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Plant Community Composition and Biomass in Gulf Coast Chenier Plain Marshes: Responses to Winter Burning and Structural Marsh Management

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ABSTRACT / Many marshes in the Gulf Coast Chenier Plain, USA, are managed through a combination of fall or winter burning and structural marsh management (i.e., levees and water control structures; hereafter SMM). The goals of winter burning and SMM include improvement of waterfowl and furbearer habitat, maintenance of historic isohaline lines, and creation and maintenance of emergent wetlands. Although management practices are intended to influence the plant community, effects of these practices on primary productivity have not been investigated. Marsh processes, such as vertical accretion and nutrient cycles, which depend on primary productivity may be affected directly or indirectly by winter burning or SMM. We compared Chenier Plain plant community characteristics (species composition and above- and belowground biomass) in experimentally burned and unburned control plots within impounded and unimpounded marshes at 7 months (1996), 19 months (1997), and 31 months (1998) after burning. Burning and SMM did not affect number of plant species or species composition in our experiment. For all three years combined, burned plots had higher live above-ground biomass than did unburned plots. Total above-ground and dead above-ground biomasses were reduced in burned plots for two and three years, respectively, compared to those in unburned control plots. During all three years, below-ground biomass was lower in impounded than in unimpounded marshes but did not differ between burn treatments. Our results clearly indicate that current marsh management practices influence marsh primary productivity and may impact other marsh processes, such as vertical accretion, that are dependent on organic matter accumulation and decay.

The Chenier Plain of the Gulf of Mexico encompasses 1295 km^2 of coastal marsh from Vermilion Bay, Louisiana to East Bay, Texas, USA (Gosselink 1979). Many marshes in the Gulf Coast Chenier Plain are managed through a combination of fall or winter burning and structural marsh management (i.e., use of levees and other water control structures; hereafter SMM). Historically, a major goal of wetland managers was to improve the attractiveness of marshes for waterfowl and furbearing mammals (Chabreck 1988). Managers burn marshes to remove dead vegetation and to decrease the abundance of dominant plant species such as *Spartina patens* and *Distichlis spicata*, thus releasing from competition preferred wildlife food plants (e.g., *Scirpus americanus* [=*olneyi*] and *S. robustus*) (Lynch 1941, Nyman and Chabreck 1995). Impoundments and water control structures generally are constructed to stabilize water levels and reduce salinities, creating conditions favorable to *Scirpus* spp. and other wildlife food plants, especially freshwater annuals (Babcock 1967, Nyman and others 1993). Although wildlife habitat improvement is still a major goal, recent management plans have emphasized other objectives, including maintenance of historic isohaline lines and distributions of marsh types, reduction or prevention of marsh loss to erosion and sea-level rise, creation of new emergent wetlands, removal of litter to reduce likelihood of catastrophic wildfires, and allowance for ingress and egress of fish and other estuarine organisms (Wicker and others 1983, Cowan and others 1988, Berry and Voisin 1989, Chabreck and others 1989, Nyman and others 1993, Rogers and others 1994, Michot 1996, US Environmental Protection Agency 1998).

Currently, there is concern that winter burning and SMM have unintended negative effects on marsh primary productivity (Cowan and others 1988, Nyman and Chabreck 1995, US Environmental Protection Agency

KEY WORDS: Burning; Coastal marshes; Gulf Coast Chenier Plain; Louisiana; Marsh process; Plant community; Plant biomass; Productivity; Structural marsh management

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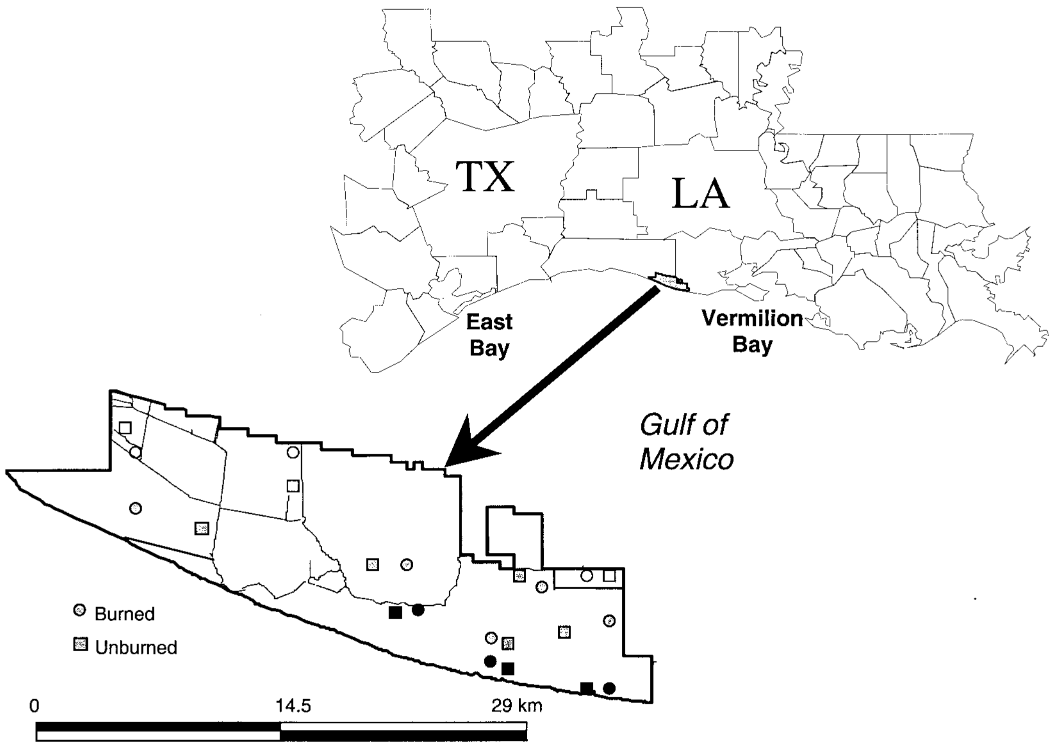

Figure 1. Map of the Gulf Coast Chenier Plain showing locations of Rockefeller State Wildlife Refuge and 11 pairs of burned and unburned sampling stations. Solid lines within the refuge boundary represent major levees. Empty symbols indicate intermediate marsh, shaded symbols indicate brackish marsh, and solid symbols indicate saline marsh.

