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SOME EFFECTS OF HERBIVORY AND 30 YEARS OF WEIR MANAGEMENT ON EMERGENT VEGETATION IN BRACKISH MARSH

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Abstract: Weirs are low-level dams used in Louisiana's coastal marshes to improve habitat quality for ducks and furbearers; however, some ecologists question whether weir management inhibits soil drainage and thereby negatively affects the emergent plant community. We compared the emergent plant communities of unmanaged marsh and marsh that was weir managed since 1958 at Marsh Island, Louisiana to test for management effects. Two data sets were analyzed: 4 permanent transects sampled 8 times between 1958 and 1988, and 44 random transects sampled in 1987. If weir management inhibited soil drainage, differences between weir managed and unmanaged marsh should have been similar to differences between naturally poorly drained and better drained marsh. Poorly drained marsh had lower species richness and diversity than better drained marsh, and poorly drained and better drained marsh differed in the importance of 4 major plant species. Neither species richness, species diversity index, major plant species, nor vegetative cover differed between weir managed marsh and unmanaged marsh in either data set. Analyses indicated that 4 minor species were negatively affected, and 2 were positively affected by weir management, but those results were not consistent in both data sets. Species richness and diversity index were negatively related to the frequency of nutria (*Myocastor coypus*), but species richness was positively related to the frequency of muskrats (*Ondatra zibethicus*). Incorrect conclusions would have been reached if variation in herbivore activity had not been noted. Although management may affect other marshes differently, any differences in emergent plant community structure between weir managed marsh and unmanaged marsh at Marsh Island are less than observed differences between naturally well-drained and poorly-drained marsh. The lack of a management effect was attributed to the lack of substantial soil drainage even in unmanaged marsh.

Key Words: estuary, brackish marsh, marsh management, herbivory, Louisiana.

INTRODUCTION

Marsh management is a common practice on the coasts of the Atlantic Ocean and Gulf of Mexico in the United States; such management is often directed at increasing submersed aquatic plants that are waterfowl foods (see articles in Smith et al. 1989). Despite the widespread practice of coastal marsh management to improve wildlife habitat, there are few reports of its effects on emergent marsh vegetation. Thus, a number of question have been asked regarding the ecology, management, and public policy of coastal marsh management on the Atlantic (DeVoe and Baughman 1989) and Gulf Coasts (Nyman et al. 1990).

A common marsh management technique in coastal Louisiana is the use of weirs without levees. Such areas are not defined as impoundments because they lack any means to prevent sheet flow of water over the marsh, and therefore they have not been included in previous reviews of marsh management (e.g., Day et al. 1990) . Weirs are constructed in the drainage systems of a marsh and function as low-level dams. The crest of the weir is usually set 15 cm below the elevation of the marsh surface so that the only great difference in water levels between weir managed marsh and unmanaged marsh is during low tides (Chabreck and Hoffpauir 1962) One purpose is to prevent complete drainage of tidally influenced water bodies when persistent north winds during winter months cause extremely low water levels (Chabreck and Hoffpauir 1962). Similar management on a smaller scale is practiced in some Chesapeake Bay marshes, where flashboards are used to prevent complete drainage of mosquito grid ditches (Hindman and Stotts 1989).

Weirs were first used in Louisiana to improve wildlife habitat. Wintering waterfowl and wading birds prefer weir managed ponds over unmanaged ponds (Spiller and Chabreck 1975), and weir managed ponds contain more submersed aquatic vegetation than unmanaged ponds (Chabreck and Hoffpauir 1962, Nyman and Chabreck, unpublished data). Weir management has also been used for over 30 years to prevent wetland loss in Louisiana (Berry and Voisin 1989). However, some researchers question whether weir management increases flooding stress on vegetation, which leads to wetland loss (see Nyman et al. 1990 and articles cited therein). This debate exists in part because the effect of weir management on emergent marsh vegetation is not known (i.e., does weir management impede soil drainage enough to increase plant stress and mortality?).

Although the primary purpose of weir management is to prevent complete drainage of marsh ponds, soil drainage in the marsh interior may also be affected. Some decrease in soil drainage is desirable in Louisiana brackish marshes because *Scirpus olneyi* (taxonimic authority for all species cited are provided in tables 1 and 2), a valuable wildlife food plant, grows better in flooded soil and often out-competes other plants (Hess 1975:38, Chabreck and Narcisse 1981). However, soil drainage can become so impeded that in salt marshes, sulfide-induced plant mortality can occur (DeLaune et al. 1983, Mendelssohn and McKee 1988).

Few reports have been published on the effects of weir management on emergent vegetation, and they were often contradictory. Neither Chabreck (1968), Larrick (1975), or Meeder (1989) found clear trends in plant species composition, richness, or cover when comparing weir managed marsh to unmanaged marsh, although Meeder (1989) noted that standing crop biomass appeared lower in managed marsh. However, these studies used a small number of transects and concentrated on the immediate vicinity of the weir managed ponds and unmanaged ponds.

