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# MANGROVE DAMAGE CAUSED BY HURRICANE ANDREW ON THE SOUTHWESTERN COAST OF FLORIDA

*Earl D. McCoy, Henry R. Mushinsky, Derek Johnson, and Walter E. Meshaka, Jr.*


## ABSTRACT

We surveyed the mangrove forest at the mouth of Lostman's River, on the southwestern coast of Florida, about 2 months after Hurricane Andrew had passed. Damage to the mangrove forest there was severe: about 60% of the trees were either uprooted or broken, about 25% of the upright, unbroken trees were dead, and only about 14% of the upright, unbroken trees were well vegetated. Larger trees were more likely to be damaged, and damaged more severely, than smaller trees. Overall, *Rhizophora mangle* (red mangrove) fared marginally better than *Avicennia germinans* (black mangrove), and both of these species fared substantially better than *Laguncularia racemosa* (white mangrove). The forest structure at our site likely will be substantially altered as a result of Hurricane Andrew for some time to come.


Hurricane Andrew passed across Florida on 24 August, 1992. Sustained winds exceeded 240 km/h, causing severe damage to homes and businesses in its path. The ecosystems encompassed by Everglades National Park (ENP), including the extensive mangrove forests on Florida's southwestern coast, also were affected by Hurricane Andrew (Alper, 1992; Davis et al., unpubl.; Dawes et al., 1995). Heavy damage appears to have occurred to nearly 150 $km^2$ of mangroves in the region (Ogden, 1992). Much of the mangrove forest damaged by Hurricane Andrew had been damaged earlier, in 1960, by Hurricane Donna (Craighead and Gilbert, 1962; Craighead, 1964).

In October, 1992, we surveyed the mangrove forest at the mouth of Lostman's River, very near where the center of the eye of Hurricane Andrew exited Florida (Fig. 1). The mangrove forest that we surveyed was nearest to the "fringe forest" and "riverine forest" community types identified by Lugo and Snedaker (1974). We used the data gathered during our surveys to reconstruct the mangrove forest at the site and to estimate local damage. To facilitate comparison with studies of damage caused by other hurricanes, we followed, when possible, the methods and analyses of Roth (1992), which she used to assess damage to mangroves in Nicaragua caused by Hurricane Joan.

## METHODS

We employed six strip transects to survey the mangroves. The transects were taken perpendicular to the shoreline, and spaced as widely as possible, to accomodate potential spatial variation in local forest structure (Smith, 1992) and damage. All transects were 5 m in width; four transects were 100 m in length (0.05 ha in area), and the other two were 60 m in length (0.03 ha in area). Surveys were taken on four consecutive days.

We identified all mangroves encountered along the transects and recorded their positions. If an individual was >1.5 m in height, we measured its diameter at that height (DBH), and if it was <1.5 m in height, we measured its diameter at 0.5 m. To compensate for the unevenness of most boles, we derived estimates of true diameter by averaging several measurements per tree, made with calipers. We attempted to measure the heights of upright individuals with a clinometer and of uprooted individuals with a tape measure, but the tangle of downed vegetation (Craighead and Gilbert, 1962) prevented our doing so effectively. Instead, we simply estimated visually the heights of representative individuals.

We placed each mangrove into one of three categories of both "stem condition" and "vegetation condition." Categories of stem condition were uprooted, broken, and intact; and of vegetation condition were dead, poorly vegetated, and well vegetated. "Dead" means that the tree was uprooted

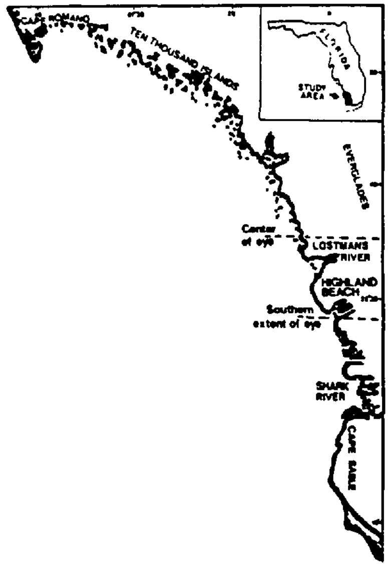


Figure 1. Map of southwestern Florida, showing the path of Hurricane Andrew (used with permission of *Journal of Coastal Research*).

