Hurricane Mitch: Acute Impacts on Mangrove Forest Structure and an Evaluation of Recovery Trajectories

Executive Summary

By Philippe Hensel and C. Edward Proffitt

USGS Open File Report
OFR 03-182

U.S. Department of the Interior
U.S. Geological Survey

Suggested citation:

Hensel, P. and Proffitt, C.E., 2002, Hurricane Mitch: acute impacts on mangrove forest structure and an evaluation of recovery trajectories: executive summary: USGS Open File Report 03-182, 25 p.

USGS ACTIVITY B6 AND B7

Hurricane Mitch: Acute Impacts On Mangrove Forest Structure And An Evaluation Of Recovery Trajectories

By

Philippe Hensel[1] and C. Edward Proffitt[2]

[1]Johnson Controls World Services, National Wetlands Research Center, Lafayette, LA

[2]U. S. Geological Survey, Biological Resources Discipline, National Wetlands Research Center, Lafayette, LA

October 7, 2002

Introduction

Hurricane Mitch was the fourth most intense hurricane of the century in the Atlantic Basin and the second most deadly in 200 years (National Climatic Data Center, 1999). An estimated 11,000 lives were lost, 70-80% of agricultural crops were destroyed, and over 1 million people were displaced from their homes (Guiney and Lawrence, 1999; U.S. Geological Survey, 2001). Hurricane Mitch caused significant damage to coastal mangrove resources over a wide region of Central America, which included both Caribbean and Pacific coasts. The hurricane, with sustained winds in excess of 280 kph, stalled in proximity to the Bay Island of Guanaja, Honduras, from the evening of October 27 to the evening of October 29 (fig. 1). These two days of 200+ kph winds caused nearly complete defoliation of the vegetation on the island, including mangrove forests, and the taller trees were either broken or uprooted (fig. 2; DeSomviele, 1999). Coastal margins as far away as Punta de Manabique in Guatemala were damaged from strong waves and associated surge, which caused up to 50 m of landward beach erosion. Eroded sediments were then deposited within interior mangrove and other brackish ecosystems. In some cases, as the beach eroded, the new shoreline encroached on mangrove forests that had previously lined interior bays (fig. 3). The trajectory of Hurricane Mitch through the center of Honduras caused massive rainfall, erosion, landslides, and debris flows that accumulated in the Gulf of Fonseca (Pacific coast). Rivers overflowed, and in one case (Choluteca River), a river changed its course and created an avulsion over tens of kilometers. Large expanses of low-lying coastal areas, including mangrove forests and

Figure 1. Storm track of Hurricane Mitch, 22 October – 05 November 1998. Data from the National Climatic Data Center, 1999.

Figure 2. Hurricane Mitch damage to mangrove forests in the Bay Island of Guanaja, Honduras (Mangrove Bight, August 1999).

Figure 3. Hurricane Mitch damage to the Gulf of Honduras shoreline of Punta Manabique, Guatemala (photo taken August 2000).

Figure 4. Sediment and debris accumulation in a shoreline mangrove forest from flooding of the Choluteca River, as a result of Hurricane Mitch (Gulf of Fonseca, Honduras; photo taken August 1999).

shrimp ponds, were destroyed by in some cases over one meter of sediments and debris (fig. 4; McKee and McGinnis, 2002).

Hurricane-related damage to mangrove forests was therefore caused by three main mechanisms, related to the geographical position of the mangroves relative to the path of the storm: winds, waves, and sediment burial. Although each of these mechanisms caused severe damage to mangrove forests, they may result in very different potential recovery trajectories. Successful, active mangrove restoration initiatives may come about after a careful consideration of these recovery trajectories.

Because of the magnitude of Hurricane Mitch-related impacts, the natural recovery of the affected forests is put into question. An intensive study was therefore designed to assess the amount and nature of hurricane-related damage, as well as the potential for recovery. The main issues addressed by this study are the following:

1) What is the nature and extent of damage to mangrove forests under three different mechanisms of hurricane-induced impact? How is damage different across the intertidal gradient (shoreline to interior forests)? Which aspect of mangrove forest structure was most sensitive to hurricane damage?
2) What is the recovery trajectory of the damaged mangrove forests, and how is this trajectory related to the different mechanisms of hurricane impact? What, if any, is the evidence of long-term chronic impacts to mangrove recovery? Is there sign of sufficient recovery so as to ensure long-term sustainability, or is sustainability now put into question given both hurricane and other chronic impacts?

3) Impacts and recovery in coastal mangrove forests is the integration of a number of different processes, including hydrology, water quality and nutrient cycling, sediment dynamics, soil physico-chemistry and plant physiological responses such as root production. A third objective of this study is to provide a platform for integrating and interpreting these specific processes that are components of hurricane impacts. Finally, the results of this study provide a basis for estimating hurricane-related impacts to mangrove forests on a wider regional scale, through its incorporation into a GIS framework.