Recent work at Marsh Island, Louisiana disclosed that weir management did not affect conversion of marsh to open water (Nyman et al. 1990) but increased the occurrence of important and preferred duck food plants in the submerged aquatic vegetation community (Nyman and Chabreck unpublished data). The purpose of the study described in this report was to test the hypothesis that emergent plant communities at Marsh Island, Louisiana were unaffected by weir management. Although weir management may affect other marshes differently than those at Marsh Island, this study may indicate how other coastal marshes respond to similar forms of minimal management. Particular attention was paid to minor species as well as major species because minor species may be more sensitive to soil drainage than major species, which are more tolerant of flooding. This detailed comparison of plant communities required that nutria and muskrat herbivory also be considered because of the role that these animals can play in the emergent plant community. Herbivory has long been known to impact coastal vegetation (O'Neil 1949, Harris and Webert 1962). Herbivore populations, particularly nutria (*Myocastor coypus*) and muskrats (*Ondatra zibethicus*), may be higher now than 10 years ago when trapping provided economic incentive to harvest large numbers of these animals (personal communication, G. Linscombe, New Iberia Field Office, Louisiana Department of Wildlife and Fisheries, New Iberia LA 70560).

STUDY AREA

Marsh Island is a large island on the central Louisiana coast bordered by the Gulf of Mexico on the south and Vermilion Bay, West Cote Blanche Bay, and East Cote Blanche Bay on the north (Figure 1). It consists of approximately 31,000 ha of brackish marsh (O'Neil 1949, Chabreck and Linscombe 1978). Elevation on the island averages about 30 cm above sea level, except on the edges of some larger bayous where slight unmanaged levees are about 60 cm above sea level (Orton 1959). Marsh is described as either well-drained with tidal channels and large lakes, or poorly drained with irregularly shaped lakes and lacking tidal channels (Orton 1959). These differences do not appear to result from elevational differences. Instead, rain water and flood tides remain on the poorly drained marsh because of an absence of drainage (Orton 1959). Poorly drained marsh is accessible only by airboat and marsh-buggy because it lacks water bodies deep enough for even the smallest motorboat. Most bayous on the island drain northward, and the island is undeveloped. The Marsh Island Wildlife Refuge, operated by the Louisiana Department of Wildlife and Fisheries, occupies all of Marsh Island. The refuge was established to provide a sanctuary from hunting for migratory birds (Louisiana Department of Wild Life and Fisheries 1946: 172–173).

A program of weir construction on Marsh Island began in 1958 to enhance habitat for wintering waterfowl (Louisiana Wild Life and Fisheries Commission 1954:106–107, 1960:164). We resurveyed the weirs in 1988 and found that the elevation of the crests had decreased from the original −15 cm to approximately −30 cm relative to the marsh surface (R.H. Chabreck, unpublished data). This was corroborated by ^{137}Cs dating, which found that the 1963 marsh surface was approximately 15 cm below the 1990 marsh surface (Nyman et al. 1993). Tide gauge data and pond bottom contours of Chabreck et al. (1979) indicate that this should cause about 25% of the weir managed pond area to drain during low water rather than 13% (64% of unmanaged pond area drains during low water). Field observations indicated that the weirs were still restricting water exchange. Weir managed ponds drained less than unmanaged ponds (M. Carloss, La. Dept. Wildl. Fish., pers. comm.), showed lower rates of short term salinity fluctuations than unmanaged ponds (unpublished data, Louisiana Department of Wildlife and Fisheries), and contained more submersed aquatic vegetation than unmanaged ponds (Nyman and Chabreck, unpublished data).

For at least 40 years, the dominant species has been *Spartina patens* and subdominant species have been *Scirpus olneyi* and *Juncus roemerianus*, although great fluctuations occur over time (O'Neil 1949, Orton 1959, Chabreck and Hoffpauir 1962). Water salinity varies from 1 to 9 ppt, with higher salinity generally occurring in the fall. The climate is humid subtropical, with 152–163 cm of precipitation each year, a 300–310 day growing season, and an average annual temperature of 20–21°C (Newton 1972). Lunar tides are weak and range only 0.3 m, and winds often dominate water-level fluctuations. The area is subject to winter storms and tropical hurricanes (Huh et al. 1989). Persistent north winds associated with winter weather fronts produce extremely low water levels and completely drain many tidally influenced water bodies in the marsh (Chabreck and Hoffpauir 1962). There may be 20–30 winter weather fronts each year (Huh et al. 1989). Strong southerly winds preceding these fronts can completely flood the marsh (Orton 1959).

Four permanent transects were located near weir managed and unmanaged drainage systems on the eastern half of Marsh Island (Figure 1). Within each treatment, weir managed or unmanaged, one transect was established in poorly drained marsh and one in better drained marsh prior to the construction of the weirs in 1958 (Chabreck and Hoffpauir 1962). When the transects were established, poorly drained marsh was dominated by *Spartina patens* and *Scirpus olneyi*; better drained marsh was dominated by *Spartina patens* and *Juncus roemerianus* (Chabreck and Hoffpauir 1962). Vegetation on the weir managed and unmanaged marsh transects was similar before the weirs were constructed (Chabreck and Hoffpauir 1962).