and/or virtually all of its original leaves—and usually branches, as well—had been lost and we could see no evidence of new growth. It should be noted that some unknown percent of individuals likely were dead prior to Hurricane Andrew. Dead individuals in seven Florida basin forests, where salt stress may lead to higher rates of mortality than in other mangrove community types, comprised from 6% to 19% of all trees (Jiménez et al., 1985). Based on these data, we assumed that the number of dead individuals at our site before Hurricane Andrew was relatively small, perhaps less than 10% of all trees. It should also be noted that branches of *R. mangle* do not resprout when broken (Gill and Tomlinson, 1971; Tomlinson, 1980), but the other two Florida mangrove species coppice well (Roth, 1992), so relatively more individuals of *R. mangle* than of the other two species are likely to be categorized as dead. "Poorly vegetated" means that relatively many of the original leaves—and usually branches, as well—had been lost and/or only modest new growth had occurred. "Well vegetated" means that relatively few of the original leaves and branches had been lost and/or substantial new growth had occurred. Before beginning our surveys, we had decided to set the division between poorly vegetated and well vegetated at 50% leaf loss, and to judge the appropriate category for each tree by consensus. Our surveys revealed, however, that the dichotomy between the two categories was much stronger than we had anticipated, and very few trees were difficult to categorize. It should be noted that refoliation of a mangrove after it has been damaged may be only temporary, and it may die later (Craighead and Gilbert, 1962).

## Results and Discussion

The six transects contained individuals of three mangrove species, *Avicennia germinans* L. (black mangrove), *Laguncularia racemosa* Gaernt. (white mangrove), and *Rhizophora mangle* L. (red mangrove). We counted 501 individuals ≥2.5 cm DBH (we refer to these individuals as "trees"), 169 individuals <2.5 cm DBH ("samplings") and 338 individuals <1.5 m in height ("seedlings") (Table 1). About 64% of the trees recorded on the six transects were relatively small individuals (<10 cm) (Fig. 2). The structure of the mangrove forest was variable among transects (Table 2), but largely consistent with our expectations, based on previous studies of mangrove forest structure on Florida's west coast (Pool et al., 1977; Ball, 1980).

For some reason, the mangrove forest was less dense north of Lostman's River (Transects 1–3) than south of it (Transects 4–6). Perhaps the difference reflects,

Table 1. Numbers of trees (A), saplings (B), and seedlings (C) of each mangrove species, recorded on the six transects and in total

| Species | | Transect 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|---|
| *Avicennia germinans* | (A) | 21 | 3 | 14 | 11 | 11 | 31 | 91 |
| | (B) | 2 | 0 | 0 | 1 | 27 | 16 | 46 |
| | (C) | 2 | 0 | 0 | 6 | 62 | 2 | 72 |
| *Laguncularia racemosa* | (A) | 8 | 17 | 25 | 86 | 20 | 14 | 170 |
| | (B) | 0 | 0 | 1 | 2 | 0 | 6 | 9 |
| | (C) | 0 | 2 | 0 | 0 | 0 | 7 | 9 |
| *Rhizophora mangle* | (A) | 7 | 21 | 1 | 94 | 34 | 83 | 240 |
| | (B) | 22 | 0 | 1 | 4 | 7 | 80 | 114 |
| | (C) | 55 | 50 | 0 | 61 | 42 | 49 | 257 |
| Total | (A) | 36 | 41 | 40 | 191 | 65 | 128 | 501 |
| | (B) | 24 | 0 | 2 | 7 | 34 | 102 | 169 |
| | (C) | 57 | 52 | 0 | 67 | 104 | 58 | 338 |

at least in part, variation in the local effects of Hurricane Donna, 32 years earlier (Craighead, 1964: 13). The difference does serve to remind us that we probably should be quite cautious about extrapolating the conclusions adduced from our samples to a broad geographical area.

