Predicting Mangrove Forest Recovery on the Southwest Coast of Florida Following the Impact of Hurricane Wilma, October 2005

By Greg A. Ward and Thomas J. Smith III

The damage to mangrove forests on the west coast of Everglades National Park from Hurricane Wilma in 2005 rivaled that of Hurricane Andrew in 1992. We describe patterns and rates of recovery following Andrew and use these estimates to gage recovery based upon site reconnaissance and forest structural damage considerations in the aftermath of Wilma.

Introduction

It is estimated that the Florida Everglades have been impacted by 38 storms since 1886 (Doyle and Girod, 1997). Of the more recent storms, Andrew crossed the southern Florida Peninsula in August 1992 (fig. 1). Andrew made landfall as a category 5 storm, the third-strongest hurricane to hit the mainland United States on record (Landsea and others, 2004). In addition to widespread human and economic suffering, wind and tidal surge resulted in severe damage to portions of the western mangrove ecosystem of Everglades National Park (Smith and others, 1994).

More recently, however, Wilma impacted south Florida in October 2005 (fig. 1). Unusual in approach, Wilma struck from the west as a category 3 storm. Although Wilma was weaker in intensity than Andrew, preliminary observations indicate a similar intensity of damage (fig. 2) but over a more widespread area.

While it is conventional wisdom that coastal mangrove ecosystems are periodically affected by hurricanes, relatively little is published about the basic patterns or rates of recovery from these disturbances. Mangrove forests, and the fish and wildlife species dependant on them, rely on the interplay of a variety of physical factors for their existence, including salinity of the water, the amount of oxygen in the soil, soil type, nutrient availability, inundation by tides, and air and water temperature, to name a few (Tomlinson, 1986; Smith, 1992). Because of the complex interactions among these factors, wide-scale damage

Figure 1. The approximate storm tracks of Hurricane Andrew (1992) and Hurricane Wilma (2005), and the respective extent of hurricane-force winds across south Florida.

caused by hurricanes may have unforeseen consequences that cascade throughout the ecosystem.

As a brief example, Cahoon and others (2003) determined that hurricane damage to mangrove forests in Honduras resulted in large-scale loss of sediment elevation. In this instance, the death of coastal mangroves and the further death and degradation of associated root material resulted in large areas of soil compaction and elevation loss. This result inhibited the ability of mangrove seedlings to reestablish in some areas, and portions of mangrove forest were subsequently converted to open water. Without renewed forest establishment and associated belowground root production, scientific models predicted that coastal elevations would continue to decline for at least another 8 years. Although this manner of large-scale coastal degradation has not been directly measured in Everglades National Park, historical photographs indicate that similar forces may be operating (see Wanless and others, 1994).

The 2005 hurricane season was the most active on record. Predictions of increased hurricane frequencies and intensities in years to come (Goldenburg and others, 2001; Knutson and others, 2001) warrant a review of mangrove forest regeneration patterns and processes in response to hurricane damage. Here, we provide a comprehensive review of mangrove forest structural regeneration over 13 years, from Andrew to Wilma. This period coincides with the average return period of major hurricanes to south Florida, reported by Elsner and Kara (1999) to be 11 years for Monroe County, Fla. We establish temporal and spatial structural patterns common across mangrove communities of south Florida. Furthermore, we use these relationships, in conjunction with assessments of mangrove forest structural damage following the impact of Wilma, to forecast biomass recovery times and associated community species shifts.

