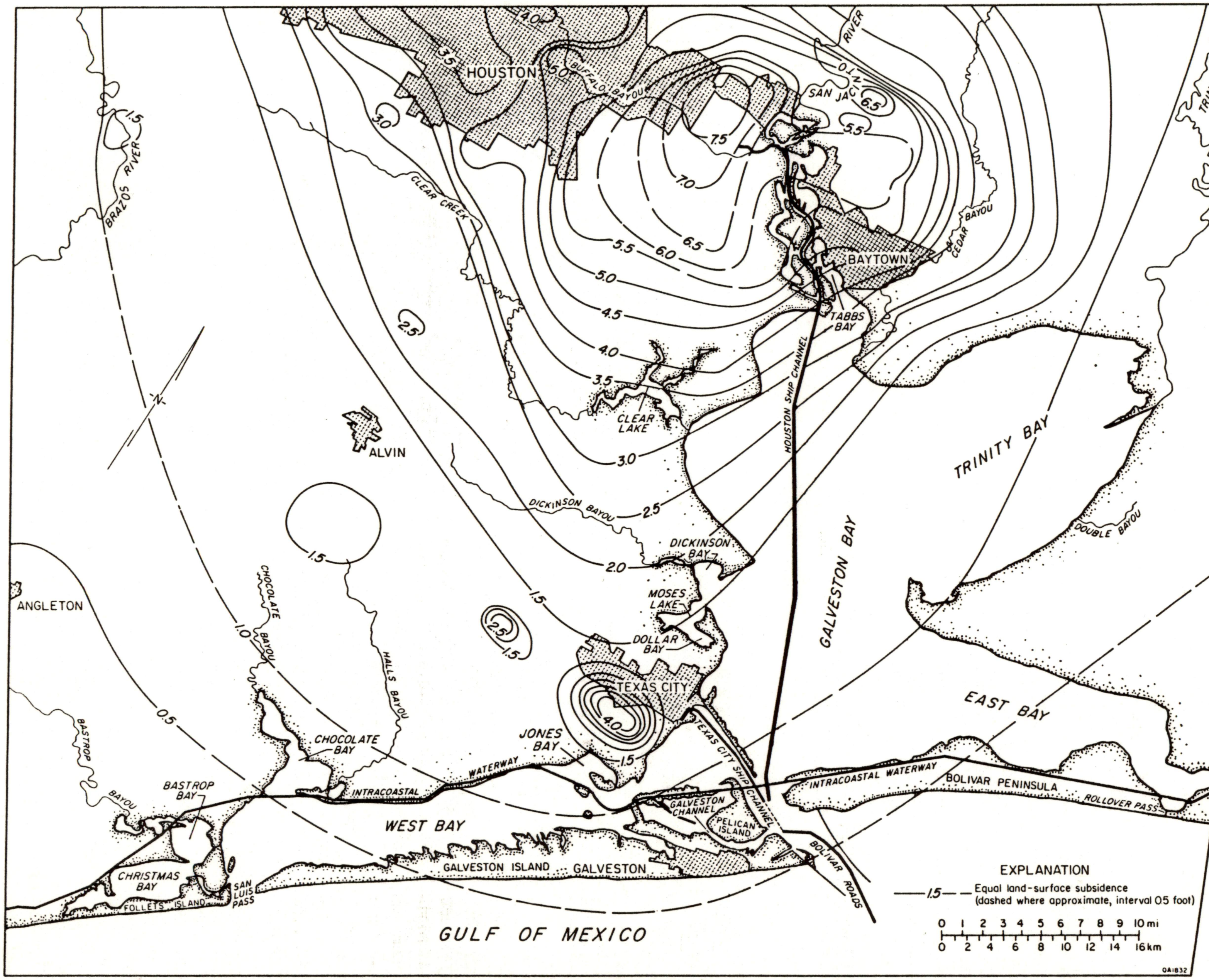

Figure 3. Land-surface subsidence in the Houston-Galveston area, 1943-1973. (From Gabrysch and Bonnet, 1975.)

