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The Impact of the October 1991 Northeaster Storm on Barrier Island Shrub Thickets (*Myrica cerifera*)

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ABSTRACT

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The 1991 Halloween storm was one of the strongest northeasters in the last 50 years along the Atlantic Coast of North America. As much as 80% of Hog Island, a Virginia, U.S.A. barrier island, was submerged during the storm. *Myrica cerifera* shrub thickets dominate the low-lying swales on the island. One week after the storm, ground water salinity levels within the thickets were as high as 6‰, especially near the bay side fringe marsh. Ground water salinities returned to pre-storm levels by May 1992. Despite the magnitude of the storm, thicket mortality was confined to an eroding portion of the island where physical damage from wave action occurred. Laboratory experiments with *M. cerifera* indicated that complete stomatal closure may have occurred during the storm pulse of salinity. However, when salinity was reduced, physiological parameters quickly returned to normal levels. *Myrica cerifera* thickets are apparently resilient in response to salinity pulses and flooding associated with maritime storms.

ADDITIONAL INDEX WORDS: *Flooding, ground water, salinity, water relations.*

INTRODUCTION

Barrier island landscapes are exceptionally dynamic, both temporally and spatially (HAYDEN *et al.*, 1991). Extratropical storms (*i.e.*, northeasters) represent a major physical force influencing island landscapes, plant communities, and ecological processes along the east coast of North America. Relative to hurricanes, northeaster storms are less violent but may do more damage to barrier islands (STALTER and ODUM, 1993). Hurricanes pass quickly, whereas northeasters may persist for days. However, high energy northeaster storms have been infrequent over the last several decades (DOLAN *et al.*, 1988; DAVIS *et al.*, 1993). Prior to 1991, the most intense northeaster storm to cause major beach erosion and barrier island flooding was the Ash Wednesday Storm of March, 1962 (STEWART, 1962; BRETSCHNEIDER, 1964).

Presumably, this period of relative environmental stability has been favorable for the growth of long-lived woody species. *Myrica cerifera* L. shrub thickets on Hog Island of the Virginia Coast Reserve have expanded dramatically over the past 50 years (YOUNG *et al.*, in press). Shrub thickets are the dominant growth form on many of the Virginia barrier islands (MCCAFFREY and DUESER, 1990). As is characteristic of most long-lived woody species, the thickets occur in the interior and older portions of the islands, beyond the influence of most storm related disturbances (STALTER and ODUM, 1993). Only the most severe storms will affect the shrub thickets through flooding and salt water intrusion of the ground water or by uprooting from high energy waves.

The October 1991 northeaster storm, which was one of the most powerful storms in the last 50 years (DAVIS and DOLAN, 1992), provided an opportunity to assess the effects of a major storm on barrier island shrub thickets. The storm was most intense in the Mid-Atlantic region as the full force of the cyclonic storm winds combined with the anticyclonic winds of a high pressure system to the north (DAVIS and DOLAN, 1992). As much as 80% of Hog Island was flooded during the storm (C.R. CARLSON, *personal communication*), including a large portion of the *Myrica cerifera* shrub thickets that dominate the low-lying swales. The objectives of the present study were 1) to quantify post-storm *M. cerifera* shrub mortality and relate damage to landscape position on Hog Island, 2) to relate post-storm spatial vari-

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ations in ground water salinity and shrub growth to pre-storm values, and 3) to experimentally simulate storm related flooding and determine the physiological response of *M. cerifera*.

METHODS

Study Sites

The study sites were located on the northern portion of Hog Island (37°40'N and 75°40'W), ~8 km east of the Eastern Shore peninsula of Virginia, U.S.A. *Myrica cerifera* L. (Myricaceae) thickets occur in the mesic, low-lying swales on the island. The four sampled sites represented different stages of thicket development, as well as different degrees of exposure to the storm and flood tides (Figure 1). The Leading Edge site was a rapidly expanding thicket of small (< 2 m tall), widely spaced shrubs in the swale behind the primary dune. This site was flooded during the storm. The Mid-Island site, ~300 m inland, represented a fully-developed, dense thicket (~3 m tall) in the most stable region of Hog Island (Figure 1). Flooding was minimal at this site. The Bay Side site was located above the fringe marsh on the bay side of the island and was characterized by a degenerating thicket covered with vines. This site was extensively flooded during the storm. These three sites are considered representative for several stages of shrub thicket development (YOUNG *et al.*, in press) and are also used for long-term intensive monitoring of ecological processes across Hog Island (HAYDEN *et al.*, 1991). A fourth site, the Eroding Surface, was a fully developed thicket on an eroding beach front (Figure 1). This site was flooded and affected directly by storm generated waves.