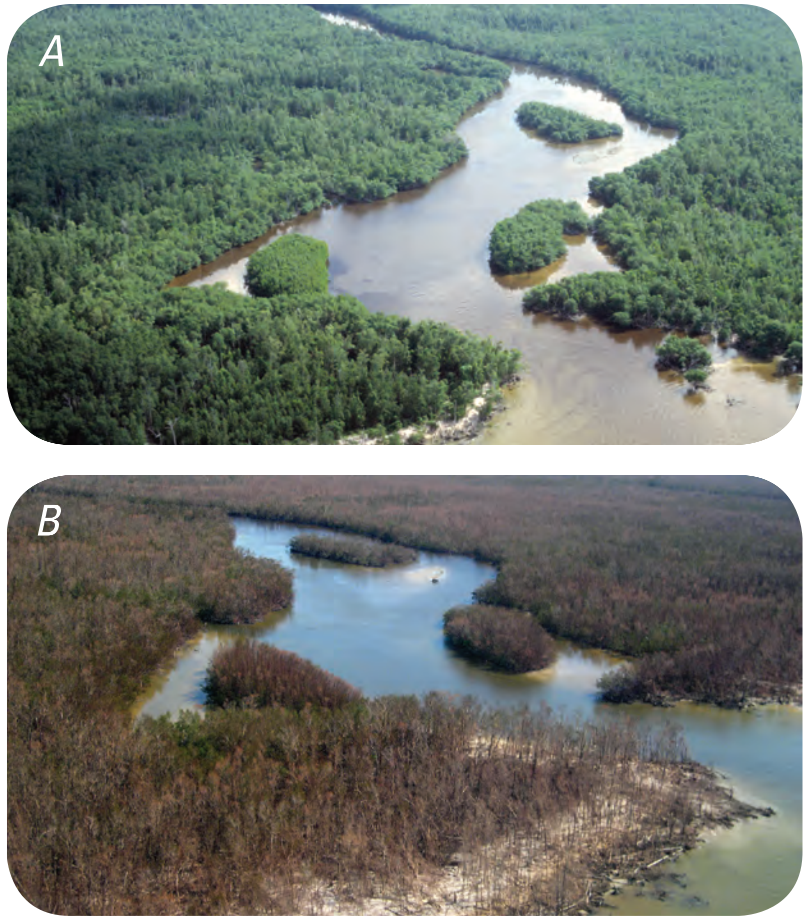

Figure 2. A mangrove forest on the southwestern coast of Everglades National Park before (*A*) and after (*B*) Hurricane Wilma, October 2005.

Methods

Shortly after Andrew, U.S. Geological Survey (USGS) scientists established a network of hydrological stations and associated mangrove vegetation plots (Smith, 2004). As part of the USGS Global Change Research Program, this network was designed to monitor hydrologic and vegetative changes associated with global sea-level rise. Operations and periodic monitoring of this network have continued to the present. The resultant database includes one of the most intensely sampled, spatially encompassing, and longest continuing records of mangrove ecosystem structural changes (Ward and others, 2006). Temporally averaged regression models of spatial structural constraints on recovery rates were quantified by using 10 sites from this database (table 1). These models were applied to current post-Wilma site conditions, based on damage assessments made in the months following impact.

Results

Mangrove Forest Structural Relationships

A common theoretical framework developed for upland plant communities appears to apply to mangroves of southwest Florida. This framework, often referred to as “Yoda’s Rule” or the “self-thinning rule,” states that there is a mathematical relationship between maximum stem density and mean stem biomass in plant communities (Yoda and others, 1963; White and Harper, 1970; White, 1981). In basic terms,

Table 1. Site location and name code, sample period, and sample frequency of all sites used in this study. Site color codes are maintained throughout all applicable tables and figures in this chapter.

[sd, standard deviation]

Site location (name code)	Plot radius (m)	Relative biomass lost from Andrew (%)	No. of samples	First sample date	Last sample date	Mean intersample period (±1 sd)
Shark River (SH3-1)	13	22	9	June 1994	Nov. 2003	1.2 year (±0.2)
Shark River (SH3-2)	13	6	9	June 1994	Nov. 2003	1.2 year (±0.2)
Harney River (SH4-1)	13	41	8	Nov. 1994	Jan. 2004	1.3 year (±0.2)
Harney River (SH4-2)	13	11	8	Nov. 1994	Jan. 2004	1.3 year (±0.2)
Broad River (BRM)	10	74	8	Oct. 1992	Nov. 2002	1.4 year (±0.2)
Johnsons Mound Creek (JMC)	10	15	8	Oct. 1992	May 2004	1.7 year (±0.4)
Lostmans Key (LMK)	10	36	8	Oct. 1992	Mar. 2005	1.8 year (±0.2)
Lostmans Ranger Station (LRS)	10	65	9	Oct. 1992	Mar. 2005	1.5 year (±0.2)
North Highland Beach (NHB)	16	97	8	Oct. 1992	Nov. 2002	1.4 year (±0.2)
Second Onion Bay (SOB)	10	77	9	Oct. 1992	Mar. 2005	1.6 year (±0.2)