No grouping of species into zones by distance from the shoreline was obvious (Fig. 3). Roth (1992) used variance-ratio tests to determine if the presences or absences of species were associated (positive and negative association, respectively), for quadrat sizes 25 $m^2$, 50 $m^2$, and 75 $m^2$. We recorded so few absences for all of our six transects combined, at any of the three quadrat sizes, that we could not employ variance-ratio tests. We could use correlation analysis to determine if cumulative abundances were related, however. We found only one rela-

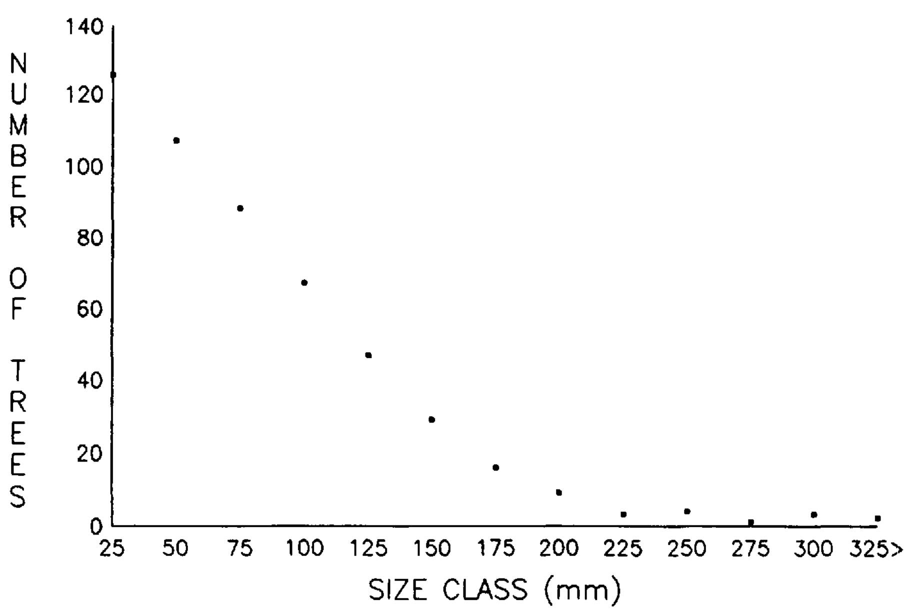


Figure 2. Size distribution of mangrove trees encountered along six transects near the mouth of Lostman's River, ENP.

Table 2. Structure of the mangrove forest before Hurricane Andrew

| | Trees ≥2.5 cm | Trees ≥10 cm |
|---|---|---|
| Mean DBH (cm) | 9.2 (±5.4) | 15.0 (±4.7) |
| Estimated stand height (m) | 26 | 26 |
| Density (trees/ha) | 1,903 (±1,189) | 704 (±242) |
| Basal area ($m^2$/ha) | 17.3 (±5.2) | 13.6 (±3.1) |

tionship: the cumulative abundances of *L. racemosa* and *R. mangle* were correlated positively (Spearman's Correlation Coefficient, $r = 0.84$, $P < 0.05$) at the 75 $m^2$ quadrat size.

Damage to the mangrove forest, inflicted by Hurricane Andrew, was severe, rivaling that caused by Hurricane Donna along Shark River (Craighead and Gilbert, 1962). About 60% of the trees were either uprooted or broken (Table 3), and about 25% of the upright, unbroken trees were dead (Table 4). Only about 14% of the upright, unbroken trees were well vegetated (Table 4). The severity of two kinds of damage, uprooting and loss of vegetation, apparently was related to distance from the shoreline (Fig. 4).

Damage was not distributed uniformly among trees of different sizes (Fig. 5). The median DBH of uprooted trees was 11.0 cm, and of erect trees (broken and entire) was 6.5 cm (*U*-test, $z = 7.73$, $P < 0.05$). The median DBH of broken trees was 8.9 cm, and of entire trees was 5.5 cm (*U*-test, $z = 2.4$, $P < 0.05$). The median DBH of well vegetated upright, unbroken trees was 3.7 cm, and of poorly vegetated and dead upright, unbroken trees was 5.9 cm (*U*-test, $z = 4.1$, $P < 0.05$). The tendency for uprooting to occur preferentially at certain distances from the shoreline (Fig. 4) may be related to tree size, at least in part: percentage of uprooting in 10-m increments of the transects was correlated positively with me-