1998). Organic matter accumulation and decay are important processes in marsh soil development and vertical accretion (Hatton and others 1983, Nyman and others 1993, Cahoon 1994, Foret 1997). Consequently, changes in organic matter accumulation as a result of altered primary productivity could affect soil formation. In addition, primary productivity in coastal marshes is a major source of detritus for both the marsh and the surrounding estuary (Gosselink 1979, Mitsch and Gosselink 1993). Management-induced changes in primary productivity, through burning or SMM, could affect nutrient cycles in the marsh–estuary system.

Effects of burning on marsh primary productivity presently are not clear (Nyman and Chabreck 1995). Burning removes above-ground vegetation and litter; however, removal of rank overshadowing vegetation may stimulate plant productivity by increasing light penetration and surface temperature. Effects of SMM on primary productivity also are ambiguous (Montague and others 1987, Day and others 1990, US Environmental Protection Agency 1998). Levees isolate a marsh from the neighboring estuary, preventing nutrient import into the marsh (except during storms) and consequently may reduce plant growth. Alternately, nutrients or fresh water may be retained within the impoundment, and thus potentially augment plant growth. In addition, salinity generally is lower within impoundments, and the depth, duration, and frequency of flooding often are increased compared to surrounding unimpounded marsh (Montague and others 1987). Such hydrologic changes probably affect plant productivity. Finally, burning and SMM together may affect vegetation interactively. For example, postfire water level influences vegetation growth rates (Mendelssohn and others 1995); if the water level within an impoundment is high following a winter burn, plant regrowth may be reduced compared to a recently burned unimpounded marsh with a lower water level.

Information on effects of burning and SMM on above- and belowground plant productivity are necessary to guide management of these marshes. We experimentally tested effects of winter burning and structural marsh management on above- and belowground vegetation biomasses in coastal marshes of the Gulf Coast Chenier Plain. In many wetland types, fire temporarily decreases vegetation biomass, density, and cover; however, such changes usually are short-lived, and recovery often occurs in one year (Mendelssohn and others

Table 1. Water salinity and water depth relative to marsh surface at 11 study marshes at Rockefeller State Wildlife Refuge in southwest Louisiana, 1996–1998[a]

			Water salinity (ppt)				Water depth (cm)			
Plot	Burn	Marsh type	Winter 96	July 96	July 97	July 98	Winter 96	July 96	July 97	July 98
1	B	I-I	1.5		0.4	2.3	0.0		12.8	6.7
1	U	I-I	0.6		0.5	0.6	0.3		17.1	11.6
2	B	I-I	2.2	6.8	0.4	3.5	−0.3	−13.4	11.5	−10.4
2	U	I-I	9.8	0.2	1.0	12.0	−0.2	−22.0	9.1	−7.9
3	B	B-I	3.1	3.8	2.0	2.0	0.1	9.8	12.2	9.8
3[b]	U	B-I	2.9	1.9			−0.0	0.0		
4	B	I-I	0.6		0.6	2.2	−0.2		6.1	−8.5
4	U	I-I	1.1		0.5	2.1	0.1		9.8	−4.9
5	B	B-I	11.0	16.0	5.9	12.7	−0.2	−26.2	−4.3	−12.2
5	U	B-I	3.3		3.9	14.9	−0.5		−9.1	
6	B	S-U	18.4	26.4	16.9	21.8	−0.4	−11.6	−4.3	−13.4
6	U	S-U	14.0	10.6	2.9	6.9	0.1		24.4	0.6
7	B	S-U	14.4	11.2	8.5	18.2	0.0	−20.0	−1.5	5.5
7	U	S-U	11.7	15.5	8.9	16.7	0.0	0.0	−4.9	0.6
8	B	B-U	15.1	16.4	7.4	16.5	−0.0	−3.1	2.4	0.0
8	U	B-U	12.5	7.4	2.5	7.8	−0.4	−15.1	−7.3	−3.0
9	B	S-U	11.8		12.9	23.4	−0.2		−0.6	−12.2
9	U	S-U	14.2	7.8	8.6	10.9	0.0	−24.4	−0.6	−13.4
10	B	B-U	11.3	2.1	9.4	19.5	0.2	−28.1	3.7	14.9
10	U	B-U	19.4	21.5	9.9	13.4	−0.0	2.4		
11	B	B-U	12.8	17.4	6.7	17.2	0.2	8.5	8.5	7.3
11	U	B-U	8.7	8.4	7.1	17.5	−0.2	−7.3	−3.0	−4.9

[a]Winter 1996 data are averages of monthly readings from January–March. Blank spaces represent water levels >30 cm below marsh level (see Methods).

B = burned, U = unburned. I-I = Intermediate impounded marsh; B-I = Brackish impounded marsh; B-U = brackish unimpounded marsh; S-U = saline unimpounded marsh.

[b]No data were collected from this plot in 1997 or 1998 due to lightning fire in July 1997 (see Methods).

1995, Gabrey 1999, Gabrey and others 1999). Thus, we predicted a marked reduction in vegetation biomass during the first postfire growing season in our experiment, but negligible differences in biomass between burned and control plots thereafter. Above-ground productivity may be higher in impounded marshes due to retention of fresh water and subsequently lower salinity (Zedler and others 1980). Because SMM in southwestern Louisiana aims to maintain low salinity, we predicted that productivity, as indexed by vegetation biomass, would be higher within impoundments than within unimpounded marshes.

