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Mapping and Monitoring of Submerged Aquatic Vegetation in Escambia–Pensacola Bay System, Florida

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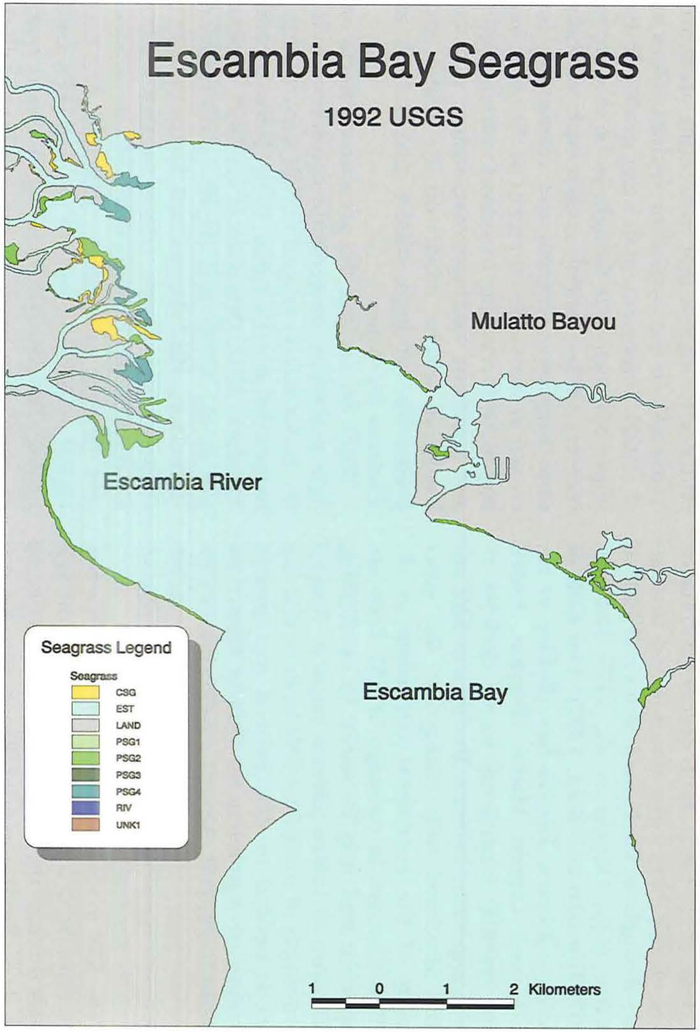
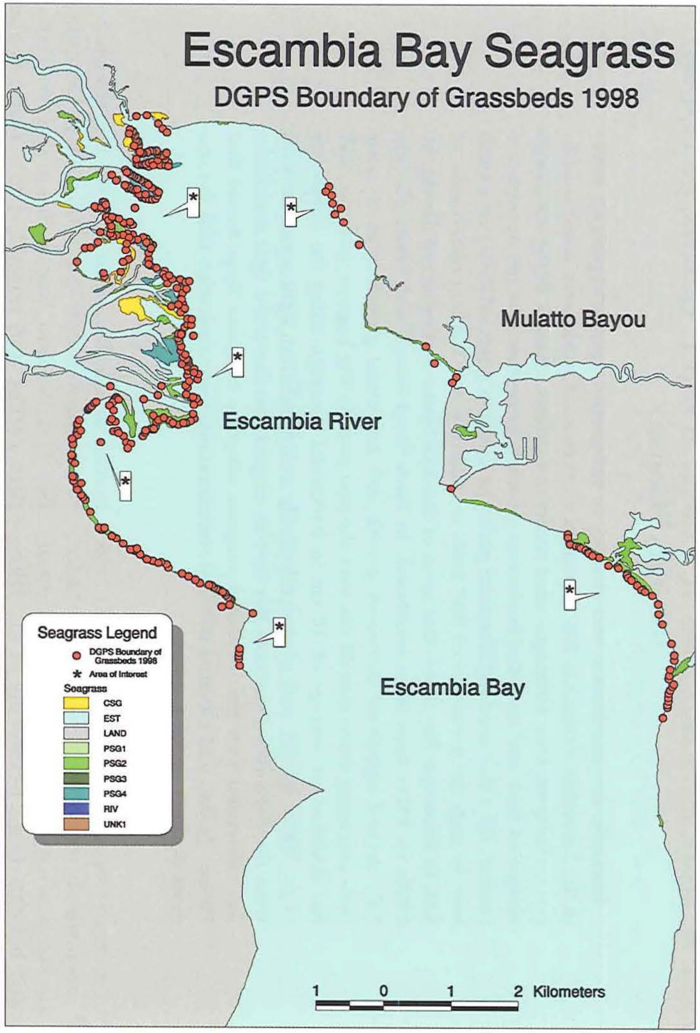
Recently, the distribution and changes in submerged aquatic vegetation (SAV) in the Escambia–Pensacola Bay System in northestern Florida were monitored by two techniques. One technique used divers to measure changes in the deepwater margin of beds and provided horizontal growth measurements to the nearest centimeter, the other used a differential global positioning system (DGPS) on a small boat to map the perimeter of SAV beds in shallow water. Current distribution of SAV in Escambia Bay shows that most of the SAV losses that occurred during the 1950s to 1970s have been recovered. In Santa Rosa Sound and Pensacola Bay, SAV showed significant increased growth with horizontal growth rates of some beds averaging more than 50 cm over the past year. In Big Lagoon, however, SAV has declined an average of 10 cm in horizontal coverage along the deepwater edge. Water quality and photosynthetically active radiation light measurements from the Escambia–Pensacola Bay System suggest that increased light availability was associated with the increased seagrass coverage in Santa Rosa Sound and Pensacola Bay, and elevated nutrient concentrations were associated with the seagrass declines in Big Lagoon.

Submerged aquatic vegetation (SAV) has been widely recognized for its importance in the sustainability and ecological function of aquatic habitats (e.g., Kenworthy et al., 1988; Fredette et al., 1990). Both declines and recoveries of SAV have been documented in estuaries throughout the United States and Gulf of Mexico (e.g., Olinger et al., 1975; Robbins, 1997; Tomasko and Ried, 1997). Two Gulf of Mexico estuaries, Florida Bay (Roblee et al., 1991) and Laguna Madre (Dunton, 1994), have recently undergone major declines in these important habitats. Declines in SAV are often associated with changes in the water quality of the ecosystems (Dennison et al., 1993). Changes in coverage of SAV beds are important and may be useful in establishing indicators of future adverse impacts. Annual monitoring of individual SAV beds or discrete sites is needed to determine if incremental changes are a problem for Gulf of Mexico estuaries in general. Annual monitoring in conjunction with water quality monitoring can improve our understanding of the factors that affect SAV survival and distribution.