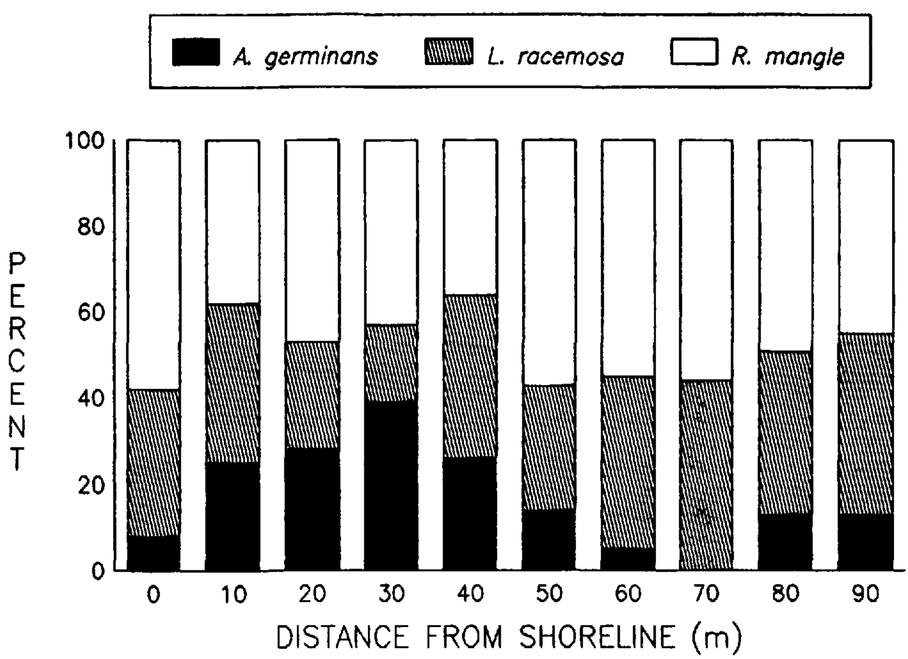


Figure 3. Distribution of mangrove trees in relation to distance from the shoreline.

Table 3. Stem condition of mangrove trees after Hurricane Andrew

| Species | Stem condition | | | Total |
|---|---|---|---|---|
| | Uprooted | Broken | Intact | |
| *Avicennia germinans* | 28 | 17 | 46 | 91 |
| *Laguncularia racemosa* | 60 | 77 | 33 | 170 |
| *Rhizophora mangle* | 52 | 66 | 122 | 240 |
| Total | 140 | 160 | 201 | 501 |

dian tree size in the same sections (Spearman's Correlation Coefficient, $r = 0.58$, $P < 0.10$). We conclude that larger trees were more likely to be damaged, and damaged more severely, than smaller trees.

Our finding, that large trees were more prone to be damaged by the hurricane than were small ones, appears to be typical of mangrove forests (Roth, 1992; Wunderle et al., 1992). Hurricanes also often damage relatively more large trees than small ones in upland forests (Gresham et al., 1991; You and Petty, 1991), but not always (Frangi and Lugo, 1991; Reilly, 1991). Frequent perturbation, that is focussed on large individuals, may be responsible for the generally smaller heights and diameters of trees in mangrove forests than in upland forests (Roth, 1992). In south Florida, mangroves may reach maturity in only 20–25 years (Craighead, 1971) at a height of less than 1 m (Smith et al., 1994), and it could be that relatively-frequent hurricanes limit the maximum biomass and structure that mangrove forests can attain in the region, and thereby influence the demography of the trees (Lugo and Snedaker, 1974; Odum et al., 1982; Smith, 1992; see Ogden, 1992). The expected return time of hurricanes on the southwestern coast of Florida, especially on an evolutionarily-relevant spatial scale, may be substantially longer than 25 years, however (U.S. Department of Commerce, 1987, 1993).