individual plants in a crowded community must share from a limited pool of resources. Because all of the individuals must build and maintain themselves from this limited pool, for some individual plants to grow in size, other individuals must die. Through time, however, as the total number of individual plants and their average plant biomass changes, the relationship for the whole community of plants will predictably fall along a "thinning curve" that traces an upper boundary with a known slope of -3/2.

For mangrove stands observed in our study, hurricane recovery and the subsequent self-thinning rule process are depicted in figure 3. The thinning curve was determined by using the maximum stem density observed in sites prior to the start of community density decreases and is therefore indicative of a limit to resource availability. The slope of the relationship is -3/2 ($r^2 = 0.96$, $F_{(2, 8)} = 113.0$, $p < 0.05$, 95 percent confidence interval = -1.88 to -1.21), thus conforming to the predictions of the self-thinning rule. As illustrated in figure 3, the -3/2 upper boundary therefore appears to be a suitable demarcation of mangrove stand dynamics, from recovering to aging processes.

Following these tracks, the progression of hurricane recovery is seen in stand trajectories as they traced a path toward the lower right of the thinning curve. During this phase, small sapling trees were recruiting into sites to reoccupy the space vacated by those lost to hurricane damage; thus, as stem density was increasing, the biomass of the average tree was decreasing. Once the point of maximum density in a site was reached, however, "recovery" was considered complete. From that point, as stands continued to age, trajectories shifted to the left and up, tracing a path along the -3/2 slope predicted by the thinning curve. During the aging phase, while some trees continued to grow in size, others expired through competitive forces; thus, stem density was decreasing as the biomass of the average tree increased.

Estimating Recovery from Wilma

Site assessments following Andrew were divided into recovering and aging phases based on the maximum observed stem density from sites. The mean recovery phase (i.e., annual rate at which trees recruited, died, and grew in biomass) was determined for each species of mangrove in each site. The relationship between these rates and various measures of structural damage that sites received from Andrew revealed that across all sites the relative amount of biomass

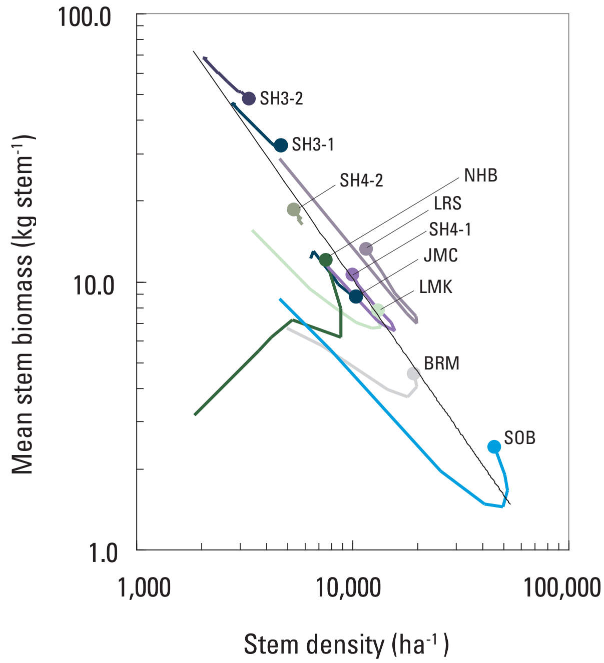

Figure 3. Recovery trends in mangrove stands following Hurricane Andrew in 1992. The self-thinning curve (black line) and relative movement of stands from 1992 to the present time are shown (colored tracks). Mean stem biomass is given as a function of stem density.

damage was predictive of red mangrove (*Rhizophora mangle*) recruitment rates and biomass growth rates (figs. 4*A* and 4*B*). Black mangrove (*Avicennia germinans*) stem recruitment and biomass growth rates, while not significantly related to site total biomass mortality, were predicted by the relative amount of black mangrove live biomass remaining in sites after Andrew (figs. 4*C* and 4*D*).