The SAV in the Escambia–Pensacola Bay System underwent a substantial decline in the late 1940s through the early 1970s (summarized by the U.S. Environmental Protection Agency [EPA], Olinger et al., 1975). Although scientific documentation of SAV distribution since that time is lacking, some observations suggest SAV growth in the oligohaline regions of estuaries in northwestern Florida has shown recent improvements (i.e., Mobile Bay, Escambia Bay and Perdido Bay: J. Stout and W. Davis, pers. comm. and unpubl. data). There is also evidence to suggest that these same areas are losing SAV in the euryhaline regions (Heck et al., 1996). Improvement in water quality of the upper bay regions is thought to be leading to recovery of low salinity grasses such as *Vallisneria americana,* whereas the continuing increases in coastal development in the lower bay region, with resulting increased nutrient input and sediment loading/resuspension, may be having an adverse impact on the health and productivity of high salinity grasses such as *Thalassia testudinum.*

Water quality and the associated effects on light availability are generally considered to be the major factors related to SAV survival (e.g., Kenworthy and Haunert, 1991; Tomasko and Lapointe, 1991; Dennison et al., 1993; Stevenson et al., 1993) and depth of distribution (Dennison, 1987; Dawes and Tomasko, 1988; Duarte, 1991). Duarte (1991) suggested a linear relationship between depth of colonization and the light attenuation coefficient. The ecological assessment team of the U.S. EPA Gulf Ecology Division (GED) initiated a water quality monitoring program and has been collecting data quarterly in the Escambia–Pensacola Bay System since May 1996. The location of the sampling stations is based on a probabilistic design that can be extrapolated to provide con-





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ditions over the entire bay system. There were two objectives of this research; the first was to map the current distribution and condition of SAV beds at several sites in northwestern Florida relative to historical distributions, and the second was to examine the relationship between changes in SAV beds and changes in water quality in the study area. To accomplish these objectives, two techniques for mapping and monitoring SAV beds were initiated to link annual changes in SAV with changes in water quality. Understanding the relationship between water quality and SAV survival and distribution will improve predictive abilities for management purposes.

MATERIALS AND METHODS

U.S. Geological Survey (USGS) Aerial Mapping.—The USGS National Wetlands Research Center in Lafayette, LA produced maps of SAV along much of the Gulf of Mexico on the basis of photo interpretation of aerial photographs (1: 24,000 resolution) taken in 1992. The mapping standards followed the National Oceanic and Atmospheric Administration C-Cap protocols (Dobson et al., 1993). Processing and classification followed the National Wetlands Inventory protocol (Cowardin et al., 1979). Horizontal positional accuracy is within 12.2 m. Maps of the SAV in Escambia and Santa Rosa County based on those aerial photographic interpretations are included (Fig. 1).

Escambia River Delta visual survey in conjunction with differential global positioning system (DGPS) mapping.—The survey of Escambia Bay was conducted with a small boat piloted along the shoreline or along the visible edge of grass beds around the entire perimeter of Escambia Bay from the entrance of Bayou Texar to Garcon Point (Fig. 1). In 1997, a Magellan® (Magellan Systems Corp., San Dimas, CA) handheld global positioning system was used to record the position of the edge of the grass beds and significant points such as corners, ends, and beginnings of beds. Accuracy of this system was estimated to be ±50 m. When necessary, grasses were collected by coring for identification (Tarver et al., 1978). In 1998, a Northstar 951XD® (NorthStar Technologies, Action, MA) DGPS was obtained, improving accuracy from 50 m to less than 5 m. This unit was used to more precisely define the margins of the beds in upper Escambia Bay, again from a small boat following the outer margins of the bed or near the shoreline where grasses were not present.

Pensacola Bay, Santa Rosa Sound, and Big Lagoon monitoring of deepwater margin.—Pensacola Bay is a deepwater bay with a pass connecting directly to the Gulf of Mexico and receiving freshwater inputs mainly from Escambia Bay and East Bay. Santa Rosa Sound is a long narrow body of water with openings to Pensacola Bay on the west end and Choctawhatchee Bay on the east end. There are no significant sources of freshwater input to Santa Rosa Sound other than the bays at either end. The northern shore of the sound and the portion of Santa Rosa Island around Pensacola Beach, FL, are areas under rapid development (Fig. 2). Big Lagoon is a relatively enclosed body of water bounded by Perdido Key on the south and the southwest corner of Escambia County mainland on the north. Big Lagoon is connected to Pensacola Bay and Perdido Bay via the Intracoastal Waterway (Fig. 2).

To monitor SAV beds in Pensacola Bay, Santa Rosa Sound, and Big Lagoon, a series of 10 sites was selected to measure the changes in the deepwater margin of the SAV beds. The sites were chosen to provide a general coverage of the existing SAV beds in the area monitored for water quality. Site selection was based on our best judgment in an attempt to select a range of impacted and unimpacted areas and to provide a range of responses to correlate with changes in water quality. When possible, sites were located along the margins of SAV beds where other research was, or is, being conducted.

Because SAV beds in Pensacola Bay, Santa Rosa Sound, and Big Lagoon are often found in water more than 2 m deep and are often not clearly visible from the surface, divers were used to mark the existing deepwater margins

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Fig. 1. (A) Map of SAV beds in Escambia Delta based on aerial color photographs taken in 1992 and photo interpretation by USGS. Legend refers to habitat type (EST = estuarine, LAND = upland, RIV = riverine) or density of SAV beds (PSG1 = very sparse, PSG2 = sparse, PSG3 = moderate, PSG4 = dense, CSG = continuous SAV beds, UNK1 = unknown). (B) Perimeter of SAV beds in Escambia Bay mapped by direct observation from a small boat with DGPS. Boxes with asterisks mark areas of notable change from the USGS map.

TABLE 1. Change in SAV deepwater margins (mean horizontal growth relative to 30 stakes[a]) at sites in Santa Rosa Sound, Pensacola Bay, and Big Lagoon, FL, between July 1997 and July 1998. Mean attenuation coefficients (n = 2) and Secchi depths are from measurements made during site visits in 1997 and 1998.

