Effects of Season and Marsh Management on Submerged Aquatic Vegetation in Coastal Louisiana Brackish Marsh Ponds

by Joy H. Merino, John A. Nyman and Thomas Michot

Correct water depth is critical for increasing submerged aquatic vegetation in managed marshes along the Louisiana coast.

Keywords: marsh management, *Ruppia maritima*, submerged aquatic vegetation, coastal ecosystems, waterfowl management

Much time and many resources are spent managing coastal wetlands for the roughly four million waterfowl that winter in Louisiana marshes (Boesch and others 1994, Michot 1996). Waterfowl managers in coastal Louisiana often aim to increase submergent aquatic vegetation (SAV) abundance to support more waterfowl because duck populations in winter are believed to be food limited (Esslinger and Wilson 2001). Management of marshes with fixed-crest weirs increases SAV by minimizing fluctuations in salinity, water levels, and turbidity (Larrick and Chabreck 1976), but the effect of weirs varies from year to year (Nyman and Chabreck 1996).

Joanen and Glasgow (1965) reported a winter decline in Louisiana SAV—declines that may be caused by wintering waterfowl depleting SAV through feeding, or in response to seasonal changes such as water temperature or day length (Pulich, Jr. 1985). However, there are no data, other than that collected by Joanen and Glasgow (1965), relating SAV abundance on the Gulf Coast to waterfowl herbivory, and those results never have been replicated. Our objective was to document the effects of season and a new type of management on SAV abundance in order to determine what seasonal patterns exist, if any, and to determine if management was effective at increasing SAV. To determine why management was effective or ineffective, we also documented water quality parameters (salinity, temperature, water level, turbidity, and nutrients) and tested a second hypothesis in which we postulated that these parameters did not differ among the study areas or with SAV abundance.

Study Location

We conducted the study at Marsh Island, which lies on the coast of Louisiana between Vermilion Bay and the Gulf of Mexico (Figure 1). There are 76,570 acres (31,000 ha) of tidally influenced brackish marsh and interior ponds on the island. In 1920, the Russell Sage Foundation donated the island to Louisiana with the understanding that the state would manage it for wintering waterfowl in particular and wildlife in general. Shallow ponds on the island historically have served as feeding ground for millions of waterfowl each year (Louisiana Department of Wildlife and Fisheries, unpublished letter from McIlhenny and others to Viosca 1934).

Emergent vegetation at Marsh Island is dominated by saltmeadow cordgrass (*Spartina patens*). A study by Nyman and

Ecological Restoration, Vol. 23, No. 4, 2005 ISSN 1522-4740 E-ISSN 1543-4079

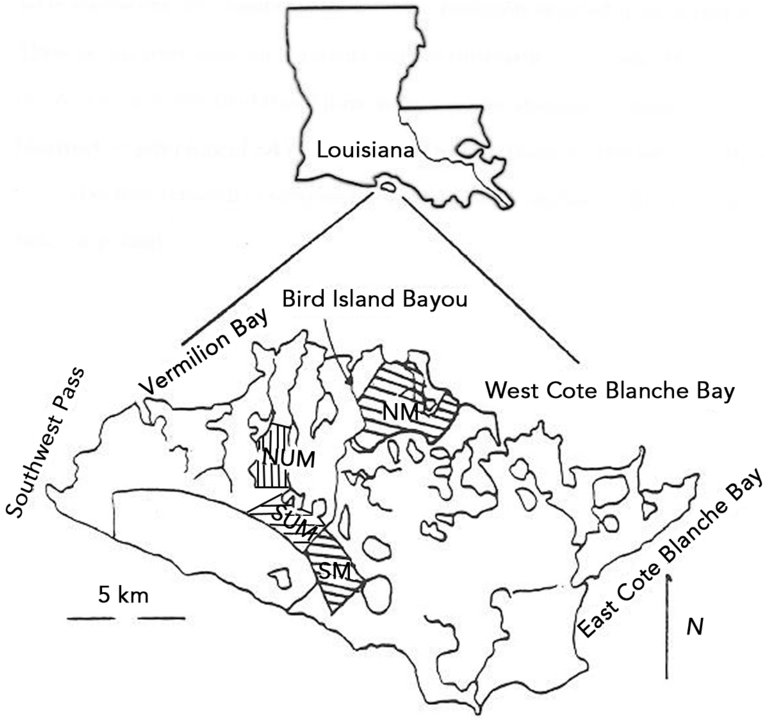

Figure 1. Study areas at Marsh Island, Louisiana. NM = North Managed, NUM = North Unmanaged, SM = South Managed, SUM = South Unmanaged.

Chabreck (1996) found that the four most abundant SAV species in order of abundance are: watermilfoil (*Myriophyllum spicatum*), widgeon grass (*Ruppia maritima*), wild celery (*Vallisneria americana*), and coontail (*Ceratophyllum demersum*).

Marsh Management

Although water levels are unmanaged on about 63,000 acres (25,500 ha) of Marsh Island, several large tracts are subject to active or passive water-level management. The largest managed area is a 7,904-acre (3,200-ha) impoundment constructed in 1958. About 3,700 acres (1,500 ha) are managed passively through the use of fixed-crest weirs that were also constructed in 1958 (Louisiana Wild Life and Fisheries Commission 1959). Fixed-crest weirs prevent ponds from draining more than 6 inches (15 cm) below marsh elevation during the low-water periods that occur periodically during winter. Previous studies have found that areas managed with fixed-crest weirs generally support more SAV than non-managed areas on the island (Nyman and Chabreck 1996), and that waterfowl are more abundant in weir-managed areas than in non-managed areas (Spiller and Chabreck 1975). There are concerns, however, that fixed-crest weirs reduce abundance of estuarine-dependent fish and crustaceans (Hoese and Konikoff 1995).