Field Sampling

To assess the impact of the storm on *M. cerifera* thickets, each site was visited monthly from May through October, 1992. Shrub mortality was noted. In addition, a relative measure of growth differences among the four sites was obtained by harvesting new shoot growth in November, 1992. New growth was clipped from 50 shoots randomly selected at each site; the samples were oven dried at 80 °C for 48 hr and weighed to determine new growth as dry mass per shoot. These data were compared to similar data collected prior to the storm (1990) for all sites but the Eroding Surface, using analysis of variance and the Tukey multiple comparisons of means (SOKAL and ROHLF, 1981).

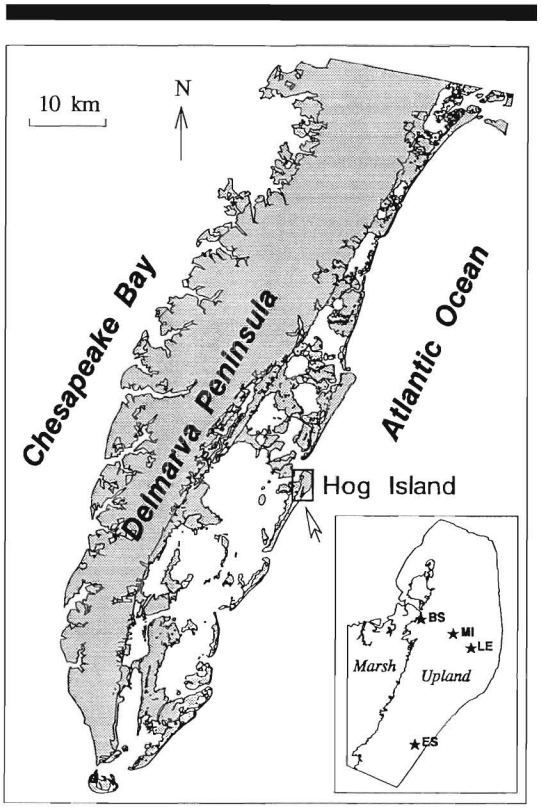

Figure 1. Virginia portion of the DelMarVa Peninsula and the barrier islands of the Virginia Coast Reserve. The inset is Hog Island, including the locations of the four field sampling sites: Leading Edge (LE), Mid-Island (MI), Bay Side (BS), and Eroding Surface (ES) thickets.

To further document possible storm related mortality patterns of thickets, pre- and post-storm (1991 and 1992, respectively) aerial photographs were compared. The false-color infrared photographs were scanned, rectified into 2 by 2 m pixels (using individual trees and marsh creek intersections as ground control points) and classified into cover types using supervised training and maximum likelihood classification procedures in the ERDAS software package. Ground reference data (collected in 1991) were used to verify and refine the land-cover classification. The resulting ERDAS raster data layer was then converted into a vector format in ARC/INFO for display and analysis.

A network of wells has been established across the northern half of Hog Island to quantify spatial and temporal variations in ground water char-

acteristics (HAYDEN *et al.*, 1991). Three wells each are located at both the Mid-Island and Bay Side sites. Ground water salinity was measured in these wells at ~2 wk intervals, beginning in June, 1991 and continuing through the next year. These measurements provided a pre- and post-storm comparison of ground water salinity levels for the two sites. Differences between the two sites were evaluated with a repeated measures analysis of variance and the Tukey multiple comparisons of means (SOKAL and ROHLF, 1981).

During May, 1992, additional wells were installed at the other two sites, Leading Edge and Eroding Surface, to further quantify post-storm spatial variations in ground water salinity across the sites. Similar to those previously established, the added wells were constructed of 4 cm diameter PVC pipe buried to a depth of 1 m. Holes were drilled in the pipe at 5 cm intervals, the bottom and sides were covered with fine mesh nylon to prevent filling with soil, and the top was capped to prevent precipitation from entering. Ground water salinities within the wells were determined with a conductivity meter (model 33, YSI, Yellow Springs, Ohio) at ~2 wk intervals. Temporal variations were related to precipitation patterns, based on data from a micrometeorological station on Hog Island. Differences among the sites were statistically evaluated with a repeated measures analysis of variance as described above.