Site	Mean change[b] (cm)	Mean 1-m attenuation coefficient (m^{-1})		Secchi depth (m)	
		1997	1998	1997	1998
East Sabine	46.9 (33)	0.94	1.0	1.9	>1.8
West Sabine	51.7 (25)	0.87	1.4	1.9	1.8
Deer Point	60.4 (39)	1.4	0.93	2.1	>1.2
Fair Point	57.4 (47)	1.3	ND[c]	2.1	ND
Naval Oaks	26 (26)	1.3	1.3	>1.5	1.2
Tiger Point	19.6 (18)	1.3	0.92	1.1	1.8
Range Point	20.8 (17)	0.9	1.0	1.9	1.5
Big Sabine	44.2 (31)	1.1	1.1	1.8	>1.6
Navarre	24.8 (33)	1.6	1.4	1.5	>1.5
Big Lagoon	−10.1 (88)	0.85	2.1	>0.7	>0.6

[a] One to three stakes were missing from three sites.
[b] SD in parentheses.
[c] ND, not determined.

beginning on 30 June 1997. The SAV beds in these areas were mostly *T. testudinum* Banks *ex* König and *Halodule wrightii* Aschers. Divers marked the deepwater margins of selected SAV beds with stakes made of polyvinyl chloride pipe (approximately 2.5 cm × 50 cm) at 3-m intervals, leaving approximately 10–15 cm of the pipe exposed above the sediment. Thirty stakes were deployed at each site to provide a sound statistical measure of the changes in SAV beds. Latitude and longitude of each site, approximate depth, and dominant species of SAV were recorded. After 1 yr (30 June 1997–13 July 1998), the divers returned to the stakes and measured the horizontal change in the margins to the nearest centimeter with rulers. Data were recorded underwater, and divers generally noted the species and density of the grass at each of the stakes. Hydrological parameters—salinity, temperature, pH, and Secchi disk transparency depth measurements—were measured from the boat during each visit.

Water quality and light monitoring.—The water quality monitoring program being conducted throughout the Escambia–Pensacola Bay System on a quarterly basis provides a statistically based assessment of water quality changes throughout the system. Water quality data have been collected at 39 stations in Escambia and Pensacola Bay since May 1996, at 37 stations in Santa Rosa Sound since June 1997, and at two stations in Big Lagoon since November 1997. Ninety-seven stations were sampled in Escambia and Pensacola Bay during the first year (1996) to determine if a lower sampling density was adequate for extrapolation. The data collected include hydrological measurements of salinity, pH, temperature, and dissolved oxygen that were taken using a Hydrolab H20 Sonde®[1] (Hydrolab, Inc., Austin, TX) and measurements of light penetration at an interval of 1 m from the surface to the bottom. In addition, surface water samples were collected for measurement of dissolved inorganic nutrients, chlorophyll *a*, particulate carbon and nitrogen, and dissolved organic carbon and were filtered on site, frozen on dry ice for transport back to the laboratory, then stored at −70 C until analyzed. Ammonium, nitrate, nitrite, ortho-phosphate and silica concentrations were obtained with an Astoria Pacifica® autoanalyzer (Astoria Pacifica Inc., Calackamus, OR).

Photosynthetically active radiation (PAR) light measurements were determined with a LI-COR® LI-1000 digital data logger and light meter with dual quantum (2π) light sensors (LI-COR, Inc., Lincoln, NE) and Secchi disc transparency depth. Light was measured simultaneously above the water surface (ambient light) and at intervals of 1 m from the surface to the bottom. The underwater sensor was lowered to just below the surface of the water, and the outputs from both the surface sensor and the underwater sensor were recorded. The underwater unit was lowered in 1-m intervals, repeating the process until the underwater sensor reached bottom. The depth of the bottom was recorded, and the process was repeat-

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[1] Mention of trade names does not constitute endorsement by the U.S. Environmental Protection Agency.

ed as the underwater sensor was raised to the surface, providing two measurements at each depth. Intensity readings for each depth were averaged, and the attenuation coefficients for each depth were calculated with the use of the pairs of simultaneous readings of underwater and surface light intensity. A station for monitoring PAR light availability was established on the west dock of Sabine Island (near the center of the study area) in October 1996. Light was measured around noon, usually on a daily basis. These measurements also included simultaneous surface irradiation and underwater measurements as described above and provided some additional insight into short-term changes in light availability due to surface irradiation and water column attenuation.

RESULTS

Escambia Bay.—Maps of SAV coverage in Escambia Bay based those generated from the 1998 DGPS survey show an increase in SAV distribution when compared with the USGS maps from the 1992 aerial survey (Fig. 1). Some of the areas where SAV margins increased by more than 10 m (alongshore or offshore) or beds that were not found in the USGS survey are marked in Figure 1B.

The dominant SAV in Escambia Bay is *V. americana* Michaux, and from our observations, it is estimated to constitute greater than 80% of the total SAV. *Ruppia martima* L. was found in a well-established bed (solid coverage) southwest of the mouth of Escambia River, in patchy beds (less than 50% coverage) off the mouth of Indian and Trout Bayou on the east shore of Escambia Bay, and in sparse beds (less than 10% coverage) covering several 100 m^2 in Mulatte Bayou. The only other SAV observed in Escambia Bay was a *Myrophyllum* sp. L. that was found intermixed with *V. americana* in some of the beds in upper Escambia Bay. Most of the beds observed appeared healthy and without epiphytes, and many were flowering profusely. However, some of the smaller patches (less than 5 m across) were covered with epiphytes where there was a notable absence of gastropods. The major portion of the SAV in Escambia Bay is above the Interstate (I-10) Bridge. On the west side of the bay, only one *V. americana* bed less than 3 m across was identified south of the bridge. On the east side, only the *R. maritima* near Indian and Trout Bayou was found below I-10.

Pensacola Bay, Santa Rosa Sound, Big Lagoon.—Pensacola Bay, Santa Rosa Sound, and Big Lagoon were part of the area surveyed by the USGS with aerial photography in 1992 (Fig. 2). To date, the USGS survey may be the only complete survey of SAV in Santa Rosa Sound and Big Lagoon. The seagrass beds in this area are extensive and are populated mostly by *T. testudinum* and *H. wrightii,* although *Syringodium filiforme* Kützing is interspersed (pers. obs.).

Results of the first-year measurements of horizontal changes in the deepwater margins of selected *T. testudinum* and *H. wrightii* beds from Santa Rosa Sound, Pensacola Bay, and Big Lagoon are shown in Figure 3. The measurements represent the distance that the margin of the bed changed relative to the individual markers deployed along the deepwater margins in 1997. Although 30 stakes were deployed at each site, there were several sites where one to three stakes were missing. New stakes were deployed to replace missing stakes along the current margin at those sites. Most of the seagrass beds showed increases in coverage (Table 1). Only the seagrass bed at the Big Lagoon site had an overall decline (negative average).