Damage also was not distributed uniformly among trees of different species. Contingency table analyses revealed that both stem condition and vegetation condition of upright, unbroken trees varied among the three species (G-tests, $G =$ 51.9 and 15.4, $P$'s $< 0.05$). By both measures of condition, *R. mangle* fared marginally better than *A. germinans,* and both of these species fared substantially better than *L. racemosa.* Because of the relative sizes of the three species (median DBH = 6.9 cm (*R. mangle*), 6.5 cm (*A. germinans*), 9.7 cm (*L. racemosa*); mean

Table 4. Vegetation condition of uprooted (A), broken (B), and intact (C) mangrove trees after Hurricane Andrew

| Species | | Vegetation condition | | | Total |
|---|---|---|---|---|---|
| | | Dead | Poor | Good | |
| *Avicennia germinans* | (A) | 20 | 8 | 0 | 28 |
| | (B) | 4 | 12 | 1 | 17 |
| | (C) | 4 | 37 | 5 | 46 |
| *Laguncularia racemosa* | (A) | 34 | 25 | 1 | 60 |
| | (B) | 52 | 25 | 0 | 77 |
| | (C) | 11 | 20 | 2 | 33 |
| *Rhizophora mangle* | (A) | 47 | 4 | 1 | 52 |
| | (B) | 54 | 8 | 4 | 66 |
| | (C) | 35 | 65 | 22 | 122 |
| Total | | 261 | 204 | 36 | 501 |

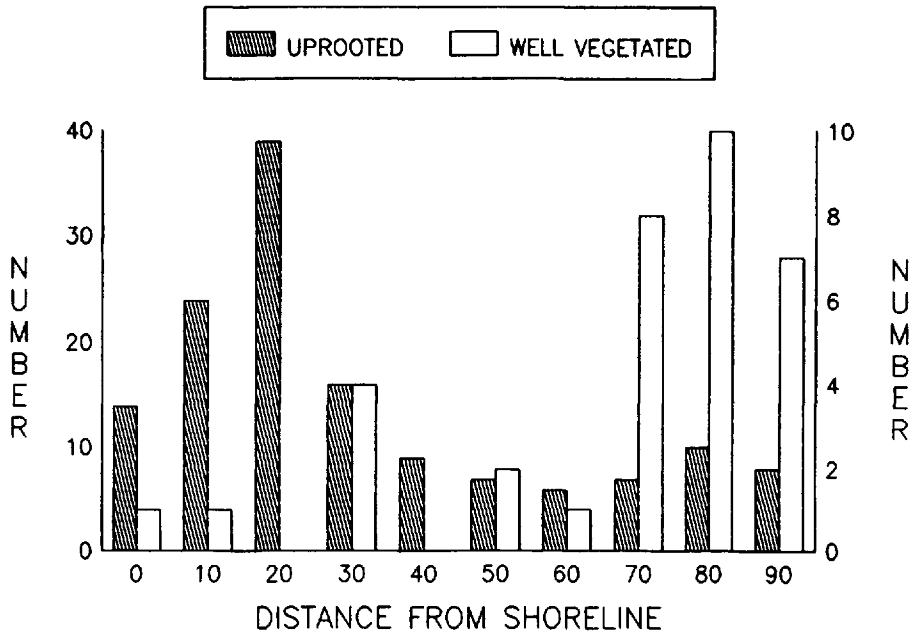


Figure 4. Distribution of uprooting (left ordinate) and vegetation loss (right ordinate) of mangrove trees in relation to distance from the shoreline.