In 1993, the Louisiana Department of Natural Resources constructed a project, known as, TV-06 Marsh Island Control Structures (LDNR 1994). In that project, they used water control structures to actively manage two 988-acre (400-ha) management units. These units have identical structures, flap-gated culverts with variable-crest weirs, in the spoil banks that separate the units from canals dredged in the 1950s (LDNR 1994). The crest height determines the minimum water level in ponds. Flap-gates allow water to drain out of the units during low tides, whereas they restrict inflow during most high tides (Figure 2). Unlike traditional marsh management units throughout the southeastern United States, theses two units lack levees. The lack of levees allows water entry into the units during periods of higher water associated with occasional normal tides and frequent winter and tropical storms. Variable-crest weirs combined with flap-gated culverts allow managers to drain ponds (low crest, flaps down), hold water in ponds (crest 1 ft or 30 cm below marsh elevation, flaps up or down), or maximize water exchange (low crest, flaps up).

Project Goals

The goals of the TV-06 project were to improve the habitat by reducing land loss and to promote submerged and emergent aquatic vegetation in the two units (LDNR 1994). This project contained restoration and management aspects. It could be classified as restoration because it was designed to reduce tidal action in interior marsh ponds where tidal exchange had been increased by a navigation channel that was created during the 1950s to accommodate oil and gas exploration. It could be classified as management because it was designed to allow artificial drawdowns of interior marsh ponds. Throughout the rest of the article, we refer to the areas as management areas rather than restoration areas.

Hydrologic goals of management in these two study areas are 1) to reduce saltwater stress on marsh vegetation, 2) to retain water in the ponds for waterfowl during fall and spring, and 3) to facilitate the removal of water from the ponds during spring and summer to encourage plant germination and growth. Marsh managers assume that periodic removal of water from ponds (drawdown) promotes SAV by stabilizing sediments and thereby reducing turbidity (Chabreck 1994). McGinnis (1997) found that this management approach reduced marsh erosion rates in ponds smaller than 32.8 ft (10 m) in diameter within these two areas, but he did not study the effect on SAV abundance.

Experimental Design

We studied the two units constructed for the TV-06 project and two unmanaged areas (Figure 1). We refer to these areas as: North Managed (NM), North Unmanaged (NUM), South Managed (SM), and South Unmanaged (SUM). Each managed area has a flap-gated, variable-crest weir that separates the areas from the channels that were artificially deepened in the 1950s to accommodate navigation.

We found noticeable geomorphic differences throughout the landscape. Ponds in the north areas were more uniformly shaped (round) than ponds in the south areas. We accounted for such landscape variability in the experimental design by testing for differences among all four areas rather than assuming the two unmanaged areas were similar and the two managed areas were similar. Although this approach assumed that SAV abundance was similar among the four areas prior to management, testing for differences among all four areas allowed us to check, rather than assume, that the two unmanaged areas were similar and the two managed areas were similar during the study.

There are records for SAV abundance elsewhere on the island beginning in the 1950s (Nyman and Chabreck 1996), but not from our study areas. However, Orton (1959) made earlier observations that indicated no differences in emergent vegetation or degree of drainage among the study areas at Marsh Island. All areas were classified as having poorly drained soils and black rush-big cordgrass (*Juncus romerianus-Spartina cynosuroides*) vegetation. We, therefore, assumed that differences between managed and unmanaged areas resulted from management. If this assumption is false, then conclusions about the effects of management are likewise faulty.

Depth of ponds in all areas ranged from roughly 0.4 to 12 inches (1 to 30 cm) below the elevation of the adjacent marsh (McGinnis 1997). Pond depth did not differ between the NM and NUM, or between the SM and SUM (McGinnis 1997).

Within each of the four study areas, we numbered all ponds measuring between 115 and 541 ft (35 and 165 m) in diameter with the aid of aerial photographs. We then randomly selected six numbered ponds in each area. From those six ponds, we used three for water and soil characteristics and three for SAV abundance studies in each area.

Figure 2. Flap-gated culverts with variable–crest weirs in the spoil banks that separate managed marsh units from canals. The managed units lack levees, allowing water entry into the units during periods of higher water associated with occasional normal tides and frequent winter and tropical storms. *Photo courtesy of Joy Merino*

Measuring SAV Abundance, Water Parameters, and Sediment Characteristics

SAV Abundance

We measured SAV abundance every six to eight weeks between October 1998 and May 2000 by making estimates of biomass and percent cover. We used these two measures because neither is effective alone across a wide range of abundance. While biomass estimates are preferred, estimating the biomass of ponds is inefficient when SAV beds are small and few. At the other end of the spectrum, estimating the percent of pond bottom covered by SAV fails to provide meaningful information when SAV beds cover virtually the entire pond bottom. Estimating both biomass and percent cover was an improvement over previous reports that have addressed temporal variation in abundance by sampling biomass only when it was at high levels (Fores-Verdugo and others 1988).

To estimate biomass per square meter, we collected 10-cm-diameter cores from five randomly selected points in each pond. We used the cores to extract all vegetation in the water column within the upward projection of the sampled area, and all sediment and root material down to a depth of at least 11.7 inches (30 cm). We kept all material retained by a 2-mm sieve (Ellison and others 1986). Our method also allowed us to estimate the biomass of SAV per square meter of a bed by ignoring cores lacking SAV.

In the lab, technicians separated SAV by species into live aboveground and live belowground biomass. Samples were placed on pre-weighed foil sheets and dried in a drying oven at 178°F (81°C) for a minimum of 72 hours. During data analysis, live aboveground and live belowground parts were pooled for all species except widgeon grass, which had easily distinguishable belowground tissues even when not intact. Other species' belowground tissues were visually indistinguishable.