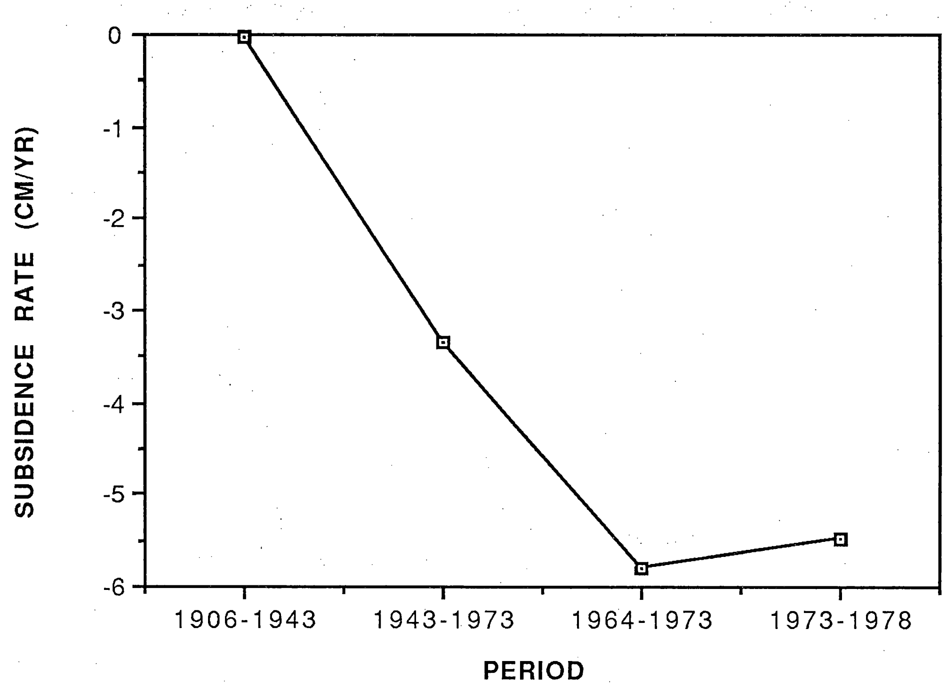

Figure 4. Subsidence rates along the Galveston Bay margin in the Seabrook area. (Based on data from Gabrysch and Bonnet, 1975, and Gabrysch 1984.)

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

	1850-52 to 1930 (Historical)		1930 to 1982 (Recent)		Ratio of Erosion Rates Recent/Historical
	No. of stations	Rate (ft/yr)	No. of stations	Rate (ft/yr)	
Trinity Bay					
East Trinity Bay	26	-3	25	-1.8	0.6
Trinity delta	10	3.9	9	7.2	
W. Trinity Bay	21	-2.6	20	-2.3	0.9
Galveston Bay	57	-2.2	55	-4.4	2
West Bay					
Galveston Is.	34	-0.8	40	-2.1	2.6
Christmas Bay area	30	-1.3	29	-1.5	1.1

along specific shorelines for two periods -- 1850-52 to 1930 and 1930 to 1982. 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 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). The Trinity River delta is the only shoreline segment in the Galveston-Trinity Bay system that is not erosional; shorelines along the active part of the delta accreted or advanced between 1930 and 1982 (Paine and Morton, 1986). This active part of the delta is characterized by shallow embayments located between active and inactive distributary channels bordered by brackish-water marshes. Submerged vegetation in the delta and, locally along the eastern Trinity Bay shoreline, occupy these shallow protected areas.

The processes of subsidence and erosion can affect water clarity. Subsidence increases water depth, which in turn can reduce the amount of light reaching bay bottoms and submerged vegetation. Increasing water depths associated with significant subsidence, such as near Seabrook, also allows larger waves to reach shore and produce more turbulent conditions. Because this shoreline is predominantly an erosional one, turbidity may be relatively high due to the constant resuspension and distribution of sediments along shore and offshore by waves and currents generated by prevailing southeasterly winds and strong north and northeast winds (Fisher et al. 1972). In addition, channel and marina development along the margins of Clear Lake, which in conjunction with Clear Creek discharges into Galveston Bay, has probably further reduced water clarity near shore.

The Galveston Bay shoreline has been artificially stabilized in many areas by bulkheads, riprap, and other erosion control measures (Paine and Morton, 1986). Structures such as bulkheads may stabilize the shoreline and prevent shoreline retreat locally, but in areas of rapid subsidence as in the Seabrook area, they also contribute to deeper-water conditions near shore. This inhibits 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 a bulkhead were measured during a survey of the Seabrook shoreline in 1988. In many areas, relative large waves generated by strong east to southeast winds did not break and release their energy until reaching the bulkheads at the shoreline.

Sediments in the Seabrook, and other SV areas are predominantly sand and muddy sand (White et al. 1985). This indicates a winnowing of silt and clay not trapped by seagrass beds, and their deposition offshore in deeper more protected water. In a study of bay-margin sand distribution in the Galveston Bay system, Love et al. (1985) found a relationship between the depth at which sand was deposited offshore and prevailing wind directions and fetch, which produced the incident waves. This relationship provides an indirect measure of the size of the wind-generated waves and the degree to which bay-margin sediments are reworked. Sand is transported and deposited in deeper areas along bay margins affected by larger waves. The average depths at which there is a significant reduction in the sand:mud ratio, range from a high of 220 cm along the Galveston Bay shoreline southeast of the Seabrook area, to a low of 76 cm in Christmas Bay. The depths of the sandy sediments support expectations based on bay geometry, size, water depth, and prevailing wind directions that wave and current activity is highest along parts of the western margin (northward facing shore) of upper Galveston Bay and lowest in Christmas Bay. These data generally correlate positively with erosion rates, which are highest along the Galveston Bay shoreline and lowest in Christmas Bay (Table 2).