Study Area

We chose Rockefeller State Wildlife Refuge (RWR) in southwestern Louisiana as a representative area of the Gulf Coast Chenier Plain (Figure 1). RWR (headquarters coordinates: 29°40′30″N, 92°48′45″W), a 30,700-ha area managed by the Louisiana Department of Wildlife and Fisheries (LDWF) in Cameron and Vermilion parishes, is bordered by Louisiana Highway 82 on the north and the Gulf of Mexico on the south (Figure 1). RWR consists of 17 impoundments ranging in size from 200 to >4000 ha (Wicker and others 1983) and approximately 11,700 ha of tidally influenced unimpounded marshes. Most impoundments were constructed during the late 1950s and are separated by a network of canals. Management burns on RWR are conducted on a three-year rotation, with approximately one third of the refuge area burned during a single fall/winter (October–February). Lightning-ignited fires also occur on RWR, usually from June through August (0–6 fires/year during 1993–1998; T. J. Hess, unpublished data).

Marsh types on RWR range from a band of saline marsh along the Gulf Coast, a band of brackish marsh further inland, and intermediate marsh still further inland (Chabreck 1970, Chabreck and Linscombe 1988). Saline marsh (salinity ≥10 ppt) is dominated by *Spartina alterniflora*, *S. patens*, and *Distichlis spicata*. Brackish marsh (5–10 ppt) is characterized by *S. patens*, *D. spicata*, and *Scirpus* spp. Intermediate marsh (1–5 ppt) is dominated by *Spartina patens* and *Sagittaria falcata* (Chabreck 1970, 1972; Chabreck and Linscombe 1988). Impounded marshes in our study were interme-

Table 2. Biomasses of above- and belowground vegetation and number of plant species on Rockefeller State Wildlife Refuge[a]

Species	1996			
	BI	BU	UI	UU
Total above (g/m^2)	872 ± 367	778 ± 200	1994 ± 715	1445 ± 357
Live above	769 ± 352	659 ± 179	758 ± 262	556 ± 127
Dead above	103 ± 94	118 ± 61	1236 ± 512	889 ± 327
S. patens	456 ± 457	464 ± 282	630 ± 385	301 ± 271
D. spicata	36 ± 72	185 ± 212	45 ± 90	104 ± 106
S. alterniflora	0	6 ± 9	15 ± 34	129 ± 194
S. robustus	33 ± 67	4 ± 7	45 ± 91	20 ± 32
Typha spp.	79 ± 132	0	10 ± 17	0
Other spp.[b]	165 ± 205	1 ± 2	12 ± 23	1 ± 2
Belowground (g/1000 cm^3)	18 ± 3	21 ± 6	19 ± 5	21 ± 4
No. species (mean ± SD)[c]	6.6 ± 3.0	4.5 ± 1.4	4.8 ± 2.7	4.3 ± 1.0

diate or brackish; unimpounded marshes were exposed to Gulf tides and were brackish or saline. Unimpounded intermediate and impounded saline marshes are not present on RWR, and we did not study the small area of fresh marsh (salinity <1 ppt) present on RWR.

Using vegetation-type and fire-history maps of RWR, we selected 14 study marshes that met the following criteria (Figure 1): (1) minimum area of 100 ha of emergent vegetation with little open water, (2) presence of a firebreak (i.e., bayou or canal), (3) homogeneous marsh type and fire history within an area, (4) site accessibility, and (5) absence of other research projects or physical structures that potentially could be damaged by fire. We chose three impounded areas in brackish marsh and five in intermediate marsh and we chose three unimpounded areas in brackish marsh and three in saline marsh. In March and September 1996, unintentional fires caused by neighboring landowners or other research crews burned three impounded plot pairs (two intermediate and one brackish); consequently, we excluded data from these sites in our analysis.

Methods

We used a split-plot experimental design (Sokal and Rohlf 1995), in which each ≥100-ha area (the whole plot) was divided into two tracts, each ≥50 ha (the split plots), with a firebreak as the dividing line. We randomly assigned burn treatment to one side of each firebreak. A 100-m × 100-m sampling station was located randomly within each tract and marked with conduit pipe at 20-m intervals along the east–west center line. Distance between paired stations ranged from 0.5 to 3.5 km, and was less than 1 km for all but two pairs (Figure 1).

Assigned tracts were burned on 9–11 and 13 December 1995 and 9 January 1996. Fires were either head or back fires and were conducted with approximately 5 cm of water over the marsh surface. One control sampling station was burned accidentally when fire advanced beyond the firebreak; this station was relocated to an unburned area about 100 m from the burn edge within the same impoundment. One unimpounded tract assigned to be burned did not burn and was relocated to another unimpounded location in a burned tract 700 m away.

We collected vegetation samples from each sampling station between 24 July and 8 August, in each of three years (1996–1998). Accordingly, our vegetation sampling corresponded to 7 months (1996), 19 months (1997), and 31 months (1998) after the burn. We cut all standing vegetation present within a 0.25-m^2 plastic frame placed at six randomly chosen locations within each station. Belowground material also was collected from within the clipped area using a 10.2-cm-diam. × 12.7-cm-high (volume = 1038 cm^3) plastic sewer pipe pushed into the ground. We separated above-ground material into live or dead categories and further sorted live above-ground material by species. Belowground material was rinsed in a 1-mm mesh sieve to remove mud. All samples were oven-dried (70°C) to constant weight (≤1 g change over 8 hr) and weighed (±0.01 g).

We measured water depth (±0.5 cm) relative to the marsh surface at each station monthly from January to March 1996 and at the time vegetation samples were collected. We took measurements from a well made of perforated sewer pipe pushed in the ground, with a stream gauge inserted to a depth of 30 cm in the center of the pipe. We also recorded (±0.1 ppt) water salinity at each well using a YSI-30 meter (Yellow Springs Instrument Co., Yellow Springs, Ohio).