We estimated percent SAV coverage (percent of pond bottom covered with SAV) using a sampling method described by Nyman and Chabreck (1996). This involved standing in an idling airboat and taking a grab sample from the pond bottom with a garden rake about every 10 ft or 3 m along two transects spaced roughly one-third the pond width apart. There were at least 20 grab samples per transect, with larger ponds resulting in more samples. Cover of SAV on each transect was calculated as the number of times SAV was present divided by the number of times the rake touched the pond bottom. Percent cover of SAV in the pond was estimated from the average of the two transects in the pond. We did not use visual estimates of cover because presence/absence data provides a better estimate of cover than visual estimates, which are subjective (Kershaw and Looney 1985, Moore and Chapman 1986, Bonham 1989), and because turbidity generally was great enough to obscure SAV even when SAV almost covered pond bottoms.

Because grab samples are equivalent to pins and the transect equivalent to a pin frame (Kershaw and Looney 1985, Causton 1988), the resulting percent cover estimates were biased upwards, as occurs with all pin or plot methods (Grieg-Smith 1964, Kershaw and Looney 1985, Moore and Chapman 1986, Bonham 1989). In fact, our technique biased cover upward more than pins would have because our rake grabbed from a 0.02-m^2 area. Nevertheless, they represent a valid estimate of the percent of the pond bottom covered by SAV beds because our plot size was similar to that recommended by Daubenmire (1968) for such a sampling method.

Although dwarf spikerush (*Eleocharis parvula*) and bacopa (*Bacopa monneri*) are not SAV, we included these species in the analysis of SAV because they are potential waterfowl food sources and occurred submerged in shallow areas of ponds where SAV grows.

Percent cover, biomass, and residuals of the model for percent cover and biomass were not normally distributed and variances were unequal. Because transformations of the data failed to normalize the data and ranking of the residuals failed to improve homogeneity of variance, statistical significance was determined with a randomization method described by Adams and Anthony (1996) to test the null hypotheses that 1) biomass and percent cover did not vary with time, and that 2) biomass and percent cover did not differ among the four areas.

Randomization is a method of resampling. This method compares the observed treatment sum-of-squares (*SS*) for the data to *SS* generated from observations randomly assigned to treatments. The frequency of observations in a treatment is maintained, the observed data are randomly assigned to treatments, and *SS* is calculated. The random assignment of observations to treatments and calculation of the *SS* is repeated 5,000 times. The frequency of randomly generated *SS* greater than or equal to the observed *SS* is an estimate of the likelihood of obtaining the observed *SS* by chance. Therefore, data may be analyzed without any assumptions of distribution. Using this methodology, we generated *SS* from a two-way ANOVA with percent cover or biomass as the dependant variable and time, area and the interaction between area and time as dependent variables. An alpha level of 0.05 was used to reject the null hypotheses. We obtained 95-percent confidence intervals by bootstrapping the means (Sokal and Rohlf 1995).

Water and Sediment Characteristics

We acquired water level, salinity, and temperature data from the Louisiana Department of Wildlife and Fisheries (LDWF) that they took from October 1998 to May 2000. A Yellow Springs Instruments (YSI) Model 6000 meter and data-logger recorded conductivity, salinity, temperature, and water level in each study area on an hourly basis. The sensor of the data logger was cleaned and calibrated to standards every one to two months by LDWF staff. The instrument determined salinity from conductivity and temperature, and water level from the water pressure detected by a pressure transducer. The LDWF staff used conventional survey techniques to determine elevation of the adjacent marsh surface relative to the depth sensor, and we expressed all water levels as relative to local marsh surface elevation.

Unfiltered water samples were collected in 500-ml polyethylene bottles from areas least disturbed by our boat activity. We also took turbidity readings at that time using a HANNA portable turbidity meter. The water samples were frozen until they could be processed by technicians at the National Wetlands Research Center. Samples were analyzed for nitrite, nitrate, and soluble reactive phosphate (SRP) by an automated segmented flow analysis in an Alpkem Flow Solution III autoanalyzer. Ammonium concentrations were determined by colorimetric analysis using an indophenol blue method (United States Environmental Protection Agency 1979). Dissolved inorganic nitrogen (DIN) was calculated as the sum of nitrate, nitrite, and ammonium readings.

We also collected a sample of the top 4 inches (10 cm) of pond bottom sediment from each pond. A representative sub-sample of sediment was dried in an oven at 177.8° (81°C) to obtain dry mass. Dried samples were then ignited in a muffle furnace at 752° (400°C) to obtain the ash weight (mineral content). We calculated the organic content by subtraction.

We decided not to use randomization methods for hourly recordings of salinity, temperature and water level because the sample size was too large (n = 58,560). Instead, we analyzed the daily means by repeated measures under the split-plot framework with salinity, temperature, and water level as the dependent variables and time, area, and the interaction as independent variables. We used an alpha level of 0.05 to reject the null hypotheses. Water nutrients and turbidity were analyzed by randomization as described earlier.

We examined the relationship between water quality variables and SAV abundance by using repeated measures under the split-plot framework with biomass and percent cover as dependent variables and area, time, and the water quality variable of interest as independent variables. Because SAV abundance and water quality characteristics were sampled on different dates, we created a new time variable that condensed all dates to within 30 days of one another. The means of hourly samples (salinity, temperature, and water level relative to marsh surface) for 30 days prior to collection of SAV abundance samples were used for analysis.