The extent of submerged vegetation in 1956 may have been partly related to climatic factors. 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 most extreme drought in recorded history occurred in Texas in the 1950's and climaxed in 1956 (Riggio et. at. 1987). Tide gauge records at Galveston reflected the drought, which produced lower average sea-levels (Fig. 5). Furthermore, reduced streamflow and runoff from coastal upland areas during the drought probably resulted in lower bay-water turbidities. These conditions may have allowed submerged vegetation to reach maximum distribution. The end of the drought in 1957 was marked by soaking rains in February, and heavier rainfall in March and April (Riggio et. al. 1987). Bay-water levels, if mirroring tide-gauge records at Galveston, rose about 15 cm (0.5 ft) in the late 1950's (Fig. 5), probably as a result of the increasing fresh-water inflows. These changing conditions, when added to the ongoing processes of subsidence, erosion, and associated shoreline

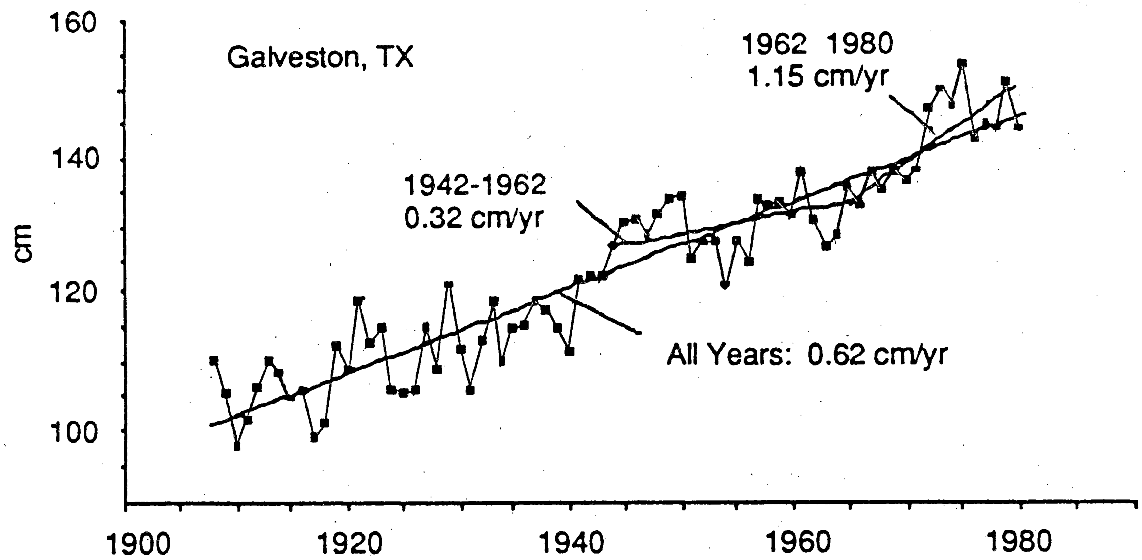

Figure 5. Annual changes in water level based on tide gauge records at Galveston (Pier 21), with variations in rates of rise indicated for different periods. (Modified from Turner, 1987.)

disturbances, may have placed submerged vegetation in the Seabrook area under considerable stress from 1957 to 1961.

In September 1961, one of the greatest storms in this century (USACE, 1962) made landfall along the Texas coast. Hurricane Carla had abnormally high tides and caused tremendous destruction from the Sabine River along the Texas-Louisiana border to Corpus Christi (USACE, 1962). Although the storm center made landfall at Pass Cavallo on September 11, 1961, the storm produced a hurricane surge that first reached the Galveston shore on September 8. The water level continued to rise until September 11 and did not return to normal until September 13. The surge along bay shorelines was considerably higher than along the Gulf shoreline. In the Galveston-Trinity Bay system, surge heights (based on measurements of still high water) ranged from 5 m (16.4 ft) near La Porte in upper Galveston Bay to 3.3 m (10.8 ft) at the western end of Galveston Island near San Luis Pass. High-water elevation reached 4.3 m (14.2 ft) at Clear Lake in the Seabrook area (USACE, 1962). A record height of 6.7 m (22 ft) was recorded at Port Lavaca in Lavaca Bay where the storm made landfall.