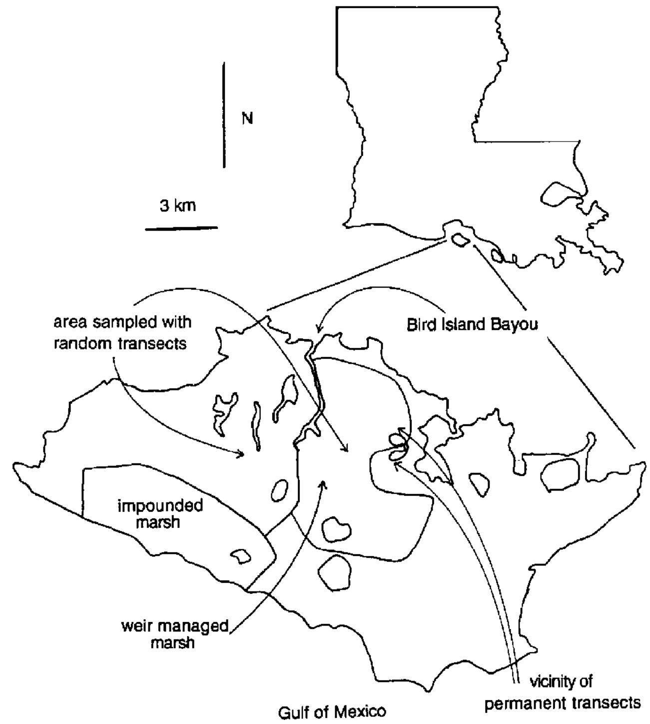

Figure 1. Marsh Island, Louisiana showing a large weir managed area where random transects were scattered throughout, a large adjacent unmanaged area where random transects were scattered throughout, and the approximate location of the permanent transects sampled.

Random transects were sampled throughout a 5,260 ha weir managed area east of Bird Island Bayou. An unmanaged area of equal size, west of Bird Island Bayou, was also sampled (Figure 1). Two weirs were constructed in the unmanaged area in the mid-1960s, but they were washed out by a hurricane a few years after they were constructed. The other weirs needed to complete the plan were not constructed, and the plan was dropped. The vegetation in these areas was similar before the weirs were installed, a condition that is necessary if this comparison is to be valid. The weir managed and unmanaged areas contained similar vegetation on O'Neil's (1949) and Orton's (1959) vegetation-type map of Marsh Island. Each area also appeared to contain similar proportions of the muskrat eatout described by O'Neil (1949) and the better drained and poorly drained marsh types described by Orton (1959). Examination of aerial photographs of Marsh Island taken before the weirs were built disclosed that the northern third of the unmanaged study area was solid marsh, but the remainder of the unmanaged area and the entire weir managed area were characterized by scattered ponds of various sizes (i.e., were broken marsh).

METHODS

Permanent Transects

The permanent transects were sampled 17 May 1988 with a modification of the line-intercept method (Canfield 1941). Each transect contained 10 equally spaced sampling stations and was approximately 295-m long. At each station, a 2-m staff graduated into 50 units (each 4 cm) was extended into the vegetation. Plant species that occurred within a 3.8-cm-(1.5 in) wide belt along each unit of the staff were recorded, and the frequency of each species and of total vegetation was calculated for each sampling station and averaged for the transect. Percent species composition was calculated from percent frequency.

These same transects were sampled with the same methods once per year in June during 7 previous years: 1958, 1959, 1960, 1961, 1962, 1967, and 1978 (Chabreck and Hoffpauir 1962, Chabreck 1968, R.H. Chabreck unpublished data 1978). Sampling stations on transects were not permanently marked; thus it is not likely that exactly the same place was sampled each year. Estimates of total vegetative cover were not available for all years. In 1988, the frequency of total vegetation was used as an estimate of vegetative cover.

Proc GLM of SAS (SAS Institute 1987) was used to analyze the permanent transect data as a 2 by 2 factorial treatment arrangement, treatment (weir managed vs. unmanaged) by marsh type (poorly drained vs. better drained), blocking on years. The 3-way interaction term was pooled into the error term *a priori*. Other interactions were pooled into the error term when appropriate (alpha = 0.3000). These data were not analyzed as a repeated measure because intervals of 5, 11, and 12 years passed between some observations. The observations from 1958 were omitted from the data set for analysis because they were made before the weirs were completed.

The assumption of a normal distribution of data points was suspect because these were percentage data. This assumption was checked by testing the distribution of the residual error terms using Proc Univariate of SAS (SAS Institute 1987). The S-statistic (alpha = 0.2000) was used to test for normality; but the box plot and plot of residuals were also considered before assuming normality. If data were not normally distributed, they were normalized with the following transformation:

Species A = log[percent cover by A ÷ (percent total cover − percent cover by A)]. (equation 1)

Effects were considered significant using an alpha level of 0.10 rather than the standard 0.05. Steele and Torrie (1980:91) stated that although the 5% level was arbitrarily chosen, it was an adequate choice in the field of agriculture where it was first used. They further stated that in small-sized experiments, it is possible that the null hypothesis will not likely be rejected unless a large real difference existed, and that this suggested the use of another significance level, perhaps 10%. Snedecor and Cochran (1989:65) also stated that other levels such as the 10% or 20% could be used when considered appropriate. The 10% level was used in this study because we suspected that differences between weir managed and unmanaged marsh may be small and because the consequences of failing to detect effects, such as decreases in vegetative cover, were considered more serious than incorrectly concluding an effect existed when there really was none.

Random Transects

Twenty-two 1.5-km transects were sampled in both areas between 3 August 1987 and 15 August 1987, for a total of 44 transects. The starting point and compass heading of each transect were randomly determined before field work began (maps detailing this information can be obtained from the authors or from the Louisiana Department of Wildlife and Fisheries, New Iberia Field Office, 2451 Darnell Rd., New Iberia, LA 70560). There were 10 equally spaced sampling stations on each transect. Vegetation data were collected with the same methods used to sample the permanent vegetation transects. Sampling stations that occurred entirely over open water (unmanaged: n = 51, weir managed: n = 69) were omitted from the analysis. One sampling station was accidentally omitted from a transect in the unmanaged area, thus 439 sampling stations were visited.