The maximum horizontal growth rate of *T. testudinum* observed for the 1-yr period in this study was 175 cm at Deer Point; however, maximum horizontal growth of *T. testudinum* in most beds was between 40 and 90 cm. For *H. wrightii,* the overall maximum horizontal growth rate observed in this study was 205 cm at Fair Point, whereas the maximum horizontal growth of most beds was between 80 and 120 cm. These maximum horizontal growth rates correspond to 0.48 $cm \cdot d^{-1}$ for *T. testudinum* and 0.56 $cm \cdot d^{-1}$ for *H. wrightii.* Using an average growth rate of 50 cm observed at many of the beds, the average daily growth is approximately 0.14 $cm \cdot d^{-1}$. These growth rates correspond to 270 $m^2 \cdot km^{-1}$ of grass bed perimeter in the east end of Santa Rosa Sound and 540 $m^2 \cdot km^{-1}$ in the west end of Santa Rosa Sound and Pensacola Bay. SAV beds are almost continuous on both sides of Santa Rosa Sound from Navarre to the west end of the sound. Assuming a linear edge of SAV on both sides of the sound over a distance of approximately 30 km, this represents a net increase in coverage of more than 1.6 hectares. Given the higher growth rate at the west end and including the SAV beds in Pensacola Bay, the total area of new coverage is probably closer to 2 hectares.

Light.—The results of PAR light intensity readings from Sabine over the past 1.5 yr show periods of high ambient light (Fig. 4) and de-

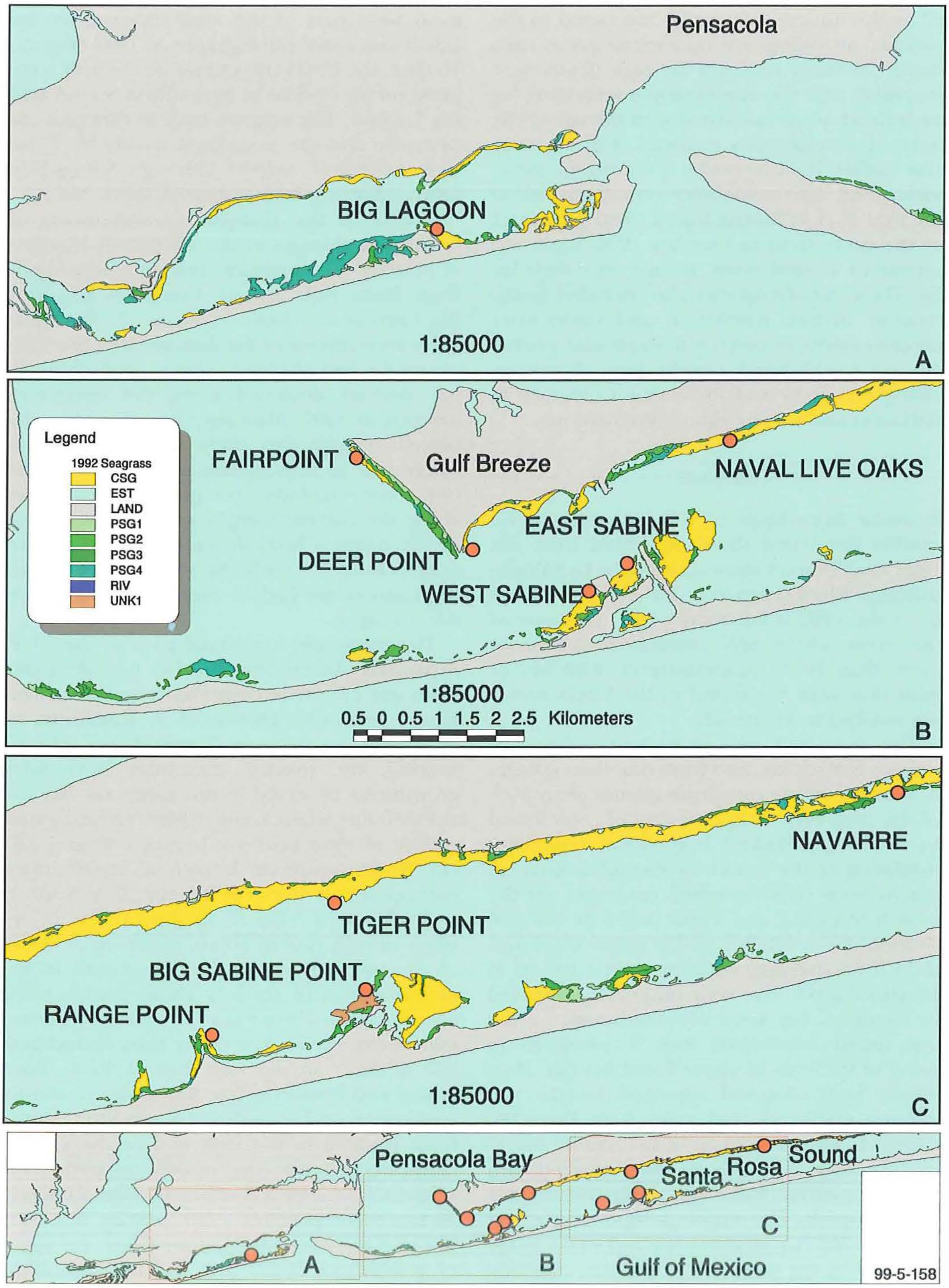

Fig. 2. Map of SAV beds in Big Lagoon, Pensacola Bay and Santa Rosa Sound based on aerial color photographs taken in 1992 and photo interpretation by USGS. Legend is the same as in Figure 1. Location of sites for monitoring the deepwater boundary are indicated.

TABLE 2. Summary of quarterly water quality data collected from areas near SAV study sites from November 1996 through February 1998. Light, pH, salinity, and temperature measurements are means of measurements made at 1-m depth. Units of light measurements are $\mu mol \cdot m^{-2} \cdot s^{-1}$).