White mangrove (*Laguncularia racemosa*) recruitment rates and biomass growth rates, however, were not related to either the relative amount of damage in sites or the relative amount of species biomass remaining in sites after Andrew. Therefore, to estimate white mangrove rates of recruitment and growth, nonspecies-specific, overarching recruitment and growth regression models were used to determine overall rates of stem recruitment and biomass growth. The respective white mangrove contributions were then determined as the difference between black and red mangrove species-specific models and the overarching model prediction.

Annual rates of recovery predicted by the relationships examined above were applied to estimates of site damage, as assessed following Wilma. The model was updated on a year-by-year basis, and recovery of a site was considered complete when the predicted live biomass equaled or exceeded the live biomass estimate that accompanied the observed point of maximum stem density following Andrew. By using Wilma damage estimates, time to recovery and resultant change in species composition of sites were estimated (table 2). The amount of hurricane site damage as a predictor of species shifts in stems appears to conform well to those observed after recovery from Andrew (fig. 5).

Conclusions

Differences in mangrove stand structural conditions will affect growth trajectories. Hurricane frequency will, therefore, alter not only the physical properties of the coastline but also the resultant vegetative community composition upon recovery. Because mangroves play such an important role in the coastal Everglades, understanding local responses to increased hurricane frequencies will offer a better understanding of possible threats to the ecosystem. Based on community observations following Andrew and recovery projections following Wilma, it appears that severe structural damage to mangrove forests favors white mangrove establishment. Black mangroves appear to be favored under light damage scenarios, and while red mangroves appear to establish themselves dependent on structural damage considerations, the red mangrove species shift upon recovery appears independent. Increased hurricane frequencies in the North Atlantic Ocean, therefore, present the possibility of associated species community shifts in ecosystem dominance. How these shifts in mangrove species composition cascade through the entire ecosystem and influence species composition of mangrove-associated fish and wildlife species remains to be determined.