The presence or absence of herbivore sign at each sampling station was also recorded. Nutria and muskrats, which are large primarily herbivorous rodents, were recorded as present if tracks were encountered along the sampling belt or if scat was present within 1 m of the sampling belt. Muskrats were also recorded as present if a muskrat lodge occurred within 10 m of the sampling station. When trails were encountered, nearby scat was used to identify the type of trail. The density of herbivores at the sampling station was not estimated.

The frequency of each plant species and the frequency of vegetation were calculated for each sampling station (unmanaged: n = 168, weir managed: n = 151). The frequency estimates for each species at the sampling stations were averaged for each of the 44 transects. Plant species with frequency estimates <0.01% in a given transect were omitted from analyses. The

Table 1. Mean and standard errors of percent species composition, species richness, and species diversity on permanent transects in better drained and poorly drained marsh in weir managed and unmanaged marsh sampled 8 times between 1957 and 1988, March Island, Louisiana.

	Better Drained Marsh		Poorly Drained Marsh	
	Unmanaged Mean (SE)	Managed Mean (SE)	Unmanaged Mean (SE)	Managed Mean (SE)
Spartina patens (Aiton) Muhl.†	55.0 (4.0)	51.5 (7.5)	59.3 (5.7)	60.9 (6.4)
Juncus roemerianus Scheele†	22.0 (4.6)	26.8 (5.4)	5.6 (4.5)	1.1 (0.8)
Eleocharis parvula (R & S) Link†	7.0 (4.0)	11.1 (4.2)	1.5 (0.9)	1.6 (1.2)
Scirpus olneyi Gray†	4.3 (1.2)	1.0 (0.4)	20.7 (9.3)	28.5 (8.2)
Distichlis spicata (L.) Greene‡	2.9 (1.7)	3.4 (2.9)	1.7 (1.5)	3.1 (1.5)
Panicum virgatum L.†	1.6 (0.9)	2.1 (0.7)	0	0.6 (0.6)
Lythrum lineare L.‡	1.5 (1.0)	0.5 (0.5)	1.3 (1.3)	0.8 (0.8)
Hydrocotlye umbellata L.	1.4 (0.7)	1.2 (0.6)	0	0
Pluchea foetida (L.) DC.‡	1.2 (1.1)	0.2 (0.1)	2.7 (2.2)	<0.1 (<0.1)
Eleocharis palustrus (L.) R & S	1.1 (1.1)	0	4.4 (4.4)	2.0 (2.0)
Cyperus spp.	0.4 (0.2)	0.2 (0.1)	0.8 (0.8)	0.2 (0.1)
Ipomea sagittata Cav.‡	0.4 (0.3)	0.8 (0.4)	00	0
Setaria glauca (L.) Beauv.‡	0.4 (0.4)	0.2 (0.2)	<0.1 (<0.1)	0
Panicum hemitomon Schult.	0.3 (0.3)	0	0	0
Aster tenuifolius L.	0.2 (0.3)	0.1 (<0.1)	<0.1 (<0.1)	0
Fimbristylis spadicea (L.) Vahl.†	0.1 (0.1)	0.4 (0.3)	0	0
Baccharis halimifolia L.	<0.1 (<0.1)	0.7 (<0.6)	0	0
Bacopa monnieri (L.) Wettst.	<0.1 (<0.1)	<0.1 (<0.1)	0.5 (0.4)	0.2 (0.2)
Polygonum spp.	<0.1 (<0.1)	0	0.6 (0.5)	0.2 (0.2)
Vigna luteola (Jacq.) Benth.‡	<0.1 (<0.1)	0	0.3 (0.3)	0
Echinochloa spp.	0	0	0.3	0
Vegetative cover	61.7 (7.1)	56.4 (7.6)	59.0 (5.4)	48.5 (7.5)
Species richness†	8.3 (0.9)	8.1 (1.1)	5.7 (1.4)	5.0 (0.7)
Diversity index†	0.40 (0.08)	0.43 (0.06)	0.51 (0.05)	0.55 (0.05)

† Differed between poorly drained and well drained marsh (P < 0.10).
‡ Differed between weir managed and unmanaged marsh (P < 0.10).

percent of stations on a transect at which muskrats and nutria were noted was used as an index of herbivore population levels on each transect, and grazing pressure was assumed proportional to population levels. Population indices based on scat counts or the presence or absence of scat are a traditional method of comparing relative abundance animal populations (Overton and Davis 1969). Species richness (i.e., the number of species encountered) was calculated for each transect. Also, the Simpson index of diversity (Simpson 1949) was calculated from the frequency estimates.

The normality of these data were also tested prior to analyses. The previously noted transformation and the square root and log transformations were also used (Steele and Torrie 1980:237–239). Twelve of the 26 variables could not be normalized and were not analyzed. Proc GLM of SAS (SAS Institute 1987) was used to analyze data as a weighted Analyses of Covariance (ANCOVA) using the nutria and muskrat indices as covariables. Weight was dependent on the number of sampling stations in a transect. The 3-way interaction term was pooled into the error term *a priori*. Other interactions were pooled into the error term when appropriate (alpha = 0.3000). Data were also analyzed as a weighted two-way ANOVA without accounting for variability in grazing pressure with Proc GLM of SAS (SAS Institute 1987) to illustrate the importance of considering grazing effects. An alpha level of 0.10 was used as the critical limit for these tests.