Table 2. (Continued)

1997				1998			
BI	BU	UI	UU	BI	BU	UI	UU
1304 ± 526	1814 ± 470	1564 ± 297	1481 ± 378	1733 ± 579	2442 ± 269	1990 ± 734	1823 ± 506
862 ± 357	1264 ± 422	552 ± 308	694 ± 196	850 ± 250	1051 ± 187	916 ± 515	729 ± 281
441 ± 183	549 ± 95	1012 ± 370	787 ± 260	883 ± 517	1391 ± 166	1073 ± 290	1094 ± 456
449 ± 479	986 ± 582	367 ± 164	360 ± 314	467 ± 215	830 ± 314	648 ± 397	405 ± 363
124 ± 270	252 ± 342	34 ± 56	153 ± 211	100 ± 223	168 ± 260	28 ± 39	182 ± 150
0	6 ± 13	18 ± 36	132 ± 174	0	49 ± 101	80 ± 169	132 ± 170
93 ± 163	15 ± 17	103 ± 189	46 ± 89	55 ± 97	4 ± 5	80 ± 151	9 ± 21
193 ± 278	0 ± 0	30 ± 38	0	145 ± 180	0	68 ± 80	0
3 ± 7	3 ± 6	0	1 ± 2	83 ± 185	0	12 ± 16	0
18 ± 3	24 ± 9	15 ± 5	23 ± 6	16 ± 2	23 ± 7	18 ± 3	23 ± 3
4.0 ± 1.0	4.5 ± 1.6	4.5 ± 1.7	4.5 ± 1.4	4.4 ± 1.8	3.8 ± 1.0	5.3 ± 1.0	4.0 ± 1.3

[a]Study marshes were either impounded or unimpounded and either burned or unburned. BI = burned impounded, BU = burned unimpounded, UI = unburned impounded, UU = unburned unimpounded. Vegetation measurements were made at 7 months (1996), 19 months (1997), and 31 months (1998) after the burn.

[b]Includes 15 other species comprising <2% of the total above-ground biomass (see Appendix 1 for species list).

[c]Includes dead vegetation as a species.

We analyzed the following response variables with split-plot ANOVAs (Proc GLM, SAS Institute 1990): (1) number of plant species, (2) proportion of dead to total above-ground biomass, (3) above-ground vegetation biomass (total, live, dead, and the five most abundant species separately), and (4) total (live and dead) belowground vegetation biomass. Our model included a plot (the 11 pairs of plots) effect, management type (manage; impounded or unimpounded) as the main plot effect, burn treatment (burn; burned or unburned) as the split-plot effect, and year (year; 1996, 1997, or 1998) as a repeated measure. We tested the manage main effect with the plot(manage) mean square, year and year × manage effects with the year × plot(manage) mean square, and all effects containing burn with the residual mean square (see Gabrey 1999 for details).

We pooled all data from the six 0.25-m^2 subsamples to obtain one value per station. We converted above-ground data to grams per square meter and below-ground data to grams per 1000 cm^3. We then transformed ($\log_{10}[Y + 1]$) all response variables before analysis to meet assumptions (normal distribution of residuals, homoscedasticity) for parametric procedures (Sokal and Rohlf 1995). We report means and confidence intervals as back-transformed values. When a significant effect was detected, we conducted pairwise comparisons using the PDIFF option in the LSMEANS statement (Proc GLM). We did not collect data in one unburned subplot (Unit 6) during 1997 or 1998 because it was struck by lightning and burned on 17 July 1997; data collected from this station in 1996 were included for analysis.

Results

Water depth (measurable range = −28.1–17.1 cm, CV = −724.5) and salinity (range = 0.5–23.4 ppt, CV = 73.1) varied dramatically among and within stations (Table 1). In July 1996, water depth was at or below the marsh surface in all but three stations (Table 1), due to severe drought (NOAA 1996).

We recorded 21 plant species (including dead vegetation as a species) over the three years of the study (Appendix 1). Six species types (dead vegetation, *Spartina patens*, *Distichlis spicata*, *Spartina alterniflora*, *Scirpus robustus*, and *Typha* spp.) comprised >98% of the total biomass (Table 2). Dead vegetation and *Spartina patens* were dominant plant species (Table 2, Figure 2). We detected a significant burn × year interaction in the analysis of dead/total above-ground biomass (Table 3). The contribution of dead vegetation to the total above-ground biomass in unburned stations was consistent (about 55%) among years. In burned plots, this ratio reached preburn levels by the third postfire growing season (Figure 2). Number of species for any burn × year × manage combination ranged from five in burned unimpounded plots in 1998 to 15 in burned impounded plots in 1996 (Appendix 1). We detected no year, burn, or manage effects (Table 3) in the analysis of number of species.

We detected significant burn × year and burn × manage interactions in the analysis of total above-ground biomass (Table 3). Total above-ground biomass increased significantly in burned plots between 1996 and 1998 but remained relatively constant in unburned plots among the three years (Figure 3A). Total above-