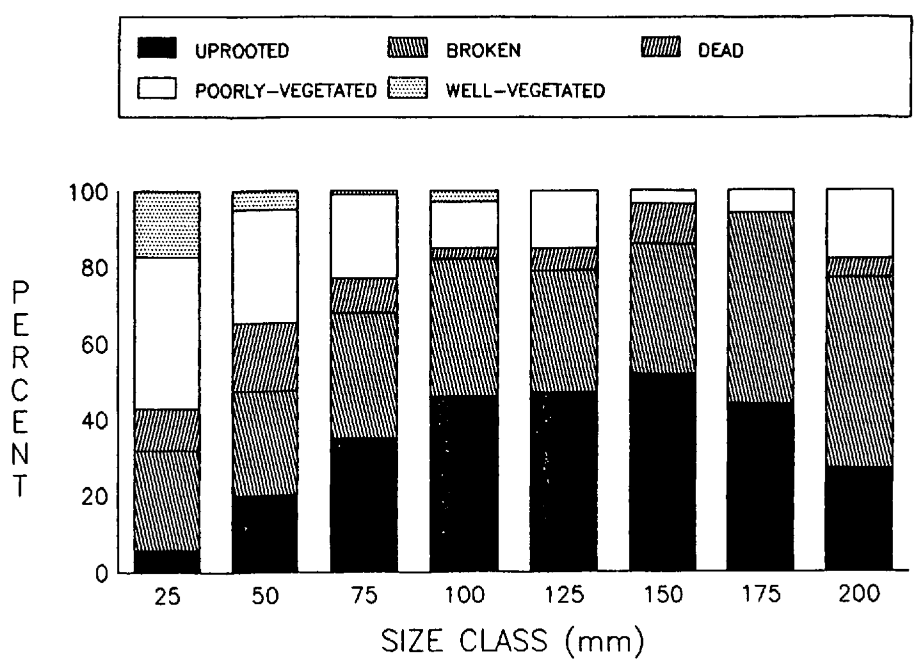


Figure 5. Stem and vegetation conditions of mangrove trees in different size classes.

DBH = 8.2 (±4.9) cm (*R. mangle*), 9.9 (±7.2) cm (*A. germinans*), 10.1 (±5.8) cm (*L. racemosa*)), we cannot conclude with much confidence that species-specific, rather than size-specific, differences in susceptibility exist, however.

The upright trees appeared to be composed of shorter broken individuals and taller intact individuals. The mean snap levels, estimated visually, of upright, broken trees were 2.7 (±1.9) m for *A. germinans,* 3.2 (±2.5) for *L. racemosa,* and 2.7 (±1.8) for *R. mangle.* About 80% of the upright, broken trees were less than 4 m tall. The mean estimated height (using the relationship between height and DBH in Ball (1980) for *R. mangle*) of upright, intact trees was 9.7 (±4.3) m. This height matched our visual estimates of intact tree height well. Only about 35% of the upright, intact *R. mangle* trees were estimated to be less than 4 m tall. We conclude that the conspicuous "leveling effect" of hurricane winds noted by Roth (1992) was not as evident along our transects.

The mean density of upright, intact, well vegetated saplings (71% of the individuals) and seedlings (29% of the individuals) was 1,636 (±1,397) individuals/ha. About 75% of them were *R. mangle,* 22% *A. germinans,* and 3% *L. racemosa.* The density of the seedlings of a species on a transect was correlated positively with the density of saplings and trees of the same species on the transect (Spearman's Correlation Coefficient, $r = 0.54$, $P < 0.05$). The density of upright, intact, well vegetated saplings and seedlings was no greater than that of the trees in the forest before Hurricane Andrew struck (Table 2), and relatively more of them were *R. mangle* and *A. germinans,* and relatively fewer were *L. racemosa* (Table 1).

It would appear that restoration of the pre-hurricane forest structure locally, in the vicinity of our transects, cannot be accomplished simply by future growth and reproduction of the mangroves remaining there (Roth, 1992). In particular, large individuals of *Laguncularia racemosa* were severely damaged by Hurricane Andrew, and relatively few small individuals remain. Furthermore, once regeneration of the forest in underway, *L. racemosa* saplings and seedlings cannot be expected to fare well relative to the other mangrove species (Ball, 1980; Roth, 1992). Input of propagules from elsewhere and the course of environmental conditions in the future will strongly influence the changes that occur at our site (Lugo, 1980). We suggest that the mangrove forest structure at our site will be substantially altered as a result of Hurricane Andrew for some time to come; just as the structure there probably was substantially altered several decades ago as a result of Hurricane Donna (Ackerman et al., 1991).

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## LITERATURE CITED

Ackerman, J. D., L. R. Walker, F. N. Scatena and J. Wunderle. 1991. Ecological effects of hurricanes. Bull. Ecol. Soc. Am. 72: 178–180.

Alper, J. 1992. Everglades rebound from Andrew. Science 257: 1852–1854.

Ball, M. C. 1980. Patterns of secondary succession in a mangrove forest of southern Florida. Oecologia 44: 226–235.