RESULTS

Permanent Transects

Spartina patens dominated all transects in 1988 and during the last 30 years (Table 1). There was great variation among sampling dates except for common species, as indicated by standard errors (Table 1). Poorly drained and better drained transects did not differ in vegetative cover but did differ in 6 characteristics. *Scirpus olneyi* ($P = 0.0001$) and *Spartina patens* ($P = 0.0251$) were more abundant in poorly drained marsh than in better drained marsh. Whereas *S. olneyi* varied more than *Spartina patens* over time, the difference

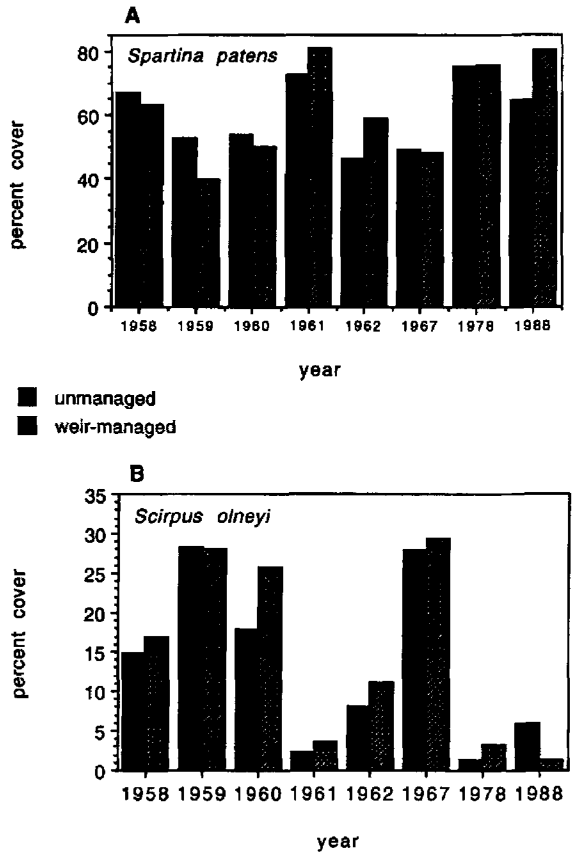

Figure 2. Percent vegetative cover by *Spartina patens* (A) and *Scirpus olneyi* (B) on permanent transects in weir managed and unmanaged marsh between 1958 and 1988, Marsh Island, Louisiana.

between managed and unmanaged areas was more consistent for *Scirpus olneyi* (Figure 2). Thus, the difference was greater for *Scirpus olneyi* (Table 1). Species richness ($P = 0.0034$) and diversity index ($P = 0.0013$) were lower in poorly drained marsh than in better drained marsh. *Juncus roemerianus* ($P = 0.0001$) and *Eleocharis parvula* ($P = 0.0110$) were less important in poorly drained marsh than in better drained marsh (Table 1).

Vegetative cover, species richness, diversity index, and abundant marsh plants did not differ between weir managed and unmanaged marsh (Table 1). Most importantly, the treatment by marsh-type interaction term was not significant for any variable. However, five minor species differed between weir managed and unmanaged marsh. Species composition was lower in weir managed marsh for 4 species: *Lythrum lineare* ($P = 0.0425$), *Pluchea foetida* ($P = 0.0015$), *Setaria glauca* ($P = 0.0208$) and *Vigna luteola* ($P = 0.0001$), but higher for *Distichlis spicata* ($P = 0.0909$) (Table 1). These species were not often present, and their importance varied greatly (Figure 3).

Table 2. Mean and standard errors of percent frequency of plant species and vegetative cover, indices of plant species diversity, plant species richness, and herbivore populations on 44 random transects in weir managed and unmanaged marsh, Marsh Island, Louisiana, 1987.

	Unmanaged Mean (SE)	Weir Managed Mean (SE)
Spartina patens (Aiton) Muhl.	24.22 (2.35)	24.83 (2.52)
Juncus roemerianus Scheele.[n]	6.11 (1.45)	6.15 (1.40)
Eleocharis parvula (R & S) Link.[m]	5.29 (1.49)	3.50 (0.95)
Scirpus olneyi Gray.	3.84 (1.05)	2.05 (0.53)
Pluchea foetida (L.) DC.	2.29 (0.99)	0.86 (0.54)
Distichlis spicata[n] (L.) Greene.	1.14 (0.61)	0.32 (0.19)
Ipomea sagittata Cav.†	0.96 (0.50)	0.22 (0.10)
Eleocharis palustris (L.) R & S†	0.62 (1.27)	0
Lythrum lineare L.†	0.29 (0.12)	0.07 (0.03)
Panicum spp.	0.21 (0.19)	0.03 (0.01)
Spartina cynossuroides (L.) Roth†	0.19 (0.14)	0
Agalinis spp.	0.14 (0.12)	0.11 (0.07)
Setaria glauca (L.) Beauv.†	0.13 (0.09)	0.12 (0.24)
Vigna luteola (Jacq.) Benth.	0.12 (0.08)	0
Aster spp.†	0.10 (0.10)	0
Bacopa monnieri (L.) Wettst.†	0.09 (0.05)	0.04 (0.02)
Echinochloa spp.‡[n,m]	0.09 (0.07)	0.68 (0.47)
Unidentified plant 1†	0.09 (0.09)	0
Hydrocotlye spp.†	0.04 (0.02)	0
Cyperus spp.	0.02 (0.05)	0.47 (0.39)
Unidentified plant 2†	0.02 (0.02)	0
Ammania coccinea Rottboell.†	0.01 (0.01)	0.01 (0.01)
Unidentified plant 3†	0.01 (0.01)	0
Vegetative cover	35.19 (2.42)	33.22 (2.60)
Species richness,[n,m]	7.05 (0.55)	5.09 (0.52)
Diversity index[m]	0.40 (0.03)	0.54 (0.04)
Nutria index†	30.24 (5.79)	54.37 (6.50)
Muskrat index†	30.24 (5.79)	12.30 (3.25)