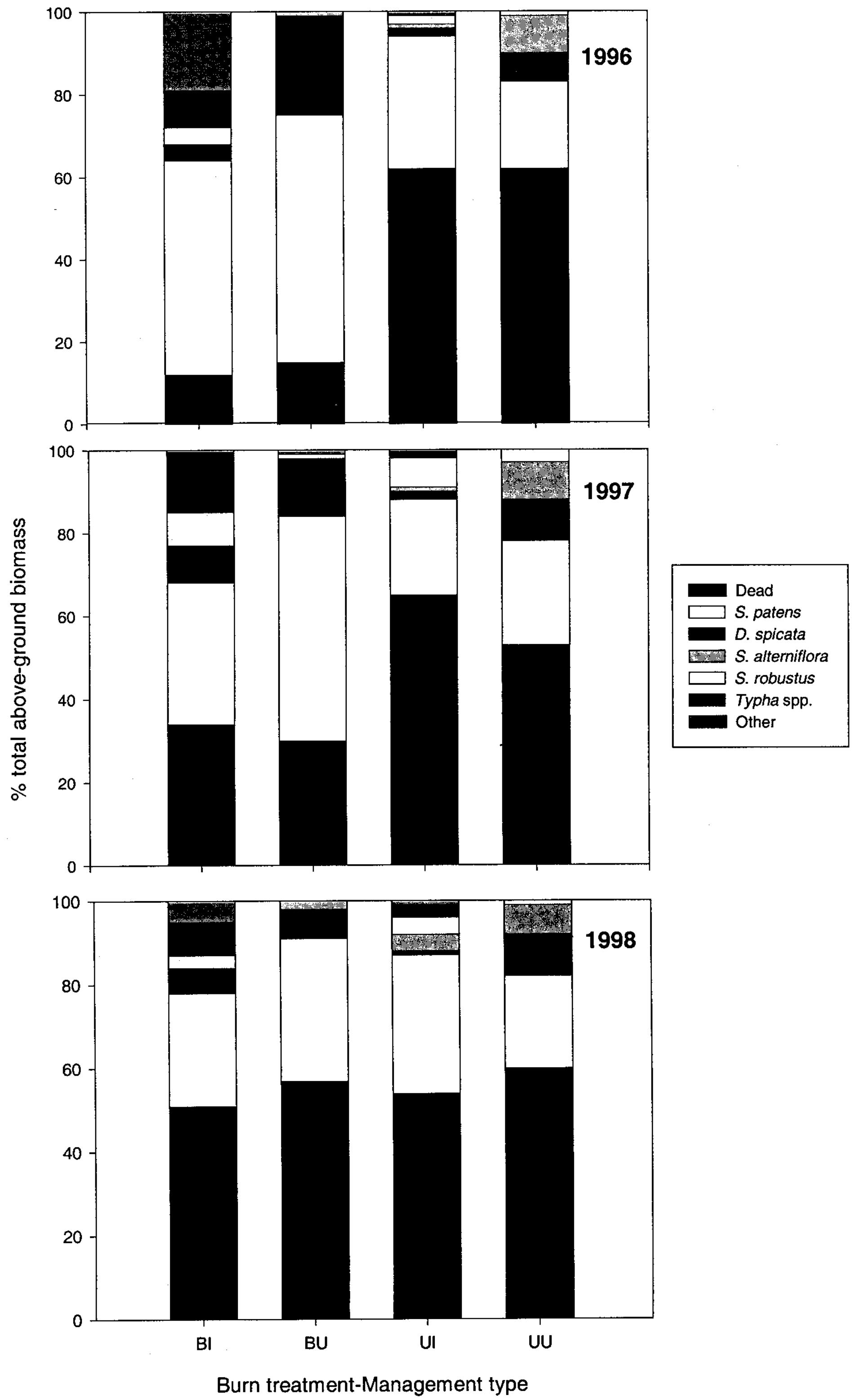

Figure 2. Contribution (%) of dead vegetation and five common species to total above-ground biomass in relation to management type (impounded or unimpounded) and burn treatment (burned or unburned) during three years on Rockefeller State Wildlife Refuge in southwest Louisiana. BI = burned impounded, BU = burned unimpounded, UI = unburned impounded, UU = unburned unimpounded. Vegetation sampling corresponded to 7 months (1996), 19 months (1997), and 31 months (1998) after the burn.

ground biomass was lower in burned than in unburned plots in 1996 but did not differ between burn treatments in 1997 or 1998 (Figure 3A). Total above-ground biomass was higher in unburned than in burned plots

Table 3 Results of split-plot analyses of variance (*F* ratios) for 11 vegetation variables on Rockefeller State Wildlife Refuge[a]

	Source of variation						
Species	M[b]	Y[c]	Y × M	B[d]	B × Y	B × M	B × Y × M
Dead/total[e]	0.16	14.88**	0.70	49.86**	8.52	1.09	0.15
No. of species	0.19	3.00	2.00	0.25	0.73	0.31	0.45
Total above-ground[f]	0.03	27.78**	2.89	8.15**	9.25**	6.11*	0.33
Live above-ground	0.41	2.63	3.28	7.62*	1.55	0.72	0.01
Belowground	6.31*	0.05	2.70	0.01	1.04	0.14	0.64
Dead above-ground	0.53	24.90**	0.35	48.15**	20.76**	6.22*	0.08
Spartina patens	0.07	2.36	1.98	2.22	0.24	14.75**	0.32
Scirpus robustus	0.32	4.97*	1.74	0.08	0.56	0.13	0.00
Spartina alterniflora	2.30	2.26	0.11	4.91*	0.02	0.10	0.07
Distichlis spicata	3.44	0.23	1.15	0.65	0.62	0.04	0.54
Typha spp.	5.00	1.16	1.24	2.23	0.09	2.23	0.09

[a]Levels of significance; $*P < 0.05$, $**P < 0.01$. See Gabrey (1999) for details.

[b]Management type (impounded or unimpounded).

[c]Year (1996, 1997, or 1998).

[d]Burn treatment (burned in December–January 1995–1996 or unburned control).

[e]Proportion of dead vegetation to total above-ground vegetation biomass.

[f]Biomass (g/m^2).

in impounded marshes but did not differ between burn treatments in unimpounded marshes (Figure 3B). Total above-ground biomass did not differ between management types within each burn treatment (Figure 3B). Live above-ground biomass was higher (Table 3) in burned ($\bar{X}$ = 850 g/m^2, 95% CI = 735–982) than in unburned marshes ($\bar{X}$ = 629 g/m^2, 95% CI = 540–734). Belowground biomass was lower (Table 3) in impounded marsh ($\bar{X}$ = 17 g/1000 cm^3, 95% CI = 15–18) than in unimpounded marsh ($\bar{X}$ = 22 g/1000 cm^3, 95% CI = 20–24).