Hurricane Carla apparently had a major impact on submerged vegetation in the Seabrook area. 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, some of which were in effect as early as 1930 (Paine and Morton, 1986), may have intensified the erosive effect in nearshore areas by reflecting much of the wave energy. Intense scouring of beaches in front of seawalls during hurricanes has been reported along Gulf shorelines (Morton 1988). Extensive reworking of near-shore sediments in the Seabrook area during Hurricane Carla is supported by TPWD reports of uprooted SV wrack on the shore after passage of the hurricane. Submerged vegetation across the bay along the eastern shore of Trinity Bay is located in a much more protected area with respect to the hurricane winds, waves, and currents. Winds during Hurricane Carla were offshore instead of onshore as in the Seabrook area, and the effect of the storm on submerged vegetation was less pronounced.

The inability of the SV to become reestablished 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, substantially modified the morphology of the bay-margin environments in the Seabrook area.

Lower Bay (West Bay and Christmas Bay)

Although Hurricane Carla, erosion, and subsidence may have contributed to the loss of submerged vegetation in West Bay, another major factor was also involved -- that of water-front development along the bay margin of Galveston Island.

As mentioned previously, the Galveston Island shoreline in West Bay is one of two areas where rates of erosion have increased during more recent periods (Table 2). In fact, the average rate of erosion during the period 1930 to 1982 is about 2.5 times the average rate during 1850-52 to 1930. More specific 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 (Fig. 6). This latter period coincides with the time during which submerged vegetation declined and disappeared. 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). Dredging of channels in nearshore areas can increase erosion by producing deeper water in which larger more destructive waves can reach shore. The larger waves may also contribute to increased turbidity through erosion, and through resuspension of silt and clay that has settled in channels.

The significance of sea-level rise in the 1960's and 1970's due to subsidence was examined by reviewing Figure 3. For the most part, high subsidence rates occurred only along the mainland side of Upper West Bay. However, the north end of Galveston Island showed a moderate decrease in elevation since 1943 (Fig. 3). It appears that subsidence was not a significant factor in the loss of sub-