Group location	Water quality parameter (units)	Mean value or concentration	Standard deviation
Pensacola Bay (four sites)	NH_4 ($\mu g \cdot l^{-1}$)	4.9	12
	$NO_2 + NO_3$ ($\mu g \cdot l^{-1}$)	13	18
	PO_4 ($\mu g \cdot l^{-1}$)	36	54
	Light at 1 m	452	310
	pH at 1 m	8.1	0.16
	Salinity at 1 m	20	6.4
	Temp at 1 m (C)	22	7.1
Santa Rosa Sound West (five sites)	NH_4 ($\mu g \cdot l^{-1}$)	3.4	7.3
	$NO_2 + NO_3$ ($\mu g \cdot l^{-1}$)	11	23
	PO_4 ($\mu g \cdot l^{-1}$)	2.5	4.0
	Light at 1 m	450	297
	pH at 1 m	8.1	0.18
	Salinity at 1 m	21	5.3
	Temp at 1 m (C)	22	6.0
Santa Rosa Sound East (20 sites)	NH_4 ($\mu g \cdot l^{-1}$)	2.8	5.8
	$NO_2 + NO_3$ ($\mu g \cdot l^{-1}$)	11	17
	PO_4 ($\mu g \cdot l^{-1}$)	4.9	3.9
	Light at 1 m	480	303
	pH at 1 m	8	0.17
	Salinity at 1 m	23	4.8
	Temp at 1 m (C)	22	6.6
Big Lagoon (two sites)	NH_4 ($\mu g \cdot l^{-1}$)	1.4	2.7
	$NO_2 + NO_3$ ($\mu g \cdot l^{-1}$)	73	83
	PO_4 ($\mu g \cdot l^{-1}$)	8.9	2.3
	Light at 1 m	400	294
	pH at 1 m	8.1	0.14
	Salinity at 1 m	23	11
	Temp at 1 m (C)	19	5.2

creased water column light attenuation (Fig. 5) during the fall of 1997. The ambient light intensity (Fig. 4) also shows a sustained period of relatively low light during the winter and early spring of 1998. The light intensity at 1 m shows the same general pattern, with only a few days in the fall of 1997 having intensity below 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and the winter/spring period having sustained periods below 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Attenuation coefficients at 1 m, calculated from the light intensity measurements at Sabine Island (Fig. 5), indicate that the water column transparency did not change much except for a significant decline in March 1998, which may be attributed to sediment-laden water from heavy rains and extremely high river discharge. The period of heavy rains was unusual in that surface salinity near this laboratory in Santa Rosa Sound was below five for several weeks. It is likely that most of the sites in this study were affected similarly considering the scale of these events.

Water quality.—Table 2 shows a preliminary summary of water quality and nutrient data that has been collected quarterly for the past 2 yr. The table shows means and standard deviations of nutrients, pH, salinity, and light at 1 m for each of the study areas (i.e., Pensacola Bay, Big Lagoon, East and West Santa Rosa Sound). Detailed reports of these measurements are the subject of another study and will be published elsewhere. The long-term goal of this project is to statistically analyze this type data for correlations between these water quality measurements and changes in the SAV growth. However, these preliminary summary data provide some insight into the causes of differences in SAV growth found in this study and may provide a point of focus for other studies. Total inorganic nitrogen (nitrate + ammonia) was similar across all areas except Big Lagoon, where mean total nitrogen was 74 $\mu g \cdot l^{-1}$ compared with means that were less than 18 $\mu g \cdot l^{-1}$ in the other sites. Phosphate was

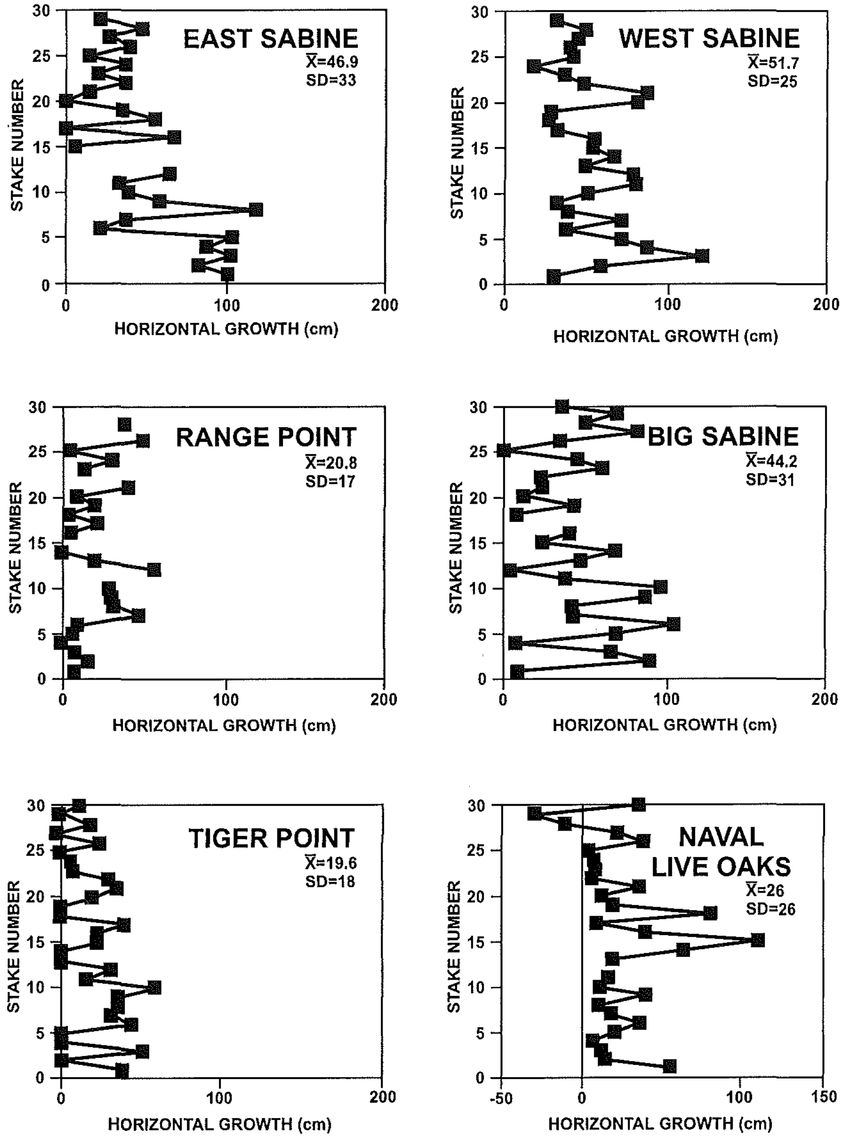

Fig. 3. Graphic representation of changes in deepwater margin of SAV beds relative to stakes deployed 1 yr earlier. The values are positive for increasing coverage and negative for decreasing coverage. Location of each site is shown in Figure 2.

highest in Pensacola Bay near the area of highest growth (36 $\mu g \cdot l^{-1}$), followed by Big Lagoon (8.9 $\mu g \cdot l^{-1}$). Mean light at 1 m was lowest in Big Lagoon (400 $\mu moles \cdot m^{-2} \cdot s^{-1}$ compared with more than 450 in other areas). Mean values for salinity were the same for all areas; however, the standard deviation of salinity measurements was more than twice as high in Big Lagoon and thus may not eliminate salinity as a contributing cause of decline in SAV in Big Lagoon.