We detected burn × year and burn × manage interactions in the analysis of dead above-ground biomass (Table 3). Dead above-ground biomass in burned plots was lower than that in unburned plots in 1996 and 1997 but did not differ between burn treatments in 1998 (Figure 4A). Dead above-ground biomass remained constant in unburned plots among the three years (Figure 4A). Dead above-ground biomass in burned impounded marshes was lower than that in burned unimpounded marshes, but did not differ between management types in unburned plots (Figure 4B). Dead above-ground biomass was lower in burned than in unburned plots in both management types (Figure 4B). The burn × manage interaction was significant in the analysis of *Spartina patens* biomass (Table 3). *Spartina patens* biomass in burned plots was lower in impounded than in unimpounded marshes and lower in unburned unimpounded than in unburned impounded marshes (Figure 5). *Spartina patens* biomass was lower in unburned than in burned plots in unimpounded marshes, but did not differ between burn treatments in impounded marshes (Figure 5). We detected a significant year effect in the analysis of *Scirpus robustus* biomass (Table 3); however, the LSMEANS test did not detect any significant pairwise comparisons. Mean biomass of *Scirpus robustus* tended to be higher in 1997 ($\bar{X}$ = 7 g/m^2, 95% CI = 3–14) than in 1996 ($\bar{X}$ = 3 g/m^2, 95% CI = 2–7) or 1998 ($\bar{X}$ = 3 g/m^2, 95% CI = 1–7). *Spartina alterniflora* biomass was higher (Table 3) in unburned ($\bar{X}$ = 6 g/m^2, 95% CI = 2–14) than in burned plots ($\bar{X} < 1$ g/m^2, 95% CI = 0–2). Biomass of *Distichlis spicata* and *Typha* spp. did not differ among years or between burn treatments, or management types (Table 3).

Discussion

We found that number of plant species and species composition did not change markedly following our experimental winter burns in Chenier Plain coastal marshes. Plant species present in unburned plots were present in burned plots, and only a very few minor species invaded burned plots in the first postfire growing season. Thus, our results are consistent with previous studies of winter burning in wetlands (see review in Mendelssohn and others 1995). This observed consistency in species composition following fire indicates that coastal marsh plants are fire-adapted (see Hackney and de la Cruz 1983, Abrahamson 1984), as would be expected in an environment in which natural lightning

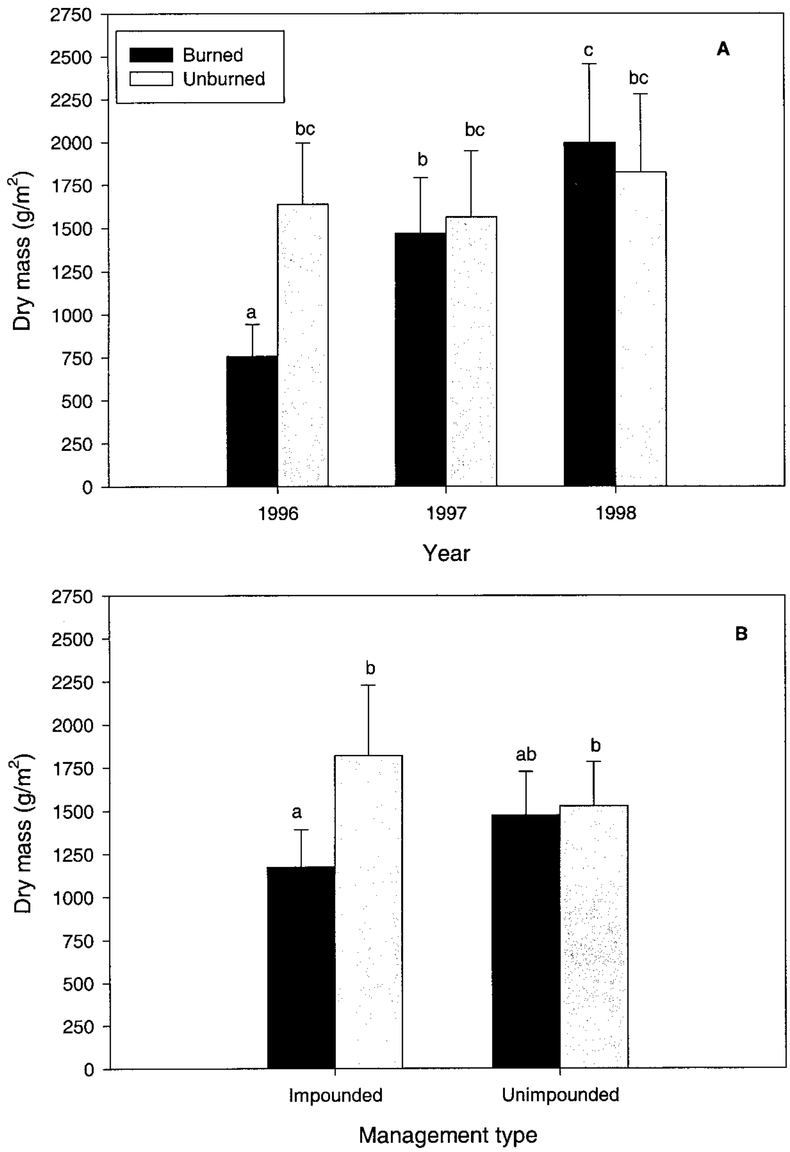

Figure 3. Total above-ground plant biomass (g/m^2) in burned and unburned plots over three years (A) and in impounded or unimpounded marshes (B) on Rockefeller State Wildlife Refuge in southwest Louisiana. Error bars represent upper 95% confidence limits of back-transformed data. Similar letters above bars indicate means did not differ ($P > 0.05$).

fires are a common occurrence (Nyman and Chabreck 1995).

Frequency and season of burning, however, may influence plant species responses. We conducted experimental burns only once, during the first winter of our study to mimic current management practices. Lightning fires in southwest Louisiana, on the other hand, occur at unpredictable frequencies, mostly from June to August. Chabreck (1981) showed that varying the season of the burn could alter species composition. Burning at more frequent intervals also can change species composition (Hackney and de la Cruz 1983). O'Neil (1949) recommended three to four years of repeated burning during fall or winter followed by periodic burns at three to four-year intervals to change *Spartina patens–Distichlis spicata* dominated marsh to *Scirpus robustus–Scirpus americanus* marsh in Louisiana. Comparative studies of managed burns of different frequencies or seasonality with natural lightning fires would be helpful in understanding the role of fire in coastal marsh ecosystem function and evolution.