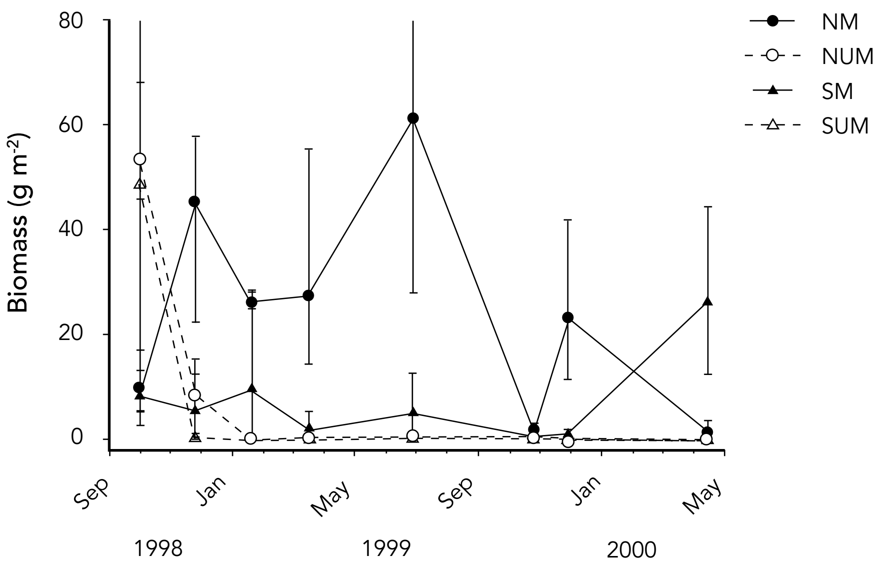

Figure 3. The mean biomass of submergent aquatic vegetation in the four study areas (NM = North Managed, NUM = North Unmanaged, SM = South Managed, SUM = South Unmanaged) on Marsh Island, Louisiana. Data is from October 1998 through May 2000 and is presented at 95-percent confidence intervals.

There were not enough new variable dates to allow for a model simultaneously relating all variables. Residuals of the model with biomass and percent cover as dependent variables and area and time as independent variables were analyzed for significant correlations with the water quality variable of interest.

We decided to analyze SAV and water quality characteristics by correlation without accounting for the effects of area and date, in addition to repeated measures described above, because area and time could be confounded with the effects of water quality characteristics. Moreover, if management was successful in altering water characteristics to promote SAV, then water characteristics would be confounded with area and date (management).

Results

SAV Abundance

We found that widgeon grass accounted for 92 percent of all SAV biomass (Table 1). Biomass of widgeon grass averaged 24 g/m^2 on a bed basis, but 7.6 g/m^2 on a pond basis. Biomass changed over time differently among the four areas ($P_{area * time} = 0.01$). Variability in biomass over time was evident more in the NM than in the other areas where biomass was generally low and invariable (Figure 3). Biomass was greater in one or both managed areas than in the unmanaged areas on five of the eight sample dates (Figure 3). Submerged aquatic vegetation averaged 17.2 g/m^2 in managed ponds, but only 4.1 g/m^2 in unmanaged ponds. Differences were also apparent between the two managed areas—the NM had more biomass than the SM area on four of the eight sample dates (Figure 3). Biomass in the unmanaged areas was never significantly greater than in the managed areas (Figure 3).

Widgeon grass was also the most abundant SAV species observed when estimating percent cover (Table 1). Out of 192 transects, 137 contained widgeon grass, while other SAV species were present in less than 23 transects. Cover of widgeon grass in ponds averaged 30 percent. Unvegetated bare sediment in ponds averaged 64.7 percent. Like biomass, percent cover changed over time differently among the four areas s ($P_{area * time} = 0.0236$), but percent cover showed differences among the areas not evident in the biomass data. Variability in percent cover over time was evident more in the unmanaged areas than in the NM where percent cover was generally high and invariable (Figure 4). Percent cover was significantly greater in one or both managed areas than in the unmanaged areas on seven of the eight sample dates (Figure 4). Cover averaged 54.4 percent in managed ponds and 12.7 percent in unmanaged ponds. Differences were also apparent between the two managed areas—the NM had a higher percent cover than the SM on five of the eight sample dates (Figure 4). Percent cover in the two unmanaged areas seldom differed from each other and never was greater than in the managed areas.

Percent cover and biomass data indicated that SAV abundance was greater in managed than in unmanaged areas, but percent cover and biomass were not linearly related (Figure 5). Percent cover estimates varied with SAV abundance only when SAV abundance was relatively low. Biomass estimates varied with SAV

Table 1. Abundance estimates for aquatic vegetation, bareground, and algae in ponds sampled using three methods at Marsh Island, Louisiana from 1998 to 2000. n = total number of samples from which means were calculated freq = number of samples in which a species was present.

	TRANSECT				CORE			
	n	freq	Cover (%)	SD	n	freq	Biomass(g/m^2)	SD
Widgeon grass (*Ruppia maritima*)	192	137	30.5	34				
Aboveground					324	99	4.9	21
Belowground					324	85	2.7	15
Watermilfoil (*Myriophyllum spicatum*)	192	22	2.3	10	324	2	0.03	0
Coontail (*Ceratophyllum demersum*)	192	15	1.8	8	324	0	0.0	0
Pondweed (*Potomageton pusillis*)	192	1	0.1	1	324	5	0.1	1
Spikerush (*Eleocharis parvula*)	192	11	2.5	12	324	2	0.06	1
Bacopa (*Bacopa monneri*)	192	1	0.2	2	324	0	0.0	0
Bareground	192	167	64.7	36				
Algae	120	47	17.8	33				