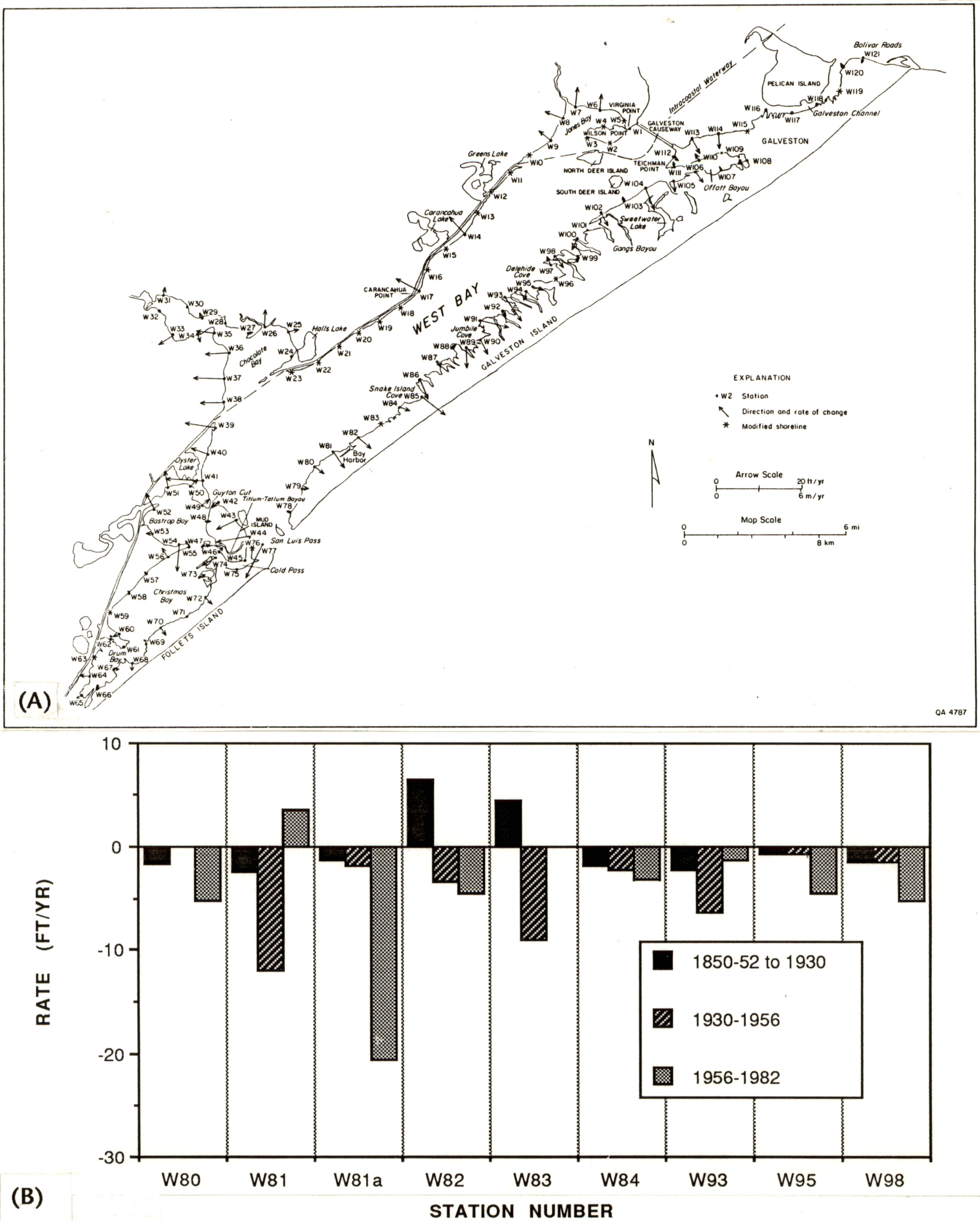

Figure 6. Bay shoreline changes along Galveston Island during specified periods. (A) Station location map and rates of shoreline change along West Bay, 1930 to 1982 (From Paine and Morton, 1986) and (B) rates of shoreline change for specified periods (From unpublished BEG data).

merged vegetation at the southwestern end of West Bay, because subsidence rates here were similar to Christmas Bay.

The extreme drought in the early and mid 1950's (Riggio et al. 1987) appeared to have a similar effect on the distribution of sea grasses in West Bay as noted in the upper bay. Aerial photographs taken in August 1956 reveal a relative broad, dense expanse of submerged vegetation along the margins of Galveston Island (Fig. 2). Photographs taken in 1958 show that channel development was well underway at the western end of the island, and that dredged sediments had been dumped onto vegetated areas along channels. As described in the Seabrook area, rising water levels at the end of the drought in 1957, plus probable increases in turbidity 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 resulted in considerable damage to these areas, as well as to areas near channel developments. 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 (Fig. 2). Photographs taken in 1964 indicate a much more patchy appearance in the grassbeds, particularly along the outer margins, compared to their texture and distribution as shown in 1956 photographs. Analysis of photographs taken a few days after Carla's landfall showed that subaerial spoil deposits placed along channels had been reworked by the storm surge. We suspect that losses in seagrass beds reflected in the 1965 photographs were partly the result of interactions of the storm surge with dredged channels and associated spoil.

The increase in Galveston Island residential and commercial waterfront developments follows closely the chronological decline of seagrasses in West Bay. Many of these construction projects represent classical examples of "dredging and filling" of wetlands. 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 by dredged channels in Figure 7. Dredged channels in the Lower West Bay physically displaced many acres of seagrasses over the 20 year period. In addition, spoil material from dredging was often disposed of in open water areas, burying adjacent seagrass beds and producing high levels of turbidity.