[n,m] Related to the nutria or muskrat index, respectively ($P < 0.10$).
† Variables not normally distributed and not analyzed, except for Nutria and Muskrat indices, which were independent variables.
‡ Differed between weir managed and unmanaged marsh ($P < 0.10$).

Random Transects

Spartina patens and *Juncus roemerianus* dominated the weir managed and unmanaged areas (Table 2). When muskrats were present, nutria were usually present, but the reverse was not true. The interactions between the treatment and nutria or muskrats did not account for significant variation in any parameter, and both terms were pooled into the error. No difference was found between the weir managed marsh and unmanaged marsh in the 6 characteristics that differed between poorly drained and better drained marsh or in any other characteristic except for *Echinochloa wal-*

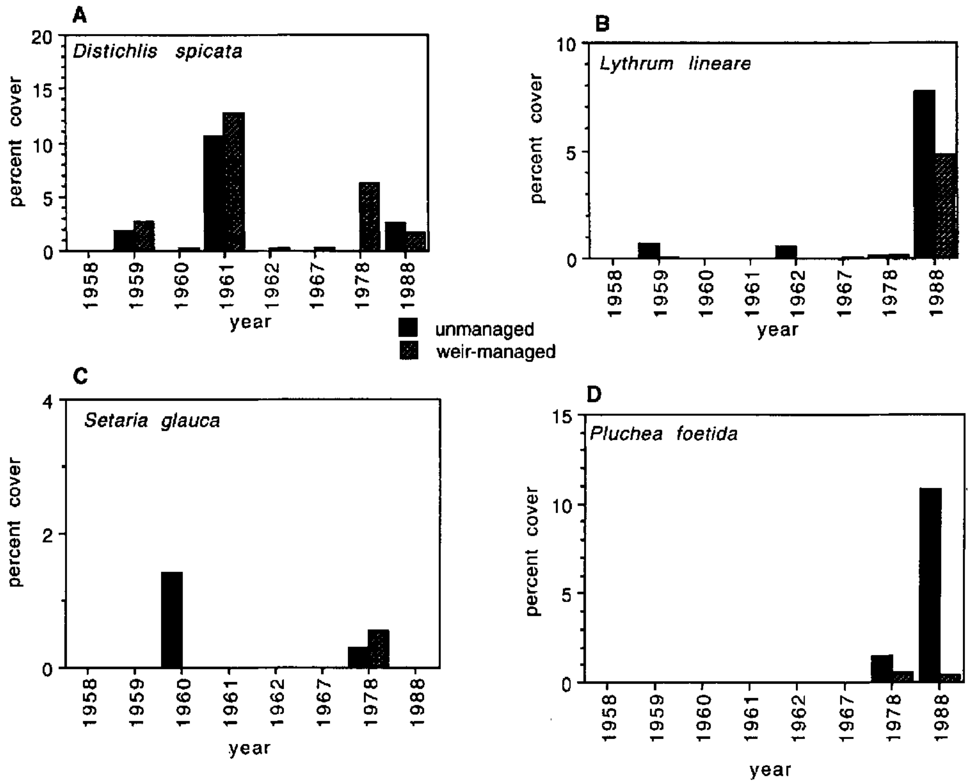

Figure 3. Percent vegetative cover by *Distichlis spicata* (A), *Lythrum lineare* (B), *Setaria glauca* (C), and *Pluchea foetida* (D) on permanent transects in weir managed and unmanaged marsh between 1958 and 1988, Marsh Island, Louisiana.

teri (P = 0.0044), which was more abundant in weir managed marsh than in unmanaged marsh (Table 2).

Species richness (P = 0.0083) and diversity index (P = 0.0115) declined as the nutria index increased, but species richness increased as the frequency of muskrats increased (P = 0.0799) (Figure 4). There seemed to be no relationship between species richness and the herbivore index at stations where both herbivore species occurred (Figure 4), and as noted, the interaction term was not significant. The frequency of nutria also was related to the frequency of *Juncus roemerianus* (P = 0.0782), *Distichlis spicata* (P = 0.0341), *Agalinis maritima* (P = 0.0328), and *Echinochloa walteri* (P = 0.0023). The frequency of muskrats was also related to the frequency of *Eleocharis parvula* (P = 0.0520) and *Echinochloa walteri*. (P = 0.0057). These plants were less frequent where the herbivore indices were high, with the exception of *Eleocharis parvula.*

Statistical analysis without accounting for variability in grazing pressure indicated that vegetation in weir managed marsh had a lower diversity index (P = 0.0289) and richness (P = 0.0137) than unmanaged marsh. These analyses also indicated that weir managed marsh had less *Pluchea foetida* (P = 0.0980), *Vigna luteola* (P = 0.0494), and *Distichlis spicata* (P = 0.0169). These analyses indicated that other characteristics were not affected by weir management.