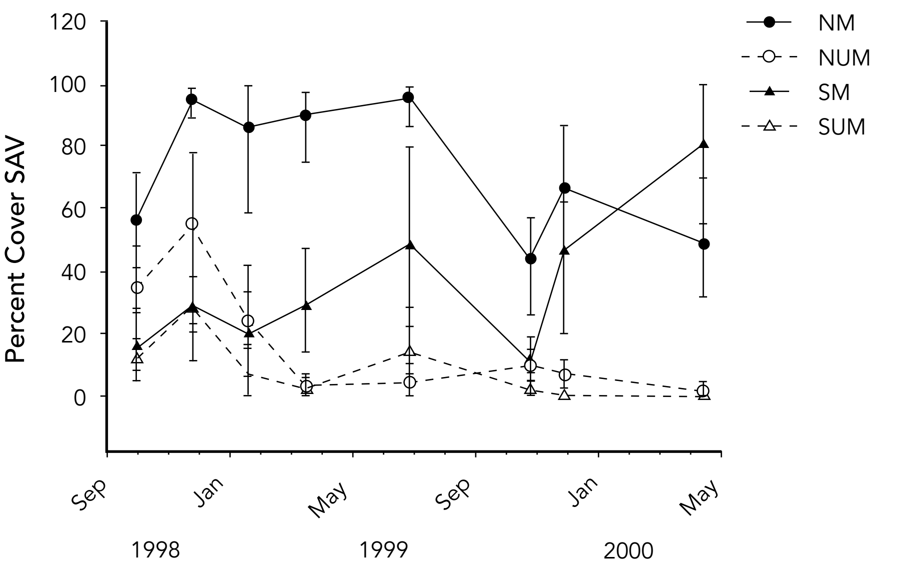

Figure 4. The mean percent cover of submergent aquatic vegetation in the four study areas (NM = North Managed, NUM = North Unmanaged, SM = South Managed, SUM = South Unmanaged) on Marsh Island, Louisiana. Data is from October 1998 through May 2000 and is presented at 95-percent confidence intervals.

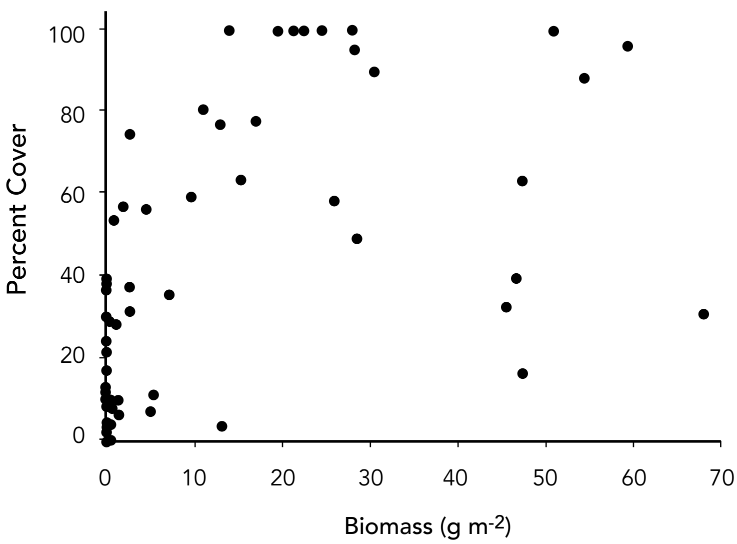

Figure 5. Percent cover data and biomass data showed no linear relationship. Biomass tended to be low and invariant when cover ranged from 0 to 50 percent, while percent cover tended to be high and invariant when biomass exceeded 10 g per m².

abundance only when SAV abundance was relatively high (Figures 3 and 4). As a consequence, biomass was low and invariant as cover ranged from 0 to 50 percent, and percent cover was high and invariant as biomass exceeded 10 g/m² (Figure 5).

Water and Soil Characteristics

After accounting for the effects of area and time, we found an inverse relationship between water level and percent cover ($P_{water\ level} = 0.0039$, r = -0.496), but not biomass ($P_{water\ level} = 0.9375$, r = -0.016). That is, as water level increased, SAV percent cover decreased. We also noted that water levels changed over time differently among the four areas ($P_{area\ *\ time} < 0.0001$; Table 2). Management increased water levels during the winter and reduced water levels during the summer, causing the daily mean water level relative to marsh surface to range from -2.0 to 2.2 ft (-0.61 to 0.66 m). In March 1999, the crest of weirs was 5.9 inches (15 cm) below marsh elevation to hold water in the managed ponds for waterfowl. The crests of the weirs were lowered in May 1999 to allow water to be drawn off the ponds to allow emergent vegetative growth. Water level in the SM was most variable—being higher than the other areas in winter and spring, and lower in the summer (Figure 6).

The SM also had higher soluble reactive phosphorus (SRP) concentrations than the unmanaged areas on five of the eight sampled dates. The NM also had higher concentrations of SRP than the unmanaged areas in September 1999. We found no differences in SRP concentrations among the areas from October 1999 to February 2000. Soluble reactive phosphorus was more correlated with SAV biomass than any other water quality characteristic ($P_{SRP} = 0.058$, r= 0.484; Table 3). As SRP in the water increased, so did SAV biomass.

After accounting for the effects of area and time, we found no significant linear relationship between SAV abundance and turbidity, salinity, water temperature or DIN (Table 2). Soil mineral and organic content did not differ among the four areas ($P_{area} = 0.43$). Highest turbidity was in late summer whereas lowest turbidity was in midsummer and fall. Southern areas, especially the managed area, had higher turbidity than the northern areas. Turbidity was not correlated with SAV abundance (Table 3).

Mean monthly salinity ranged from 1.2 to 16.5 parts per thousand (ppt). Salinity in all areas was higher in the second year of this study (a drought year) than in the first year, but salinity in the SM was usually more stable at about 4 to 8 ppt and did not show the extreme lows and highs shown in the other three areas. The NM, by contrast, usually tracked the unmanaged areas, although it sometimes lagged behind them during periods of increasing salinity and remained more fresh than unmanaged areas The SM had higher salinity than the other areas in February, March and July 1999 and May 2000, but lower salinity than the other areas in February 2000.