DISCUSSION

Olinger et al. (1975) documented a significant decline in SAV in Escambia Bay from the late 1940s through the early 1970s (Fig. 6). Few surveys of the SAV in Escambia Bay have been conducted since 1975. The recent USGS and DGPS surveys document a significant improvement in SAV coverage relative to the last years of the report by Olinger et al. (1975). Possible reasons for the decline of SAV in Escambia Bay observed by Olinger et al. (1975) included

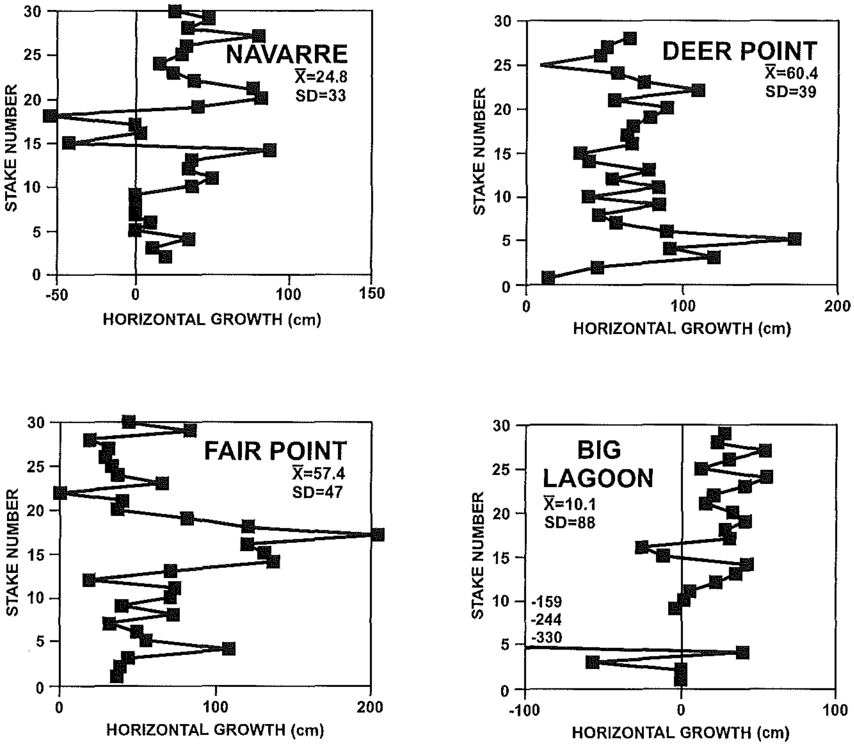

Fig. 3. Continued.

high nutrient input as a primary cause. Since 1975, improvements in water quality have been achieved through improved wastewater treatment to both the municipal and industrial effluents that were cited in Olinger et al. (1975). In that report, annual mean dissolved inorganic nitrogen (DIN = nitrate + nitrite + ammonia) for Escambia Bay was >120 $\mu g \cdot l^{-1}$; in contrast, recent mean DIN was <60 $\mu g \cdot l^{-1}$ for nine stations in Escambia Bay on the basis of our quarterly monitoring from May 1996 through February 1998. Although most of the recovery is currently limited to the upper regions of Escambia Bay, there are some small SAV beds beginning to develop in the middle portions of Escambia Bay on the east and west sides. Because the SAV beds in the Escambia Delta were never completely eliminated, they apparently have been able to rapidly exploit the improving conditions.

The various techniques used to map and

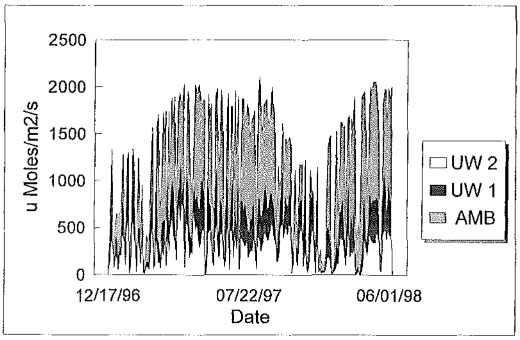

Fig. 4. PAR light intensity measurements taken at Sabine Island. AMB represents surface light intensity, UW1 is light intensity at 1 m below the water surface, and UW2 is light intensity at 2 m below the surface.

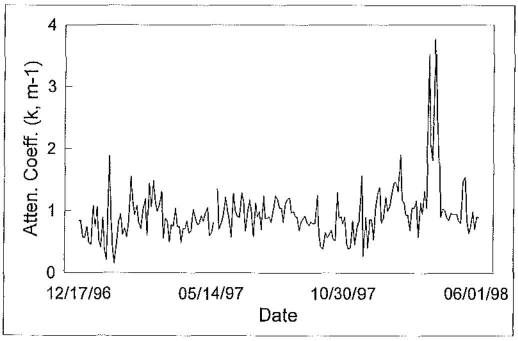

Fig. 5. Attenuation coefficients (k) calculated from PAR light measurements shown in Figure 4.