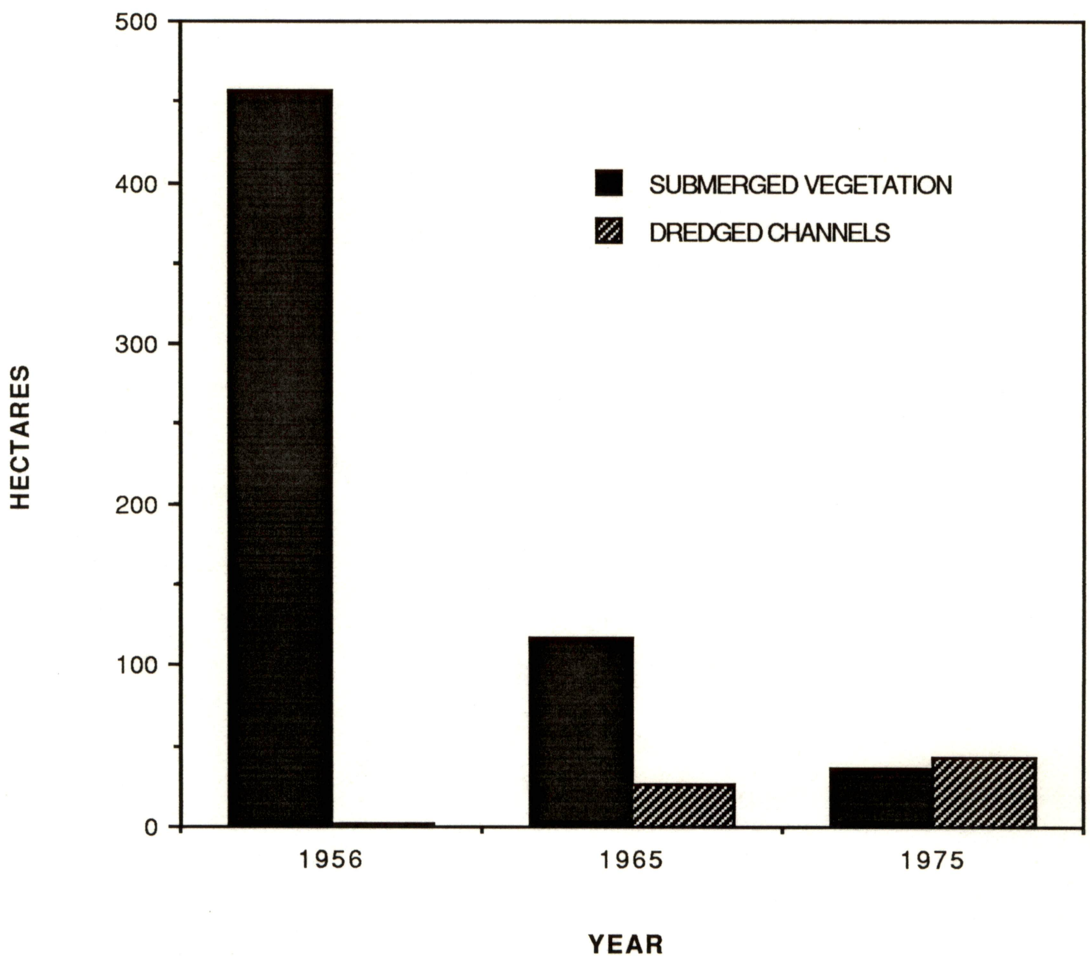

Figure 7. Changes in areas of submerged vegetation and dredged channels along the western half of Galveston Island, West Bay, 1956-1975.

Other effects of development include increased boat traffic 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 regularly flushed out of channels into the bay. Wastewater discharge sites are another obvious source of excess nutrients. Five major wastewater treatment plants are permitted by the Texas Water Commission on Galveston Island alone. The distribution and proximity of these point source discharges to declining seagrass beds around West Bay is illustrated in Fig. 1. Christmas Bay is notable for its lack of discharge sites.

The potential impact of effluent discharges on the West Bay environment can be estimated from reports of fish kills in TPWD files. A total of 61 fish kills were 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 Galveston 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. Excessive nutrient or organic loading is known to exert moderate stress on SV populations by stimulating growth of epiphytic and planktonic algae, as well as causing premature senescence (Phillips et al. 1978, Kemp et al. 1983). Heavy growths of epiphytes or phytoplankton will in turn inhibit SV photosynthesis by reducing the light available for absorption by SV leaves (Penhale 1977, Sand-Jensen 1977). Anoxic water poses a lethal stress to SV due to sulfide production from decomposition processes, especially during warm weather and calm water conditions. Senescence, and then plant death, will quickly result if these highly toxic sediment conditions continue (Nienhuis 1983). Such stagnant, eutrophic conditions were probably more frequent than records indicate since TPWD staff were notified mostly when die-offs of fisheries or other aquatic organisms actually occurred.

An increase in bay water turbidity caused by increased suspended material from agricultural runoff, shoreline disturbance, channel dredging, and boat traffic has been postulated by some scientists (NOAA 1989). Higher turbidities would then 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 compensation point. Moreover, TPWD data files for 1977-1987 document that turbidity levels in

West Bay and Christmas Bay water were not appreciably different at this time. When bimonthly means were compared (Fig. 8), the two areas showed essentially similar turbidity regimes over this ten year period. The current SV sites on the east shore of Trinity Bay also serve as controls for the lower bay turbidity regimes. Although these areas experience higher turbidities than the lower bay areas, due to freshwater inflows from the Trinity River, Ruppia still grows well at this higher turbidity level.

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, are similar to salinities in West Bay where seagrasses have disappeared.

SUMMARY AND CONCLUSIONS

This paper has (1) reviewed the chronological sequence of SV losses in the upper and lower Galveston Bay system since 1956 and (2) described corresponding changes in physical and hydrographic factors possibly related to the declines. When the results are synthesized and correlated, the SV declines are attributable to basically different processes in the two parts of Galveston Bay.

The upper bay near Seabrook has experienced major geomorphic modifications from Hurricane Carla in combination with land subsidence. Hurricane Carla physically removed the majority of the Ruppia 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 subsequent subsidence has effectively eliminated most suitable SV habitat along the Seabrook shoreline. A few areas here, which do have shallow depths, are in exposed, high-wave energy zones where SV would be subject to uprooting. This hypothesis is borne out 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 Ruppia beds during the proper season.