The number of plant species generally is higher in impounded than in unimpounded marshes (Chabreck 1960) and increases with decreasing salinity (Odum 1988). In contrast, we found that number of species did not differ between management types, although there was a trend for more species in impounded than in unimpounded marshes. In another study in the same area during May 1996–1998 (Gabrey 1999), number of plant species was dramatically higher in impounded

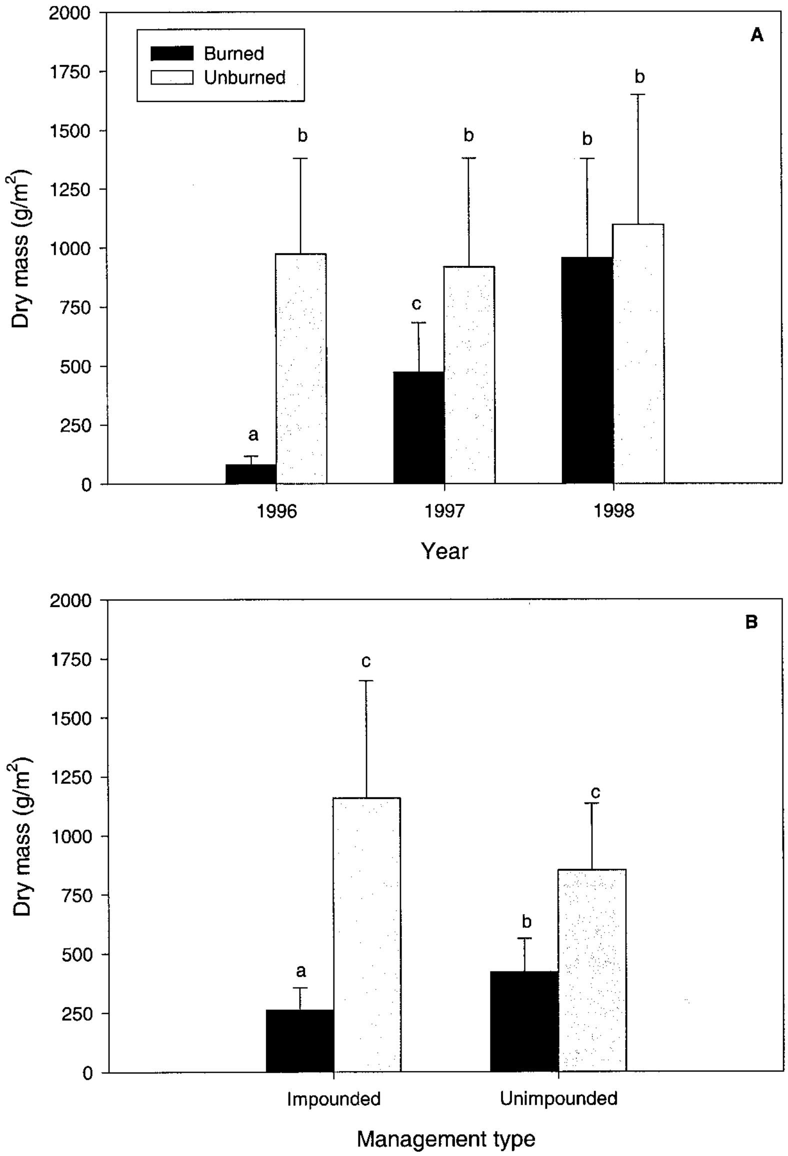

Figure 4. Dead above-ground plant biomass (g/m^2) in burned and unburned plots over 3 years (A) and in impounded or unimpounded marshes (B) on Rockefeller State Wildlife Refuge in southwest Louisiana. Error bars represent upper 95% confidence limits of back-transformed data. Similar letters above bars indicate means did not differ ($P > 0.05$).

than unimpounded stations only in 1996, a year during which a severe drought occurred in southwest Louisiana (NOAA 1996) (Table 1). The drought resulted in a natural drawdown within impoundments from April to June (Gabrey 1999), allowing annuals and flood-intolerant species to germinate and complete their life cycle (van der Valk 1981, Pederson and Smith 1988, Baldwin and others 1996) before normal precipitation patterns returned in mid-June. These species senesced before we sampled vegetation in July–August for this study.

We found that biomass of *Spartina patens* increased in response to burning in unimpounded but not in impounded marshes. *Spartina patens* is competitively inferior to other plant species in low salinity–high water conditions (Babcock 1967, Broome and others 1995) and appears better adapted to the postfire environmental conditions in unimpounded marshes (high salinity and periodic drying due to tides) than in impounded marshes. Impounded marshes, particularly those of the intermediate marsh type, are managed to reduce salinity and maintain water levels at or above the marsh surface. Salinity in our intermediate impounded burned plots was <5 ppt during the winter immediately following burning (see Table 1). Consequently, environmental conditions within impoundments favored growth of plant species other than *Spartina patens*, particularly in the first postfire year.

Winter burning increased live above-ground biomass compared to unburned control plots. Similar responses were reported for *Juncus roemerianus* and *Spartina cynosur-*

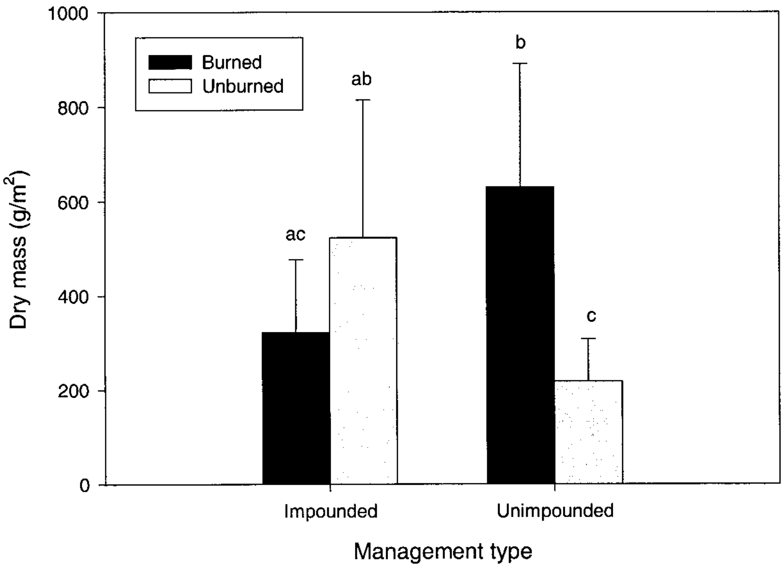

Figure 5. *Spartina patens* biomass (g/m^2) in burned and unburned plots in impounded or unimpounded marshes on Rockefeller State Wildlife Refuge in southwest Louisiana. Error bars represent upper 95% confidence limits of back-transformed data. Similar letters above bars indicate means did not differ ($P > 0.05$).