Post-storm spatial variations in salinity among the four sites were also examined through measurements of soil chloride levels in July, 1992. Soil samples (~150 g) were collected to a depth of 10 cm under 50 randomly selected shrubs at each site. Within the laboratory, the soil samples were oven dried at 105 °C for 48 hr; thereafter, 40 g subsamples were analyzed for total chloride with a chloride electrode (model 9617b, Orion, Boston, Massachusetts) in a 1:5 ratio (w/v) of soil to distilled water with 5 M $NaNO_3$ (2 mL per 100 mL of sample) added as an ionic equalizer. The results were expressed as mass of chloride per mass of dry soil. Differences in the frequency distributions for soil chloride among the four sites were identified with Kolmogorov-Smirnov tests (SOKAL and ROHLF, 1981).

Laboratory Experiment

To determine the effect of storm related flooding on shrub physiology, individual *M. cerifera* (30–40 cm tall) were potted in sand collected from Hog Island and subjected to the following four treatments: flooded with fresh water, flooded with salt water (10‰), submerged in ocean-strength salt water (30‰) for 24 hr and then flooded with salt water (10‰), and non-flooded control. After 14 d, salinity was reduced to 5‰. After 30 d, all plants were thoroughly flushed with fresh water in order to monitor recovery. Thereafter, the plants were watered every other day for 1 mo. To simulate mid-summer conditions for maximum growth or physiological activity (YOUNG, 1992), the plants were maintained in an environmental chamber (model E-15, Conviron, Pembina, North Dakota) with a 16 hr photoperiod, a 25/20 °C temperature regime, and a photon flux density of 400 μmol m^{-2} sec^{-1}.

To quantify plant response to the treatments, every 3 d, predawn and midday leaf xylem pressure potential and maximum stomatal conductance were determined for each treatment and non-flooded control plants (n = 5). Leaf xylem pressure potentials were quantified with a pressure chamber (model 650, Plant Moisture Stress, Corvallis, Oregon) at the end of the dark period and at midday (1000 to 1400 hr). Stomatal conductances were also quantified at midday, using a null balance porometer model Li-1600, Lambda Instruments, Lincoln, Nebraska). Significant differences in plant water relations parameters among the treatments were identified with a repeated measures analysis of variance and the Tukey multiple comparisons of means (SOKAL and ROHLF, 1981).

RESULTS

Field Sampling

Ground surveys throughout the 1992 growing season revealed little apparent damage to the *M. cerifera* thickets. As quantified with the digital comparison of pre- and post-storm aerial photographs, shrub mortality on Hog Island occurred over less than 5% of the total area covered by thickets. Moreover, shrub mortality was limited to the relatively exposed beach front thicket at the Eroding Surface (Figure 2). Most of the dead shrubs had been uprooted by high energy waves associated with the storm. However, for the three sites with pre-storm growth data, post-storm new shoot growth was significantly ($p < 0.001$) reduced, about 30% (Table 1). Among the four sites, post-storm new shoot growth was lowest for the Eroding Surface and significantly ($p < 0.01$) different from the other sites. New shoot growth for

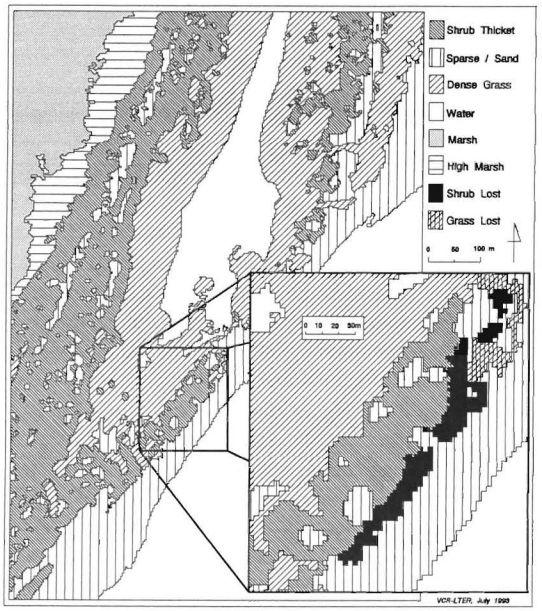

Figure 2. Land-cover classification for Hog Island showing the storm related shrub loss in the Eroding Surface thicket based on a digitized GIS comparison of aerial photographs from 1991 and 1992.