Craighead, F. C. 1964. Land, mangroves and hurricanes. Fairchild Trop. Gard. Bull. 19(4): 1–28.

———. 1971. The trees of South Florida, Vol. I. The natural environments and their succession. University of Miami, Coral Gables, Florida. 212 p.

——— and V. C. Gilbert. 1962. The effects of Hurricane Donna on the vegetation of southern Florida. Q. J. Fla. Acad. Sci. 25: 1–28.

Dawes, C. J., S. S. Bell, R. A. Davis, E. D. McCoy, H. R. Mushinsky and J. S. Simon. 1995. Initial effects of Hurricane Andrew on the shoreline habitats of southwestern Florida. J. Coastal Res. 21:103–110.

Frangi, J. L. and A. E. Lugo. 1991. Hurricane damage to a flood plain forest in the Luquillo Mountains of Puerto Rico. Biotropica 23: 324–335.

Gill, A. M. and P. B. Tomlinson. 1971. Studies on the growth of red mangrove (*Rhizophora mangle* L.) 3. Phenology of the shoot. Biotropica 3: 109–124.

Gresham, C. A., T. M. Williams and D. J. Lipscomb. 1991. Hurricane Hugo wind damage to southeastern U.S. coastal forest tree species. Biotropica 23: 420–426.

Jimenéz, J. A., A. E. Lugo and G. Cintrón. 1985. Tree mortality in mangrove forests. Biotropica 17: 177–185.

Lugo, A. E. 1980. Mangrove ecosystems: successional or steady state? Biotropica 12 (suppl.): 65–72.

——— and S. C. Snedaker. 1974. The ecology of mangroves. Annu. Rev. Ecol. Syst. 5: 39–64.

Odum, W. E., C. C. McIvor and T. J. Smith, III. 1982. The ecology of the mangroves of south Florida: a community profile. U.S. Fish Wildl. Serv., FWS/OBS-81/24, Washington, DC. 144 p.

Ogden, J. C. 1992. The impact of Hurricane Andrew on the ecosystems of south Florida. Conserv. Biol. 6: 488–490.

Pool, D. J., S. C. Snedaker and A. E. Lugo. 1977. Structure of mangrove forests in Florida, Puerto Rico, Mexico, and Costa Rica. Biotropica 9: 195–212.

Reilly, A. E. 1991. The effects of Hurricane Hugo in three tropical forests in the U.S. Virgin Islands. Biotropica 23: 414–419.

Roth, L. C. 1992. Hurricanes and mangrove regeneration: effects of Hurricane Joan, October 1988, on the vegetation of Isla del Venado, Bluefields, Nicaragua. Biotropica 24: 375–384.

Smith, T. J., III. 1992. Forest structure. Pages 101–136 *in* A. I. Robertson and D. M. Alongi, eds. Tropical mangrove ecosystems. Springer-Verlag, New York.

———, M. B. Robblee, H. R. Wanless and T. W. Doyle. 1994. Mangroves, hurricanes, and lightning strikes. BioScience 44: 256–262.

Tomlinson, P. B. 1980. The biology of trees native to tropical Florida. Harvard University, Allston, Massachusetts. 480 p.

U.S. Department of Commerce. 1987. Hurricane climatology for the Atlantic and Gulf coasts of the United States. National Atmospheric and Oceanic Administration, Silver Spring, Maryland. 195 p.

———. 1993. Hurricane Andrew: South Florida and Louisiana, August 23–26, 1992. National Atmospheric and Oceanic Administration, Silver Spring, Maryland. 131 p.

Wunderle, J. M., Jr., D. J. Lodge and R. B. Waide. 1992. Short-term effects of Hurricane Gilbert on terrestrial bird populations on Jamaica. Auk 109: 148–166.

You, C. and W. H. Petty. 1991. Effects of Hurricane Hugo on *Manilkara bidentata,* a primary tree species in the Luquillo Experimental Forest of Puerto Rico. Biotropica 23: 400–406.

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ADDRESSES: (E.D.M., H.R.M., D.J.) *Department of Biology, University of South Florida, Tampa, Florida 33620-5150.* (W.E.M.) *Department of Biological Sciences, Florida International University, Miami, Florida 33199.*