Salinity was not correlated with SAV abundance (Table 3).

Daily mean water temperature ranged from 40°F to 91.8°F (4.5 to 33.2°C) and exhibited a typical seasonal pattern. The SM often had cooler water than the other areas. Temperature was not correlated with SAV abundance (Table 3).

Discussion

We feel it is important to note that our sites are not atypical. The average biomass of widgeon grass in SAV beds in this study (24 g/m^2) was in the low range of previous reports. We could not compare our estimates of SAV biomass in ponds (7.6 g/m^2) to previous reports because we are unaware of any recorded biomass data on a pond basis. The average percent cover of widgeon grass in this study (30 percent) was within the range of other Gulf Coast reports for widgeon grass (Nyman and Chabreck 1996, Adair and others 1994).

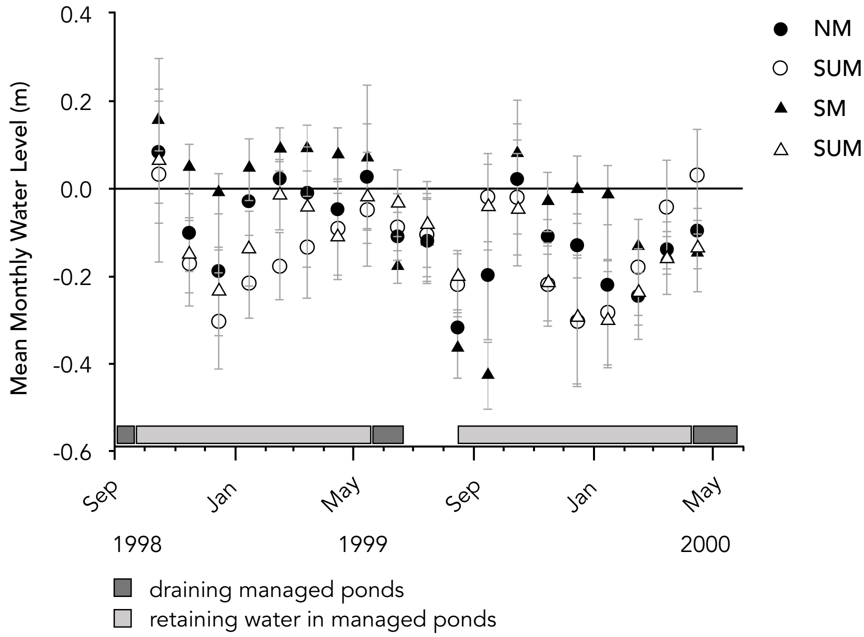

Figure 6. Mean monthly water level with standard error bars at four areas at Marsh Island, Louisiana from October 1998 to May 2000. Lines represent marsh elevation (0) and average pond depth (-0.3 m).

SAV Survey Methods

Our data suggest that neither biomass nor percent cover fully reflect spatial, temporal, and management-induced variability in SAV. We concluded that biomass samples are more suitable than percent cover when SAV beds dominate marsh ponds, but percent cover is more suitable when SAV beds are small and scattered. Our results are consistent with those of Adair and others (1994), who concluded that percent cover was more sensitive to species in low abundance. Percent cover and biomass describe different attributes of SAV abundance. Percent cover estimates alone could never reflect all the variability in abundance because biomass can increase after beds cover 100 percent of the pond bottom. Theoretically, biomass estimates could reflect all changes in abundance, even when SAV beds were small and scattered, if enough cores were collected from each pond. However, it took 19 times as long to estimate biomass per pond as it did to estimate percent cover per pond for this study. Although sampling five cores per pond was enough to detect differences among the study areas, it was not enough to detect differences when SAV beds were few and small. We calculated that to sufficiently estimate abundance using biomass, would take 105 times longer than using percent cover (28 cores per pond instead of five per pond). We therefore suggest that it is more efficient to estimate abundance with a combination of percent cover and biomass estimates than it is to use a small number of cores only where and when SAV beds dominate, or to exclusively use a large number of cores to estimate biomass.

Other Gulf Coast studies have reported two growing seasons (spring and fall) for widgeon grass (Joanen and Glasgow 1965, Pulich, Jr. 1985). Their conclusion that widgeon grass has two growing seasons has been used as the basis for scheduling SAV sampling (Nyman and Chabreck 1996). However, our results show neither clear seasonal patterns nor clear winter decline in SAV abundance. We may have failed to find a seasonal pattern because of the drought.

Management and Restoration of SAV

Although water control structures on managed study areas were planned, constructed

Table 2. Relationship of the area and time as main effects to water quality characteristics, and relationship with submerged aquatic vegetation abundance after accounting for any main effects. Data taken from October 1998 to May 2000 at Marsh Island, Louisiana.

	Area	Time	Area and Time	Cover		Biomass	
	P	P	P	P	r	P	r
Temperature (°C)			<0.0031	0.821		0.9014	
Level (m)			<0.0001	0.004	-0.496	0.9375	-0.016
Salinity (ppt)			<0.0001	0.395		0.6678	
Dissolved inorganic nitrogen (mg L^{-1})			<0.0001	0.766		0.8556	
Soluble reactive phosphorus (mg L^{-1})			<0.01	0.058	0.484	0.02	0.0573
Turbidity (NTU)	0.0001	0.0010	0.4100	0.4440		0.6209	

Table 3. Correlation between submerged aquatic vegetation abundance using two sampling methods and water quality characteristics. Data from October 1998 to May 2000 at Marsh Island, Louisiana. r = Pearson correlation coefficient