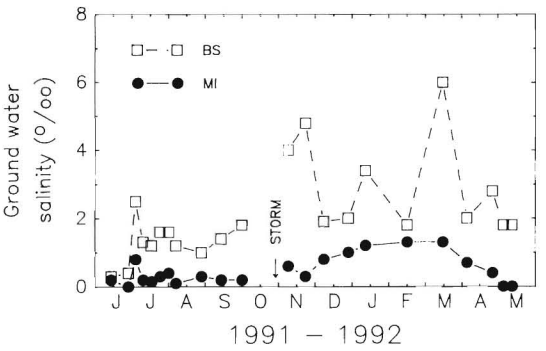

Figure 3. Pre- and post-storm ground water salinity for wells in the Mid-Island (MI) and Bay Side (BS) thicket sites on Hog Island. Values are means ± one standard error (n = 3 per site). Error bars are not shown where the standard error did not exceed the size of the symbol.

the Bay Side thicket was significantly ($p < 0.01$) less than the Leading Edge (Table 1).

Ground water salinity was significantly greater ($p < 0.001$) in the Bay Side *M. cerifera* shrub thicket, both before and after the storm, when compared with measurements in the Mid-Island thicket (Figure 3). Moreover, there was less temporal variation in ground water salinity at the Mid-Island site. Relative to pre-storm values, ground water salinity levels in both locations increased after the storm, up to 6‰ for the Bay Side thicket but not exceeding 2‰ in the Mid-Island thicket (Figure 3). The high values in March were due to flooding from exceptionally high spring tides (KROVETZ *et al.*, 1992). For both thickets, ground water salinity returned to pre-storm levels by early May (Figure 3).

Spatial variations in ground water salinity throughout the post-storm growing season (1992) reflected the relative amount of exposure of the four sites (Figure 4). Ground water salinity was significantly ($p < 0.05$) greater (4‰) and more variable at the Eroding Surface thicket when compared to the other three sites. Maximum salinity at the Bay Side thicket, adjacent to the fringe marsh, exceeded 2‰, but was below 2‰ for the Leading Edge thicket (Figure 4). At the relatively protected Mid-Island thicket, salinities were significantly ($p < 0.05$) lower than the other thickets, often below the limit of detection by the conductivity meter (Figure 4). For all four sites, ground water salinities were highest in late June and early July when precipitation was infrequent and lowest in September after several rain storms (Figure 4). Salinity increases in October 1992 were due to storm related flooding.

Frequency distributions for soil chloride from samples collected during July of 1992 reflected the patterns of the ground water salinities (Figure 5). The greatest range in soil chlorides, from less than 1 to almost 5,000 $\mu g\ g^{-1}$, occurred for both the Eroding Surface and Bay Side thickets, which differed significantly ($p < 0.05$) from the other two sites. The narrowest range, from less than 1 to almost 100 $\mu g\ g^{-1}$ occurred for the Mid-Island thicket, which also was significantly different (p

Table 1. *New shoot growth (g dry mass/shoot) for* Myrica cerifera *shrub thickets at four sites on Hog Island. Values are means ± one standard error (n = 50 per site).*

Site	Pre-storm 1990	Post-storm 1992	% Change
Leading edge	13.67 ± 1.71	8.94 ± 1.13	−34.6
Mid-island	10.22 ± 1.82	6.44 ± 1.03	−37.0
Bay side	6.14 ± 1.22	4.74 ± 0.73	−22.8
Eroding surface	—	1.27 ± 0.18	—

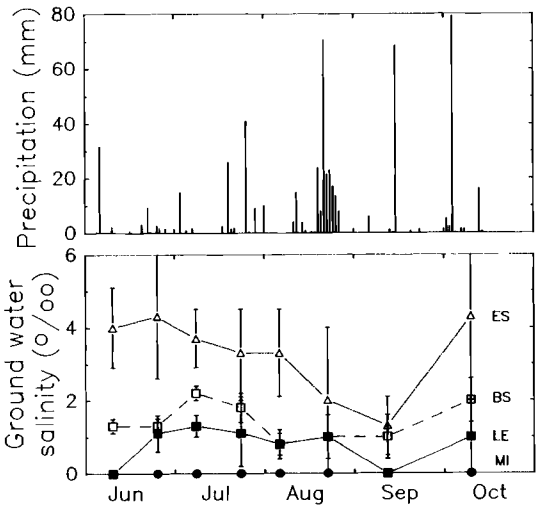

Figure 4. Precipitation and variations in ground water salinity during the summer and fall of 1992 for wells located in the Leading Edge (LE), Mid-Island (MI), Bay Side (BS), and Eroding Surface (ES) thickets on Hog Island. Values are means ± one standard error (n = 3 per site).