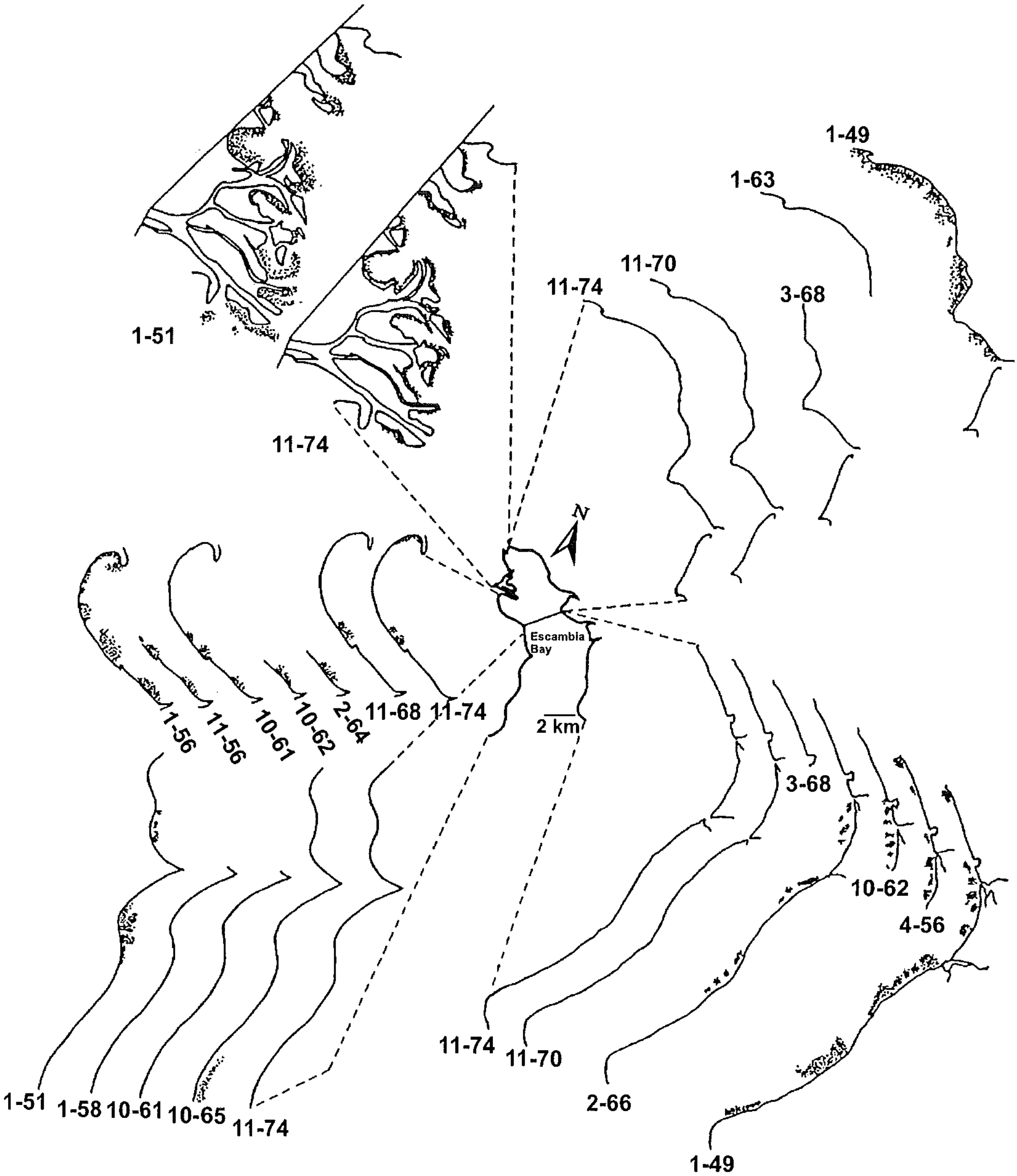

Fig. 6. Map of SAV distribution in Escambia Bay from Olinger et al. (1975).

monitor SAV have their advantages and disadvantages. The maps of the decline of SAV beds in Olinger et al. (1975) were generated from black and white aerial photographs. More sophisticated geographic information systems (GIS) and photo interpretation techniques based on remote sensing or color photography are now used. Aerial photography and photo interpretation are relatively expensive and require sophisticated equipment and photo interpretative skills that are not widely available. Conditions required to obtain suitable photographs can be restrictive. Processing of the data can require a significant period of time, and significant effort must be devoted to ground truthing. The area that can be mapped in this manner is extensive and it provides a valuable reference for the future. The accuracy of this technique is generally in the 3–5-m range (Art Calix, USGS, pers. comm.) but is dependent on the altitude of the photography. Robbins (1997) reported the accuracy in lo-

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cation of seagrass polygons in the range of 15–30 m based on 1:24,000 photography. Overall, aerial photography and photo interpretation provide a comprehensive assessment of SAV distribution, but this method is time consuming and expensive and requires specialized skills.

The use of DGPS and direct observation can be limited by water depth and clarity if the grasses are not apparent from the surface. However, although most of the difference between the USGS map and the current map (Fig. 1) is probably because of increased growth of SAV; part of the difference may be attributed to an increased ability to see the submerged grass through the opaque water from the surface. The accuracy of DGPS is also in the 3–5-m range. If applied on an annual or biannual basis, it can provide an indication of trends on a time basis of 3–5 yr. It is not labor intensive: the entire Escambia Delta area was mapped in less than 3 days. This technique is best applied when the grasses are at their maximum growth (August–September) during low tides or periods of high water clarity and bright sunlight. One other technique that was considered for mapping of submerged grass beds was hydroacoustics, but this technique does not work well in shallow turbid waters (pers. comm.).

The idea to monitor SAV beds through the measurement of annual changes in the deepwater boundary was based on the concept that the maximum depth of plant survival is associated with the plants' light requirements, and this method incorporates all of the light-limiting factors (i.e., suspended sediments, epiphyte growth, and water column chlorophyll). The technique of marking the deepwater boundary and measuring change is limited in its applicability to systems that offer sufficient water clarity to allow divers to make measurements and in the area that can be covered. This technique is expected to provide accurate and timely information on the rate and direction of change and, depending on the geography and choice of sites, can be representative of larger areas. The accuracy of this technique is in the centimeter range, and the relatively large number of measurements provides a good estimate of variability. This technique does require the use of divers, but it does not require expensive equipment. Overall, it is not labor intensive because an individual site can be measured by two divers in less than 2 hr. More frequent measurements and additional parameters (i.e., epiphyte load) could also be made. The results in this study suggest that the method is useful in measuring small short-term changes that may be associated with changes in water quality and/or light availability.

Water column transparency is not the only factor that affects the availability of light to SAV. Light availability to the plant leaf can be affected by epiphytes which can be affected by grazers as well as nutrient availability. There were no measurements of epiphyte loads in the first year of this study, and it is possible that changes in the epiphyte loading may have contributed to changes seen here. An estimation of the epiphyte load is planned for future visits to the study sites. Other factors that can affect growth are stressors such as bioturbation (Valentine et al., 1994), salinity, temperature and disease. Another factor that can affect the light availability to SAV is the total irradiance at the surface of the water. Total irradiance can be affected by climate factors such as cloud cover and atmospheric conditions. Changes in global climate may have significant positive or negative impacts on SAV growth because a heavy cloud cover can reduce surface irradiance by as much as 90%. Light intensity measurements made at Sabine Island over the past 2 yr (Figs. 4, 5) reflect both the water quality factors driven by nutrients, such as phytoplankton blooms, and those driven by climatic factors, such as changes in ambient light availability, wind driven resuspension, and riverborne turbidity. It is possible that the period of increased light availability in the fall of 1997 (Figs. 4, 5) is related to the increase in SAV growth in the Pensacola Bay—Santa Rosa Sound area. This assumption is based on the fact that cloudy conditions and reduced water transparency through much of the spring of 1998 do not appear to meet the minimum light requirements of *T. testudinum* (Fourqurean and Zieman, 1991). It is expected that suggestions such as this can be tested statistically as the study continues.