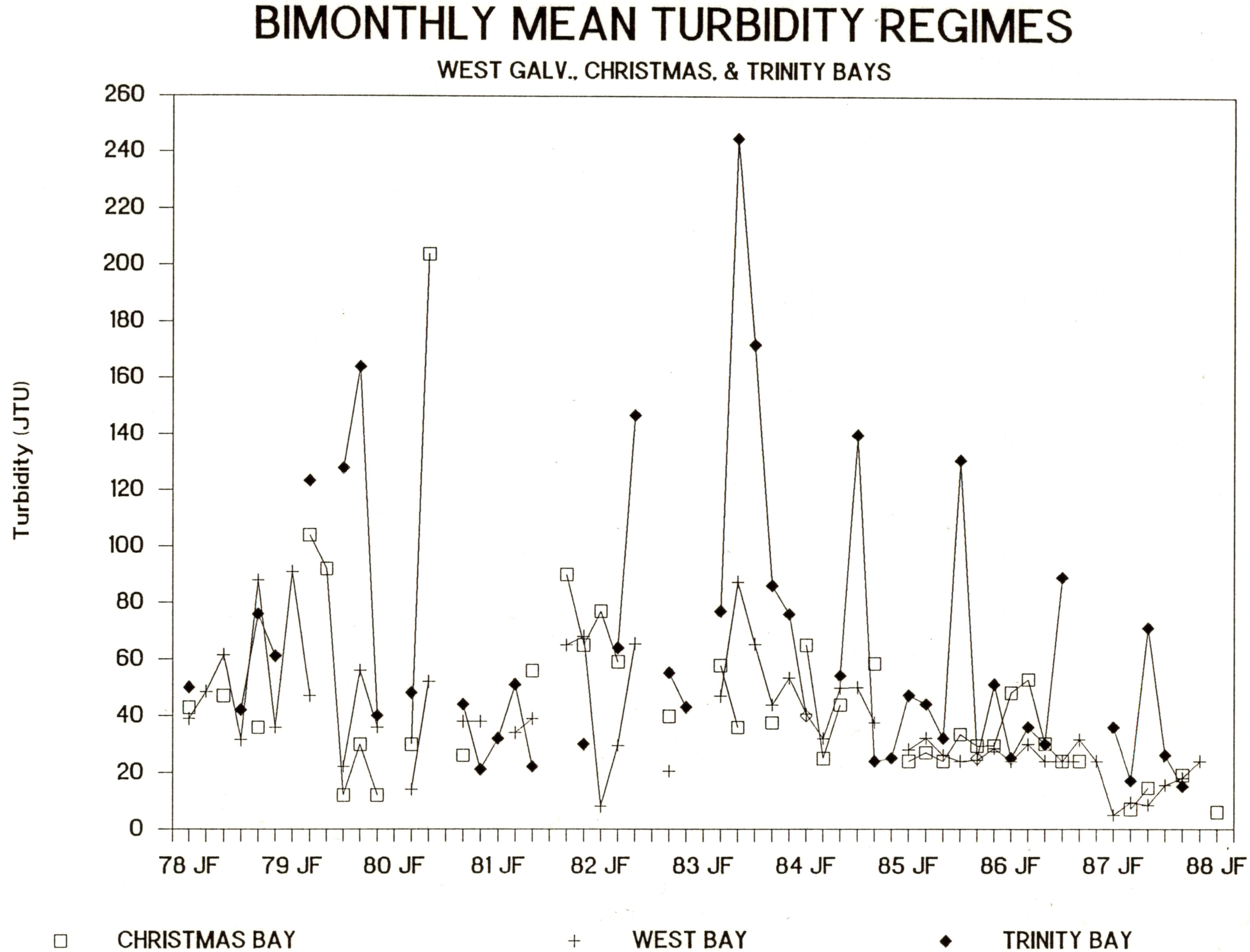

Figure 8. Mean turbidities in areas of submerged vegetation in Christmas, West, and Trinity Bays.