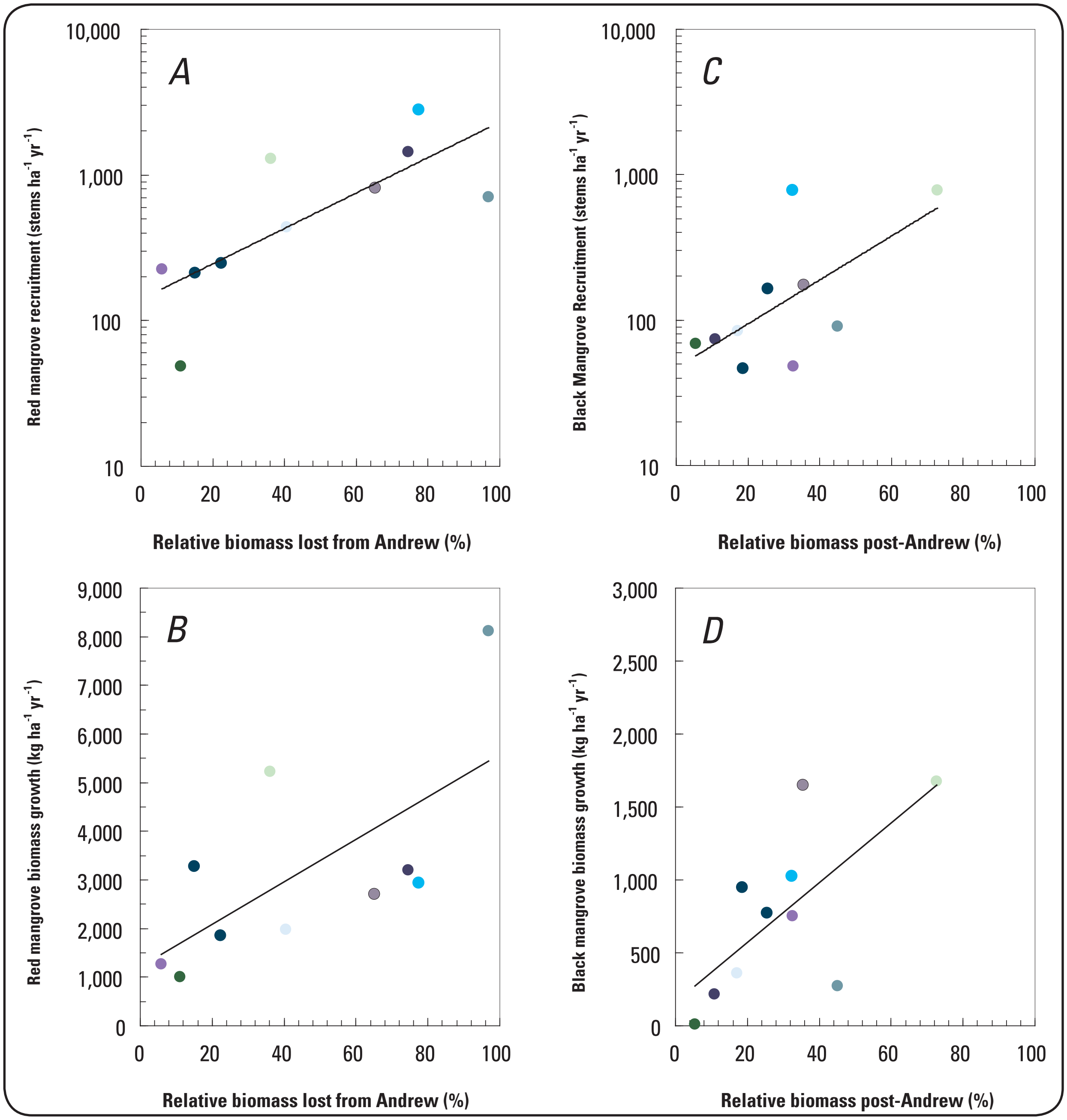

Figure 4. The mean red mangrove (*Rhizophora mangle*) recruitment rate (*A*) and the mean red mangrove biomass growth rate (*B*) in relation to the relative amount of biomass lost in sites to Hurricane Andrew. The mean black mangrove (*Avicennia germinans*) recruitment rate (*C*) and the mean black mangrove biomass growth rate (*D*) in relation to the relative amount of black mangrove biomass remaining in sites after Hurricane Andrew.

Table 2. Estimates of total biomass recovery time and the projected relative change in species contributions to stem density and living biomass for sites impacted by Hurricane Wilma, October 2005 (see table 1 for site name codes).

[Black, black mangroves (*Avicennia germinans*); White, white mangroves (*Laguncularia racemosa*); Red, red mangroves (*Rhizophora mangle*)]

			Relative change in stem density (%)			Relative change in biomass (%)		
Site	Biomass lost from Wilma (%)	Estimated time to recovery (years)	Black	White	Red	Black	White	Red
SH3-1	9	4	-2.1	2.1	0.0	-0.8	-1.5	2.3
SH3-2	5	3	-1.9	0.0	1.9	-2.5	-2.3	4.8
SH4-1	7	1	-0.8	13.7	-12.9	-0.2	2.4	-2.2
SH4-2	1	<1	4.2	1.0	-5.2	0.9	0.8	-1.6
LRS	23	3	-0.7	-0.7	1.5	-0.8	-6.9	7.7
NHB	99	6	-7.1	9.2	-2.1	-14.4	-7.8	22.2