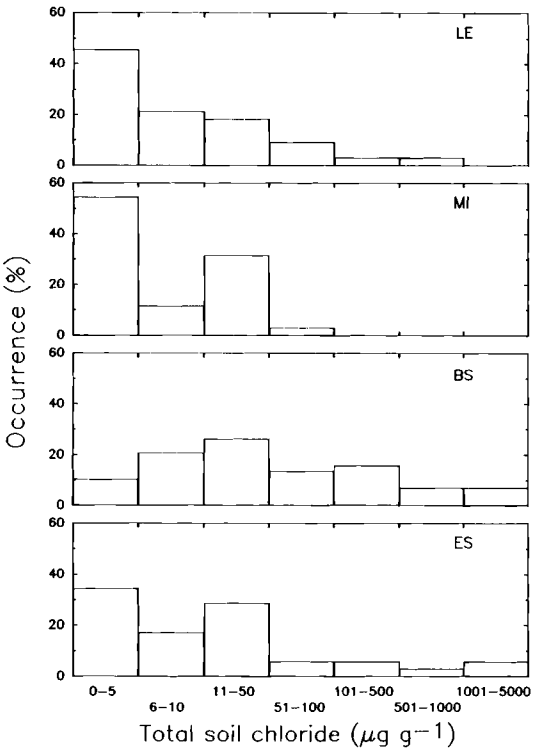

Figure 5. Frequency distributions of total chloride in soil samples collected during July 1992 from the Leading Edge (LE), Mid-Island (MI), Bay Side (BS) and Eroding Surface (ES) thickets on Hog Island (n = 50 per site).

< 0.05) from the Leading Edge thicket (Figure 5).

Laboratory Experiment

Stomatal closure in *M. cerifera* was rapid in response to all three flooding treatments (Figure 6). Significant decreases ($p < 0.01$) relative to the controls occurred within 4 d for both the submerged/flooded and flooded salinity treatments. A significant ($p < 0.05$) decrease in stomatal conductance for the plants flooded with fresh water occurred by day 9 (Figure 6). Stomates remained closed throughout the experiment for the plants that had been submerged in 30‰ salinity prior to flooding with 10‰. In contrast, both maximum and minimum xylem pressure potentials during the experiment were significantly ($p < 0.01$) greater for the submerged plants when compared to the controls (Figure 6). Although maximum xylem pressure potentials did not significantly differ among the other two treatments and controls, minimum values were significantly ($p < 0.05$) greater relative to the controls during the period of stomatal closure, day 14 through day 30. After flushing with fresh water and allowing soils to drain, stomatal conductance and xylem pressure potential recovered within 30 d and were nearly identical for all three salinity treatments relative to the controls (Figure 6).

DISCUSSION

Monitoring with remote sensing technology, coupled with field observations and laboratory experiments, facilitated an assessment of the physical, ecological and physiological impacts of the 1991 northeaster storm. The physical impact of the high energy storm on Hog Island shrub thickets was dependent on the degree of exposure to wave action. Possible ecological effects were subtle and identified as reduced shoot growth in the growing season following the storm. The physiological impact was also minimal; effects may depend on storm timing relative to plant physiological activity.

Myrica cerifera is abundant on barrier islands and coastal environments of the southeastern United States (DUNCAN and DUNCAN, 1987), but

it is sensitive to salinity and flooding. Photosynthesis, nitrogen fixation, and growth are reduced in response to salinity levels below 5‰ (SANDE and YOUNG, 1992). Small-scale distribution patterns on barrier islands may be related to salinity intolerance (YOUNG *et al.*, 1992). Further, both *Myrica cerifera* and *M. pensylvanica* are restricted to sites where overwash, wave effects, and sand deposition are minimal (FAHRIG *et al.*, 1993). Despite the magnitude of the October 1991 northeaster storm, shrub thicket mortality on Hog Island was limited to an eroding beach, further indicating that the *Myrica cerifera* dominated thickets occur in relatively protected areas.