DISCUSSION

Permanent Transects

The effects of impeded soil drainage and resulting stress on marsh vegetation have been greatly studied in salt marshes in Louisiana (Mendelssohn and McKee 1988, Pezeshki and DeLaune 1988) and elsewhere (e.g., King et al. 1982). Although these effects in brackish marshes have received little direct attention, it was not surprising that poorly drained soil was associated with reduced species richness and diversity index in this study. The greater amount of *Scirpus olneyi* in poorly drained marsh and the greater amount of *Juncus roemerianus* in better drained marsh also agreed with previous work on the Gulf coast of the United States. *Juncus roemerianus* occurs at higher elevations than *Scirpus olneyi* (O'Neil 1949:117) and requires intermittent relief from flooding (Chabreck and Condrey 1979). Eleuterius and Eleuterius (1979) found that *Juncus roemerianus* stands were seldom flooded but noted that tidal phenomena *per se* could not entirely account for the zonation of that species. Chabreck and Narcisse

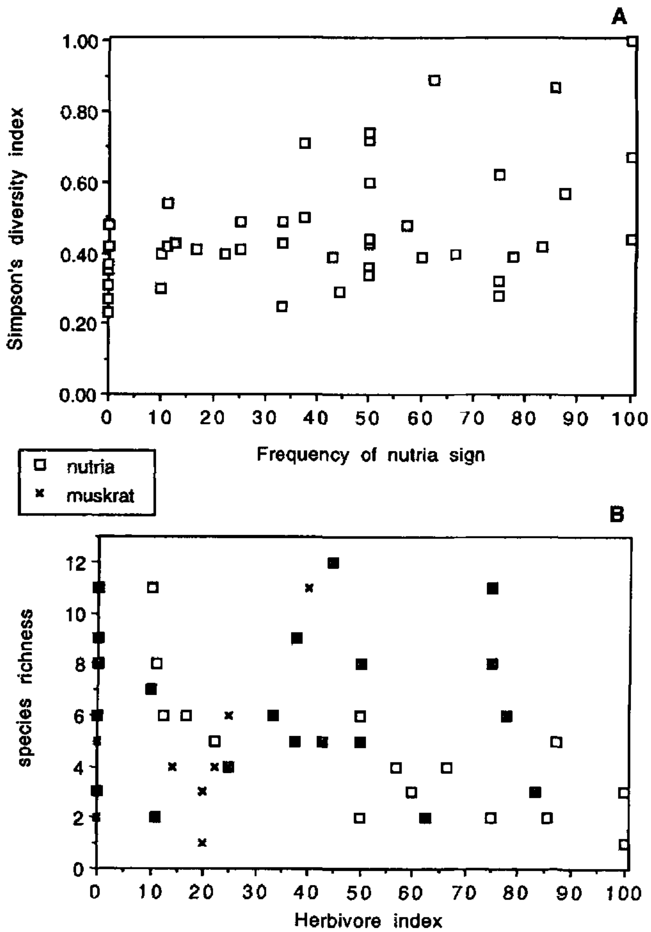

Figure 4. Relationship between the frequency of herbivores and plant species diversity (A) and species richness (B) on 44 random transects on Marsh Island, Louisiana, sampled August 1987. Simpson's diversity index increases in value as species diversity declines.

(1981) found in a greenhouse experiment that the density and length of *Scirpus olneyi* culms are greater when water levels are maintained 15 or 30 cm above marsh surface than when water levels are maintained at marsh surface. Palmisano (1967:100) found in a field study that *Scirpus olneyi* occurred only below annual minimum water levels, and Hess (1975:95–96) found that it out-competes other plants when water levels are 5 to 10 cm above marsh surface. This study detected differences in species richness, diversity index, *S. olneyi*, and *J. roemerianus* between naturally poorly drained and well drained marsh. Thus, it should have the power to detect such differences between unmanaged and weir managed marsh if they existed. The lack of such difference in these parameters between weir managed marsh and unmanaged marsh indicated that weir management did not affect emergent vegetation at Marsh Island or that any differences between weir managed marsh and unmanaged marsh were smaller than the differences observed between well drained marsh and poorly drained marsh.

The reason for the difference in *Eleocharis parvula* and *Spartina patens* between better drained and poorly drained marsh is less clear. *Eleocharis parvula* is a small sedge that is usually restricted to otherwise bare mud or to rather open areas in the plant community. *Spartina patens* dominates Louisiana brackish marshes (Chabreck 1970) and apparently tolerates a wide range of water levels (Eleuterius and Eleuterius 1979). Although not confirmed by previous work, our data indicated that *Spartina patens* is more abundant and *Eleocharis parvula* is less abundant in poorly drained marsh than in well drained marsh. Thus, this study likely also had the power to detect differences in *S. patens* and *E. parvula* between weir managed marsh and unmanaged marsh if they existed. The lack of these differences also indicated that weir management did not affect emergent vegetation at Marsh Island.

If weir management decreased soil drainage enough to affect emergent vegetation, then weir management should have affected better drained marsh and poorly drained marsh differently. However, the treatment-by-marsh-type interaction term was not significant for any variable. This also indicted that weir management did not affect emergent vegetation.

Either weir management did not affect emergent vegetation, or effects were beyond the precision of this study. If a small undetected difference did exist, it was probably not progressive. If the effects of weir management on vegetative cover, species richness, and diversity index were progressive, a large difference should have existed between weir managed and unmanaged marsh after 30 years. However, additional sampling should be conducted in the future to ensure that 30 years is enough time for effects to be realized in the emergent plant community.