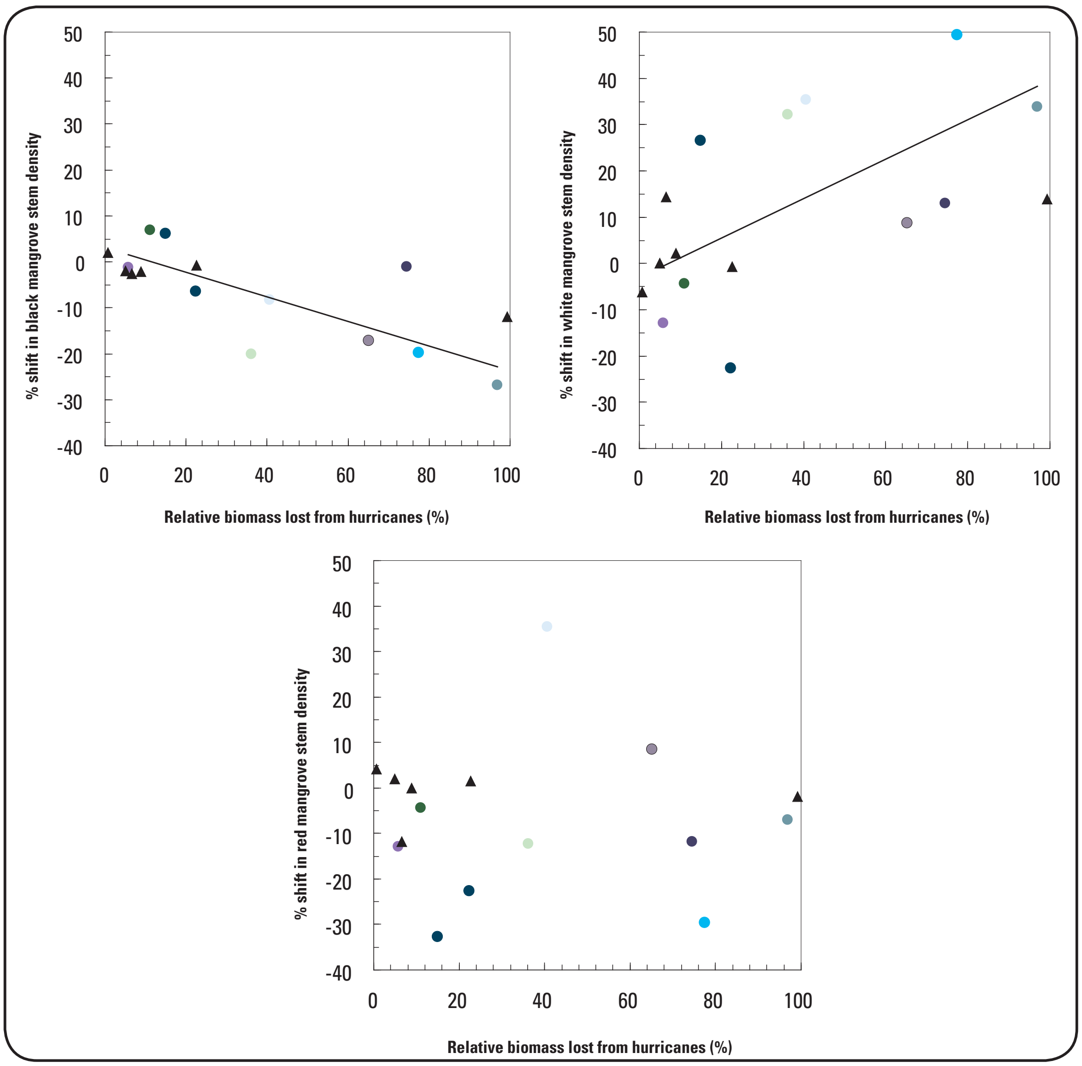

Figure 5. The relative species composition shift in stem density associated with the relative amount of damage observed for sites recovering from Hurricane Andrew (closed circles) and for recovery projections of sites damaged by Hurricane Wilma (black triangles).

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