	Biomass (g/m^2)			Cover (%)		
	r	P	n	r	P	n
Temperature (°C)	-0.088	0.662	27	-0.153	0.446	27
Level (m)	-0.009	0.965	27	0.115	0.568	27
Salinity (ppt)	-0.094	0.643	27	-0.079	0.696	27
Dissolved inorganic nitrogen ($mg\ L^{-1}$)	-0.022	0.408	16	-0.226	0.399	16
Soluble reactive phosphorus ($mg\ L^{-1}$)	0.484	0.058	16	0.263	0.324	16
Turbidity (NTU)	-0.030	0.297	14	-0.300	0.297	14

and operated together, the results of management were not similar. The NM clearly had more SAV than the unmanaged areas. The SM occasionally had more SAV than the unmanaged areas, but usually less than the north managed area. The generally greater abundance in SAV in the managed areas indicated that management altered at least one environmental factor limiting SAV abundance, that being water depth. Water depth was the most likely factor affecting SAV, but other measured or unmeasured environmental factors also may have been important. For instance, a possible reason that we detected effects of water depth, but not turbidity or nutrient concentrations, on SAV abundance is that water depth and salinity were measured hourly throughout most of the 14-month study, but other variables were only measured when we sampled submerged aquatic vegetation. Assuming that the depths of managed ponds were nearly 1 ft (0.3 m) below the depth of other ponds in the area (McGinnis 1997), then water depths less than 1 foot but more than 4 inches (0.1 m) were correlated with greatest SAV abundance in these highly turbid ponds. We suggest that this range may be valuable to managers who are attempting to increase SAV in similar coastal brackish ponds.

The negative relationship between water level and SAV percent cover indicates that in managed areas of Marsh Island, alteration of water level, but not salinity or temperature, affected SAV. We attribute the negative relationship between water level and SAV percent cover to the attenuation of light in the water column even though water depth at Marsh Island was much less than other places where widgeon grass has been studied. In a review of widgeon grass depth limitations, Kantrud (1991) reported that the depth distribution of widgeon grass is governed by the susceptibility of bottom substrate to wind-induced turbidity. We suspect that the bottom substrate at Marsh Island was more susceptible to wind-induced turbidity than other places where widgeon grass has been studied. The study ponds were surrounded by Laffitte and Scatlake soils (United States Department of Agriculture 1979), which have 30 to 85 percent clay content (United States Department of Agriculture 1984). Those clay contents are much greater than in widgeon grass beds in Texas, which range only 0.5 to 21 percent clay (Pulich, Jr. 1985).

In the SM, the marsh was flooded from October 1998 to May 1999, which indicates control structures were inadequate to drain water. All areas, except the SM, are surrounded by natural ridges of high ground, whereas the SM is surrounded by man-made levees and spoil banks higher than natural ridges, and a high, natural beach rim to the south. Water drains to the north because elevations on the island are highest on the south and lower toward the north end of the island (Orton 1959). Spoil banks and levees northeast and northwest of the SM restrict water drainage to the north. Additional water control structures may be necessary to prevent marsh flooding in the south managed area. The highest SAV abundance in the SM occurred in the second year of the study, which was a drought year. It may be that the inadequate drainage was detrimental to SAV growth in a non-drought year and beneficial during a drought year.

Mean soluble reactive phosphorus (0.1 mg/L) was similar to the mean for Chesapeake Bay (0.089 mg/L) where SAV has been well studied (Boynton and others 1996). Phosphorus typically decreases rather than promotes SAV by increasing algal blooms (Harlin and Thorne-Miller 1981), but we found SRP in the water column to be weakly, but positively, correlated with increased SAV biomass. For instance, the SM had the highest recorded SRP level, but not the highest SAV biomass. For these reasons, we conclude that phosphorus does not promote SAV at Marsh Island and the statistical relationship was spurious.

Summary

We found SAV was generally more abundant in areas without levees that are managed with a water control structure that allows drawdown and prevents overmarsh water exchange. Although SAV was generally more abundant in managed than in unmanaged areas, the effect varied among areas and over time. Management was more effective in increasing SAV abundance in one area than another even though both managed areas were planned, constructed, and managed in a similar fashion. The difference in effectiveness probably results from differences in local drainage patterns attributable to spoil banks. Additional water control structures may be necessary to prevent marsh flooding in that area. We concluded water level governed SAV abundance. Submerged aquatic vegetation percent cover decreased with increasing water level probably because deeper water decreased light availability. The type of marsh management that we studied may be an improvement over traditional marsh management techniques because it is less intrusive since soil does not need to be excavated for levees and less expensive because soil does not need to be excavated nor levees constructed. It can, as we have demonstrated here, effectively increase SAV, which is an important aspect of waterfowl and nekton habitat.

ACKNOWLEDGMENTS

Funding and logistical support were provided by a contract from the Louisiana Department of Wildlife and Fisheries to J.A. Nyman and T. Michot (contract number CFMS #53756), and by the USGS National Wetlands Research Center, University of Louisiana at Lafayette (Department of Biological Sciences and Graduate Student Organization), and United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. We were assisted in data collection and sample processing by Edmond Mouton, Garret Thibodeaux, Sergio Merino, Alejandro Arrivillaga, Scott Kemmerer, Ron Boustany, Jacoby Carter, Louis Michot, and Megan Jennings. Robert Twilley, Paul Leberg, Beth Vairin, and Darren Johnson provided helpful comments to earlier drafts of this manuscript. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the United States government.

REFERENCES

Adair, S.E., J.L. Moore and C.P. Onuf. 1994. Distribution and state of submerged vegetation in estuaries of the upper Texas coast. *Wetlands* 14:1120-112.

Adams, D.C. and C.D. Anthony. 1996. Using randomization techniques to analyze behavioral data. *Animal Behavior* 51:733-738.

Boesch, D.F, M.N. Josselyn, A.J. Mehta, J.T. Morris, W.K. Nuttle, C.A. Simenstad and D.J.P. Swift. 1994. Scientific assessment of coastal wetland loss, restoration and management in Louisiana. *Journal of Coastal Restoration* Special issue No. 20.