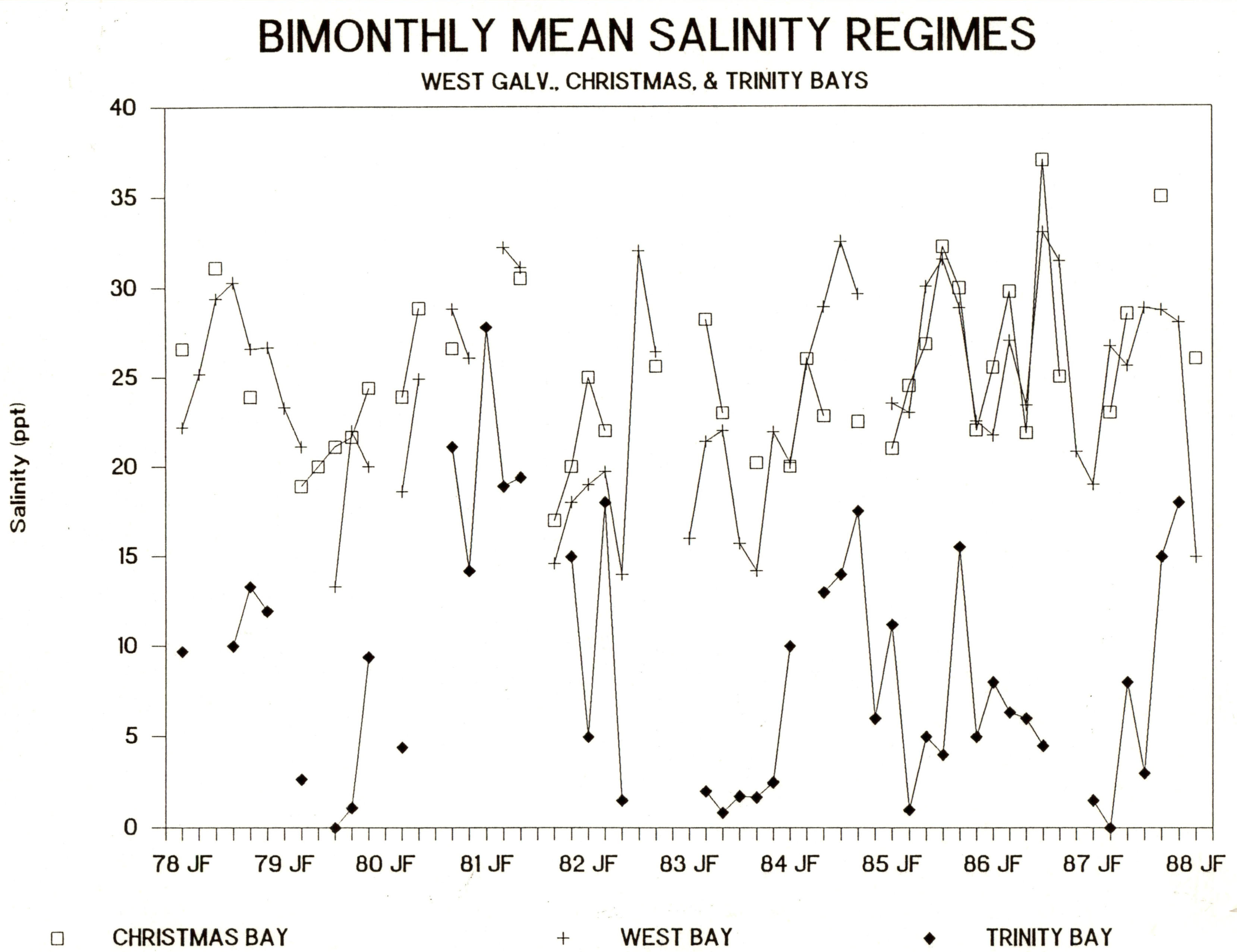

Figure 9. Mean salinities in areas of submerged vegetation in Christmas, West, and Trinity Bays.

A different scenario for the lower (West) bay system emerges from synthesis of available data. Hurricane Carla in 1961 apparently decimated some of the seagrass beds in West Bay along upper Galveston Island. After the hurricane, further decline of SV along west Galveston Island suggests a stronger correlation with increases in shoreline urban and industrial development. The proposed mechanism involves erosion and redistribution of dredged sediments, followed by excessive nutrient loading from wastewater discharges and toxic spills from petrochemical industries and nonpoint source runoff. In some respects, this explanation parallels the explanation for the decline of SV in Chesapeake Bay (Kemp et. al. 1983). The major difference in the two systems appears to be the degree to which increased turbidity has contributed to the problem in Galveston Bay compared to Chesapeake Bay.

The dynamics of seagrass loss, specifically, in lower Galveston Bay should also be viewed from an ecological perspective. Halodule and Thalassia are essentially tropical to subtropical species at the northern limits of their range in the Galveston Bay system. These northern populations of seagrass are much closer to their environmental tolerance limits and more sensitive to stress conditions than those in subtropical-tropical regions (Odum 1974). A true seasonal dimension to their annual growth cycle is caused by the average cooler temperatures of this bay compared to southern Texas bays (Carr 1967). This produces essentially marginal distribution conditions. While ecotypes may have adapted to this environment, plants could still be stressed beyond their tolerance limits when extreme changes in environmental factors are superimposed on seasonal cycles.

Examples of this phenomenon are when radical events such as a hurricane or channel/marina dredging occur during early fall when normal annual leaf senescence is beginning. If senescing seagrass beds are subjected to erosion or burial, they may continue to deteriorate during the ensuing winter and be totally devastated by the following spring. Periodic exposure to high wave action or high currents can cause erosion foci to develop in seagrass beds. "Patchy" distribution and "blowouts" 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. In a review of the effects of hurricanes on coastal ecosystems, 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 (Conner et al. 1989).

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