Fourqurean and Zieman (1991) have described the whole plant carbon budget for *T. testudinum* in Florida Bay and provided a measure of minimum light required to produce growth. On the basis of their irradiance curves, a midday irradiance of just over 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ is needed to provide a positive carbon budget. However, because *T. testudinum* in this area has a dormant season, it is possible that grasses in northwestern Florida may require more light during the growing season to meet respiration requirements during the dormant season. On the basis of the regression formula for the depth of colonization and attenuation coefficient for *T. testudinum* given by Duarte (1991), an attenuation coefficient of 1

m^{-1} should result in a colonization depth of approximately 1.87 m. This value is fairly close to the colonization depth found throughout most of Pensacola Bay and Santa Rosa Sound, and, as can be seen in Figure 5, the average attenuation coefficient at 1 m was approximately 1 m^{-1} over the past year. There was a significant period in the fall of 1997 when the attenuation coefficient was less than 1 m^{-1}, which would therefore support growth at greater depths.

The technique of marking the deepwater SAV margin used in this study allows an accurate measurement of horizontal growth rates. Our annual growth rates *in situ* averaged 20–50 $cm \cdot yr^{-1}$ (0.05–0.15 $cm \cdot d^{-1}$) and are similar to *in situ* rates reported by Klady and Dunton (2000) in Texas where the growing season is similar. In microcosm experiments on effects of nutrient enrichment, Lapointe et al. (1994) reported horizontal growth rates for *H. wrightii* and *T. testudinum* of 0.11 and 0.06 $cm \cdot d^{-1}$, respectively, in control treatments and lower rates in nutrient treatments. Growth rates at several sites in this study exceed those reported by Lapointe et al. for controls. Tomasko and Lapointe (1991) reported an average growth rate of 0.4 $cm \cdot d^{-1}$ over a 5-wk period for *T. testudinum* in outdoor aquaria with low nutrients. The maximum annual growth rate reported here is less than the daily rhizome growth rates reported by and Tomasko and Lapointe (1991), however the growing season in this area is significantly shorter than in South Florida, where there is no dormant season (dormant season here is at least 4 mo).

The summary of water quality data that has been collected quarterly for the past 2 yr from the local estuaries (Table 2) allows some insight into the driving forces affecting water column transparency. Grouping the mean growth rate of SAV beds for comparison with the water quality summary, the average growth for beds in the east end of Santa Rosa Sound (Naval Oaks, Tiger Point, Navarre, Big Sabine, and Range Point) was 27 $cm \cdot yr^{-1}$, while mean PO_4 was 4.9 (±3.9) $\mu g \cdot l^{-1}$. Phosphate was lower in the west end of Santa Rosa Sound (East and West Sabine and Deerpoint), 2.5 (±4.0) $\mu g \cdot l^{-1}$, and the average growth was 53 $cm \cdot yr^{-1}$. Total N was similar in the west and east ends of Santa Rosa Sound, 14 (±30) and 13 (±23) $\mu g \cdot l^{-1}$, respectively. In Big Lagoon, where the average SAV loss was 10.1 $cm \cdot yr^{-1}$, the total N was 74 (±85) $\mu g \cdot l^{-1}$ and PO_4 was 8.9 (±2.3) $\mu g \cdot l^{-1}$. However, the growth at Fair Point (the only site in Pensacola Bay) was 57.4 $cm \cdot yr^{-1}$, whereas the mean PO_4 was 35.8 $\mu g \cdot l^{-1}$ and the total N was 18 (±30) $\mu g \cdot l^{-1}$. The use of more site-specific nutrient data should allow a more precise nutrient correlation at all sites. These initial values suggest that nutrients, especially total N, are correlated with changes in SAV beds in the Pensacola–Escambia Bay system; however, a longer term study and more comprehensive statistical analysis will provide insight for environmental management decisions.

Big Lagoon is the only area with an overall loss in SAV coverage, and it has the highest average NO_2-NO_3 (73 ± 83 $\mu g \cdot l^{-1}$) and lowest mean light at 1 m (400 ± 294 $\mu mol \cdot m^{-2} \cdot s^{-1}$). The Big Lagoon area was first reported to be in decline by Heck et al. (1996). Reasons for the decline in Big Lagoon are unknown at this time; however, suggested causes include decreasing salinity, increasing nutrient input, and increasing turbidity (informal meeting in Pensacola, FL, held by Florida Department of Environmental Protection in 1998). Our data substantiate the decline reported by Heck et al.(1996) and suggest that nutrients and turbidity may at least in part explain this phenomenon. Housing development in this area may be contributing to changes in the salinity by increasing stormwater runoff or contributing to increased nutrient supply, but other physical factors such as the closing of an old channel and sediment resuspension from boat traffic may also be involved. Whether this SAV loss is because of changes in water clarity or other factors such as salinity change cannot be determined at this time. Further studies in this area are needed to determine the cause(s) of the loss.

Over the longer term, this study is expected to improve our understanding of the relationship between water quality and SAV distribution and allow more significant correlations between water quality and SAV response to be established. At this time, the data do not allow significant trends to be established; however, this study does include important observations supporting the decline in SAV in Big Lagoon reported by Heck et al. (1996) along with water quality measurements that provide insight into possible causes. The overall positive values seen here indicate that the perception of loss of high-salinity SAV in this area may be true only in Big Lagoon.

CONCLUSIONS

The techniques described in this study offer a relatively simple means for assessing short-term changes in SAV coverage on a timescale that can be associated with changes in water

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quality or ambient light availability. SAV in Escambia Bay, Pensacola Bay, and Santa Rosa Sound are showing significant improvements. More research is needed to establish the overall long-term trends in SAV growth in Santa Rosa Sound and the factors associated with the changes. Big Lagoon was the only area we observed that showed a decline in SAV coverage; however, more research is needed to establish the cause of this decline. This study will improve our ability to differentiate causative factors such as global climate change from local anthropogenic effects.

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