Bonham, C.D. 1989. *Measurements for terrestrial vegetation*. New York: Wiley.

Boynton, W.R., J.M. Barnes, B.J. Weaver, L.L. Magdeburger and P. Sampou. 1996. Sediment-water fluxes and sediment analyses in Chesapeake Bay: Tidal fresh Potomac River and Maryland main stem. U.S. Army Corp of Engineers Report W-96-1.

Causton, D.R. 1988. *An introduction to vegetation analysis: Principles, practice and interpretation*. London: Unwin Hyman Ltd.

Chabreck, R.H. 1994. *Marsh management in Louisiana for production of emergent and aquatic plants*. Baton Rouge: Louisiana Landowners Association, Inc.

Daubenmire, R. 1968. *Plant communities*. New York: Harper and Row.

Ellison, A.M., M.D. Dertness and T. Miller. 1986. Seasonal patterns in the belowground biomass of *Spartina alterniflora* (Gramineae) across a tidal gradient. *Journal of Botany* 73:1548-1550.

Esslinger, G. and B. Wilson. 2001. North American Waterfowl Management Plan, Gulf Coast Joint Venture: Chenier Plain Initiative. Albuquerque, NM: North American Waterfowl Management Plan.

Fores-Verdugo, F.J., J.W. Day, Jr., L. Mee and R. Briseno-Duenas. 1988. Phytoplankton production and seasonal biomass of seagrass, *Ruppia maritima* L., in a tropical Mexican lagoon with an ephemeral inlet. Estuaries 11:51-56.

Greig-Smith, P. 1964. *Quantitative plant ecology*. London: Butterworths.

Harlin, M.M. and B. Thorne-Miller. 1981. Nutrient enrichment of seagrass beds in a Rhode Island coastal lagoon. Marine Biology 65:21-229.

Hoese, H.D. and M. Konikoff. 1995. Effects of marsh management on fisheries organisms: The compensatory adjustment hypothesis. *Estuaries* 18:180-197.

Joanen, T. and L.L. Glasgow. 1965. Factors influencing the establishment of wigeongrass stands in Louisiana. *Proceedings of the Southeastern Association of Game and Fish Commission* 19:78-92.

Kantrud, H.A. 1991. Wigeongrass (*Ruppia maritima* L.): A literature review. Fish and Wildlife Research10. Washington, D.C.: U.S. Fish & Wildlife Service.

Kershaw, K.A. and J.H.H. Looney. 1985. *Quantitative and dynamic plant ecology*. Baltimore, MD: Edward Arnold.

Larrick, W.D. and R.H. Chabreck. 1976. Effects of weirs on aquatic vegetation along the Louisiana coast. *Thirtieth Annual Conference of the Southeastern Association of Game and Fish Commission* 13:100-115.

Louisiana Department of Natural Resources (LDNR). 1994. Monitoring plan (revised) TV-06 Marsh Island control structures. Downloaded 29 July, 2003 from www.savelawetlands.org/site/Projects/tv06/tv06.html

Louisiana Wild Life and Fisheries Commission. 1959. Biannual Progress Report, 1958-1959, W-29-RII. New Orleans: Louisiana Wild Life and Fisheries Commission.

McGinnis, T. E. 1997. Shoreline movement and soil strength in a Louisiana coastal marsh. MS thesis, University of Southwestern Louisiana.

Michot, T.C. 1996. Marsh loss in coastal Louisiana: implications for management of North American *Anatidae*. *Gibier Faune Sauvage Game and Wildlife* 13:941-957.

Moore, P.D. and S.B. Chapman. 1986. *Methods in plant ecology*. Boston: Blackwell Scientific Publications.

Nyman, J.A. and R.H. Chabreck. 1996. Some effects of weir management on coastal marsh aquatic vegetation and implications to waterfowl management. *Gulf of Mexico Science* 14:16-25.

Orton, E.W. 1959. A geological study of Marsh Island, Iberia Parish, Louisiana. Technical report of the Louisiana Wild Life and Fisheries Commission. New Orleans: Louisiana Wildlife and Fisheries Commission, Refuge Division.

Pulich, W.M., Jr. 1985. Seasonal growth dynamics of *Ruppia maritima* L. s.l. and *Halodule wrightii* (Aschers) in southern Texas and evaluation of sediment fertility status. Aquatic Botany 23:53-66.

Sokal, R.R. and F.J. Rohlf. 1995. *Biometry: The principles and practice of statistics in biological research*. Third edition. New York: W.H. Freeman and Company.

Spiller, S.F. and R.H. Chabreck. 1975. Wildlife populations in coastal marshes influenced by weirs. *Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commission* 29:518-525.

United States Department of Agriculture. 1979. Soil survey of Iberia Parish, Louisiana. United States Department of Agriculture, Soil Conservation Service.

__. 1984. Soil survey of Lafourche Parish, Louisiana. United States Department of Agriculture, Soil Conservation Service.

United States Environmental Protection Agency. 1979. Methods of chemical analysis of water and wastes. USEPA-600/4-79-020. Cincinnati, OH.

Joy H. Merino is a fisheries biologist with the National Marine Fisheries Service, 646 Cajundome Blvd, Lafayette, LA 70506; 337/291-2109, Fax 337/291-2106, joy.merino@noaa.gov

John A. Nyman is an assistant professor with School of Renewable Natural Resources, Louisiana State University, Baton Rouge, LA 70803-5604; 225/578-4220, Fax 225/578-4227, jnyman@lsu.edu

Thomas Michot is a research wildlife biologist with USGS National Wetlands Research Center, 700 Cajundome Blvd, Lafayette, LA 70506; 337/266-8664, tommy_michot@usgs.gov