oides marshes in Mississippi (Hackney and de la Cruz 1983) and for *Juncus roemerianus* and *Spartina bakeri* marshes in Florida (Schmalzer and others 1991). Penfound and Hathaway (1938) suggested that ash acted as fertilizer. Increases in soil calcium, magnesium, potassium and phosphate have been detected in wetland soils one month after burning (Schmalzer and Hinkle 1992). However, Hackney and de la Cruz (1983) demonstrated that addition of fertilizer had no effect on productivity in brackish marshes and suggested that increased productivity in burned plots was a response to increased light reaching the soil surface and consequently higher soil temperatures. We suspect that the latter explanation also applies in our study because heavy rainfall (NOAA 1996) immediately following our experimental burns probably diluted any deposited ash.

Marsh managers in the Louisiana Chenier Plain typically avoid burning when water levels are at or below the marsh surface because such fires may burn peat or root layers, exposing mineral sediment. These peat burns often result in persistent areas of unvegetated open water (Nyman and Chabreck 1995). Our experimental burns were conducted with >5 cm of water over the marsh surface; consequently, burn treatment had no effect on belowground biomass. However, we found that belowground biomass was higher in unimpounded than in impounded marshes. Large root mass may be a response to the high salinity and low water potential conditions of unmanaged marshes, enabling plants to maintain water uptake and reduce internal salt concentrations (Smith and others 1979). In addition, root growth in impounded marshes, may be inhibited because persistent anaerobic conditions (as would occur in impounded marshes) increase concentrations of toxic hydrogen sulfide (Koch and others 1990). Sulfide toxicity would be less likely to occur in unimpounded marshes due to frequent tidal exposure of the marsh surface.

Our previous research (Gabrey 1999, Gabrey and others 1999) showed that species composition and vegetation structural characteristics (percent cover, visual obstruction) in burned plots recovered to unburned levels in less than one year. In the present study, we found that species composition was unaffected by winter burning, but recovery of total above-ground and dead above-ground biomass required two and three years, respectively. The proportion of dead to total above-ground biomass in burned plots also was lower than in unburned plots until the third year after the burn. A similar pattern of rapid recovery in species composition and vegetative cover, but slow recovery of biomass, occurs in Florida coastal marshes (Schmalzer and others 1991). Although total above-ground and dead above-ground biomasses remained below unburned levels for several years, we found that live above-ground biomass recovered relatively quickly following burning. These results are similar to those reported for *Juncus roemerianus*, *Spartina cynosuroides*, *S. bakeri*, and *S. spartinae* marshes (McAtee and others 1979, Hackney and de la Cruz 1983, Schmalzer and others 1991). Thus, a major consequence of burning in marshes throughout much of the Gulf Coast is removal of dead vegetation and a reduction in total biomass that may persist for several years. Because organic matter contributes significantly to marsh vertical accretion (Hatton and others 1983), repeated removal of biomass through frequent burning (e.g., at yearly intervals) could lower marsh accretion rates and increase marsh erosion in areas of rapid sea level rise.

In summary, we found that winter burning (December–January) and SMM did not alter plant species composition during July–August (e.g., *Scirpus* spp. did not replace *Spartina patens*) in Gulf Coast Chenier Plain marshes. We observed that burning increased biomass of live vegetation in subsequent growing seasons, although biomass of dead above-ground vegetation was reduced for several years after the fire. We also observed that burning and SMM interacted to inhibit *Spartina patens* productivity. Our impounded marshes had lower belowground biomass than did unimpounded marshes. Our results clearly indicate that current marsh management practices influence marsh primary productivity and may impact marsh processes dependent on organic matter accumulation and decay. Further research on vegetation turnover, decomposition, and soil formation rates will help determine whether management-induced changes in plant productivity affect these important processes.

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Appendix 1. Plant species presence (+) or absence (blank) in burned or unburned experimental plots in impounded or unimpounded marshes during three summers on Rockefeller State Wildlife Refuge in southwest Louisiana.

	1996				1997				1998			
Species	BI[a]	BU	UI	UU	BI	BU	UI	UU	BI	BU	UI	UU
Dead vegetation	+	+	+	+	+	+	+	+	+	+	+	+
Spartina patens	+	+	+	+	+	+	+	+	+	+	+	+
Distichlis spicata	+	+	+	+	+	+	+	+	+	+	+	+
Scirpus robustus	+	+	+	+	+	+	+	+	+	+	+	+
Spartina alterniflora		+	+	+		+	+	+		+	+	+
Typha spp.	+		+		+	+	+		+		+	
Aster spp.		+	+	+		+		+				+
Ipomoea sagittata	+		+		+				+		+	
Pluchea purpurascens	+		+						+		+	
Baccharis halimifolia	+	+		+	+							
Cyperus spp.	+								+		+	
Chenopodium album	+	+										
Batis maritima						+						
Scirpus americanus						+						
Rumex crispus	+											
Vigna luteola			+									
Sesbania drummondii	+											
Setaria magna	+											
Phyla nodiflora	+											
Polygonum spp.									+			
Echinocloa walteri	+											

[a]BI = burned impounded, BU = burned unimpounded, UI = unburned impounded, UU = unburned unimpounded.