Permanent transects in weir managed marsh and unmanaged marsh contained different amounts of the minor species *Distichlis spicata*, *Lythrum linear*, *Pluchea foetida*, *Setaria glauca* and *Vigna luteola*. Given that these species were sampled infrequently and in low amounts, it likely that some of the significant differences are spurious. However, it is also possible that these minor species are more sensitive to soil waterlogging than important species. Future efforts to detect the consequences of subtle alterations to soil drainage in emergent marsh plant communities may benefit from measurements of the amount and vigor of minor plant species, rather than concentrating on dominant plants such as *Spartina patens* and *Spartina alterniflora* that tolerate a wide range of water levels (Babcock 1967: 52, Eleuterius and Eleuterius 1979).

Random Transects

Echinochloa walteri was more abundant on random transects in weir managed marsh than in unmanaged marsh and was the only plant species that differed between the 2 areas. The areas did not differ in vegetative cover, species diversity, species richness, or the frequency of important plant species. As noted for the permanent transects, if the weirs affected soil drainage, then weir managed marsh should have contained less *Juncus roemerianus*, more *Spartina patens* and more *Scirpus olneyi* than unmanaged marsh, and species richness and diversity index should also have differed. Thus, these analyses also indicated that weir management did not affect emergent vegetation.

It was not surprising that the presence of nutria and muskrats was related to plant species richness and diversity. Dirzo (1984) concluded that herbivory reduced diversity when the preferred food was not the competitive dominant in an area and increased diversity when the preferred food was the competitive-dominant plant. The abundance of nutria was negatively associated with diversity index and species richness, but muskrats were positively associated with species richness. These different effects on species richness probably resulted from the preference of muskrats to marsh dominated by *Scirpus olneyi* (Keyser 1984:27), which is their most important food (O'Neil 1949:65–66), and the extensive use by nutria of marsh dominated by *Spartina patens*, which is not a preferred food (Chabreck et al. 1981). Muskrats feeding in areas dominated by *Scirpus olneyi* feed primarily on the dominant vegetation and may increase opportunities for subdominant and minor species, thereby increasing species richness. Nutria feeding in areas dominated by *Spartina patens* feed on subdominant or minor species and may leave the canopy intact and decrease species richness and diversity. What was surprising was that nutria and muskrat densities varied enough within a homogeneous-appearing habitat to cause measurable differences in species diversity and richness.

Some plant species were also associated with different levels of herbivores. The frequency of nutria and the frequency of *Juncus roemerianus* were negatively related. Nutria do not feed on *Juncus roemerianus* (Chabreck et al. 1981) and may avoid marsh dominated by *Juncus roemerianus*. The frequency of *Echinochloa walteri* was negatively related to the nutria and muskrat indices, and Junkin (1989:23) showed that *Echinochloa walteri* stands were reduced 70% by nutria grazing. The frequency of *Eleocharis parvula* and the frequency of muskrats were positively related, possibly in response to disturbances in the vegetation caused by muskrat activity. As noted, *Eleocharis parvula* is a small sedge that commonly grows on mats in openings where sunlight is more available. Muskrats feeding in areas dominated by *Scirpus olneyi* may have increased opportunities for *Eleocharis parvula* to grow. The observation that the frequency of *Spartina patens* was not related to these herbivores also agreed with previous workers who found that of brackish marsh species, *Spartina patens* was the least affected by muskrat grazing (Lynch et al. 1947) and nutria grazing (Harris and Webert 1962). This most likely resulted from the fact that *Spartina patens* is not a preferred food of either muskrats (O'Neil 1949) or nutria (Chabreck et al. 1981).

The results of this study indicated no difference between weir managed and unmanaged marsh at Marsh Island and that any possible undetected differences were smaller than the difference between naturally poorly drained marsh and naturally well-drained marsh. This, and the lack of a consistent effect of weir management on emergent vegetation in previous studies, suggests that factors other than weir management have a greater effect on emergent marsh vegetation. Furthermore, weirs may have different effects on soil drainage under different hydrologic conditions and in different marsh types. The reason that weir management has little effect on emergent marsh vegetation may be related to soil hydrology. On the Atlantic coast of the United States, ground-water levels do not fall more than a few cm below the marsh surface in the marsh interior (i.e., more than 4 m from tidal creeks) (Hemond and Fifield 1982, Agosta 1985). Subsequent work at Marsh Island has confirmed that there is little soil drainage in the marsh interior (Nyman et al. 1993). So, although it may be logical to assume that weir management impedes soil drainage, interior marshes may not drain substantially under natural conditions. Thus, effects of weir management on emergent vegetation communities may be slight.

It seems that herbivory may have a greater effect on emergent marsh vegetation than weir management. Previous studies of herbivory have consistently concluded that grazing affected emergent marsh vegetation, but studies on the effects of weirs on emergent marsh vegetation have not demonstrated consistent effects. If we had not noted variability in grazing pressure, our analyses would have indicated that weir management reduced species richness, diversity index, and the abundance of 3 minor species (*Distichlis spicata*, *Pluchea foetida*, and *Vigna luteola*). Other studies of marsh vegetation may also benefit from efforts to account for variation in marsh vegetation introduced by varying grazing pressure. Varying grazing pressure may result from differences in herbivore numbers between

2 areas, as well as from fluctuations within an area over time as herbivore natality and mortality occur.

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