The flooding experiment revealed that reduced physiological activity may contribute to *M. cerifera* shrub survival during storm induced salinity pulses. In similar studies, *Pinus taeda*, a dominant tree of barrier island forests, also showed reduced stomatal conductance in response to flooding with ~3‰ salinity (PEZESHKI, 1992); no seedlings survived more than 2 d flooding with 30‰ salinity (CONNER and ASKEW, 1992). Bottom land coastal forests in South Carolina, U.S.A. were flooded during the Hurricane Hugo induced tidal surge; extensive tree mortality was attributed to physiological stress in response to persistent soil salinization (GARDNER *et al.*, 1992). In contrast, *M. cerifera* shrubs were damaged at five locations differing in exposure to flooding in the North Inlet region of South Carolina, but all shrubs fully recovered by the following spring (D.R. YOUNG, *unpublished data*).

The flooding experiments described above used physiologically active plants. However, storm frequency is high in the Mid-Atlantic region from October to April (DOLAN *et al.*, 1988; DAVIS *et al.*, 1993) when plants are dormant. The three storms closest in total energy to the October 1991 storm occurred in February and March (DOLAN *et al.*, 1988, 1990). Thus, even though *M. cerifera* shrub thickets may have been completely submerged during these storms, mortality was most likely related to direct physical effects of waves. Salinity effects on winter dormant plants would be minimal.

Elevated salinity levels during the winter months may be reduced prior to plant physiological activity in the Spring. Salinity would be naturally leached from the porous, sandy soils by precipitation. Fresh water flooding is common in the low lying swales of Hog Island during the winter months (D.R. YOUNG, *personal observation*). Although flooding may lead to stress when *M. cerifera* is physiologically active (CARTER and YOUNG, 1993), little effect would be expected during the cold winter months. New shoot growth for the growing season after the storm was 30% below pre-storm values, but these values may be within the range of year to year variations which have not been quantified.

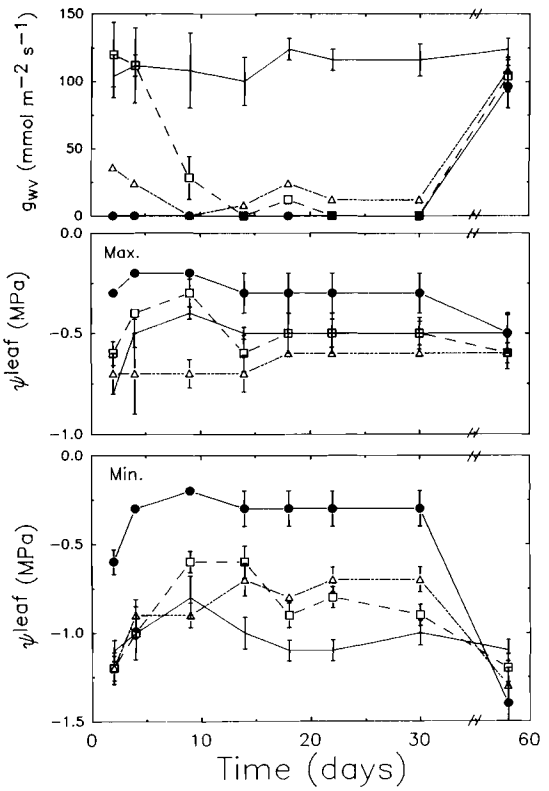

Figure 6. Effects of flooding and salinity on potted *Myrica cerifera* stomatal conductance (g_{wv}) and both maximum and minimum leaf xylem pressure potential (Ψ^{leaf}). Treatments included: flooded with fresh water (□), flooded with 10‰ salt water (△), submerged in 30‰ salt water for 24 hr followed with flooding in 10‰ salt water (●), and a non-flooded control (——). After 14 d, salinity was reduced to 5‰ and after 30 d all plants were flushed with fresh water and permitted to drain. Values are means ± one standard error (n = 5 per treatment). Error bars are not shown where the standard error did not exceed the size of the symbol.

The frequency and magnitude of coastal storms, as well as timing relative to physiological activity, will determine the ecological impact on shrub thickets, as well as other barrier island plant communities. In addition to salinity and flooding, these

communities may be exposed to high winds and sand burial during storms (CLARK, 1986; EHRENFELD, 1990; STALTER and ODUM, 1993). These storms represent a strong selective force in the evolution of coastal species (CLARK, 1990; EHRENFELD, 1990), especially the long-lived woody species that may require years before reproducing. Further, these storms influence community composition by modifying population abundances, altering recruitment patterns and permitting species to persist that otherwise might not (CLARK, 1990). *Myrica cerifera* shrub thickets appear to be well suited for the survival of storms in the harsh environment of barrier islands.

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