Materials and Methods

Three regions were chosen to represent the three mechanisms of hurricane-related impacts to coastal mangrove forests: wind (the Bay Islands of Honduras), wave (Punta Manabique, Guatemala), and sediment (Gulf of Fonseca, Honduras; fig. 5). In the Bay Islands of Honduras (Caribbean coast), shoreline mangrove forests here are dominated by the red mangrove *Rhizophora mangle* (L.), with important contributions of black mangrove *Avicennia germinans* (L.) Stearn in interior forests. Mangrove forests were chosen to represent low, medium, and high levels of wind and flooding impact: both shoreline and interior forests were chosen within each impact level. Three replicate plots, 50 m^2 each, were randomly established within each of the six forest types in January 2000. The high impact area was limited to the Mangrove Bight area of Guanaja, where mangroves suffered virtually 100% mortality due to the hurricane (fig. 6). A medium and a low impact area were identified along the north and south shores, respectively, on the east end of Roatan (fig. 7). Mangroves along the north shore generally showed moderate

Figure 5. Map of Honduras showing the track of Hurricane Mitch in relation to the three geographic areas studied (circled in red): the Bay Islands of Roatan and Guanaja (Honduras), Punta Manabique (Guatemala) and the Gulf of Fonseca (Honduras).

Figure 6. Map of Guanaja (Bay Islands, Honduras), showing area of Mangrove Bight where the study plots were established (circled in red).

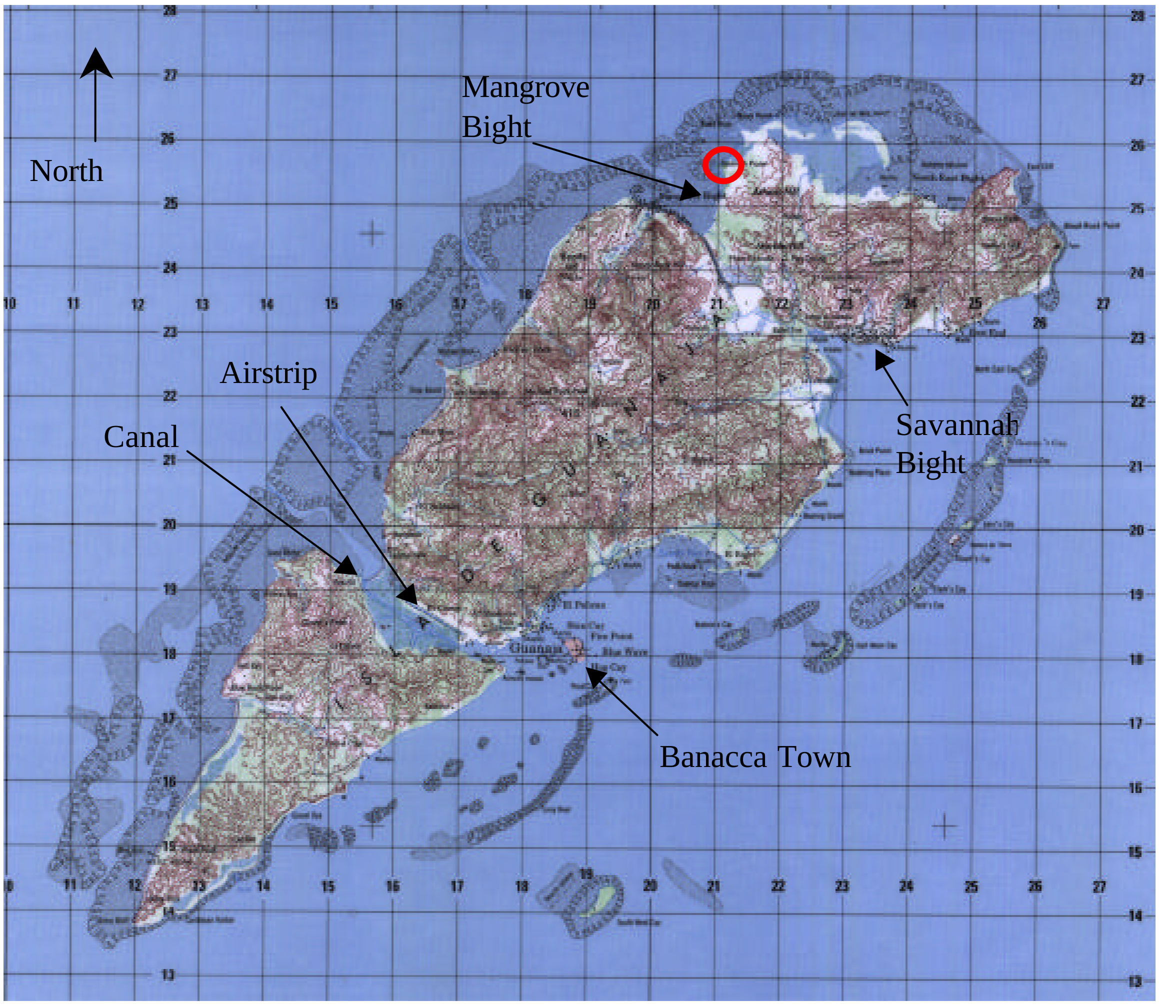
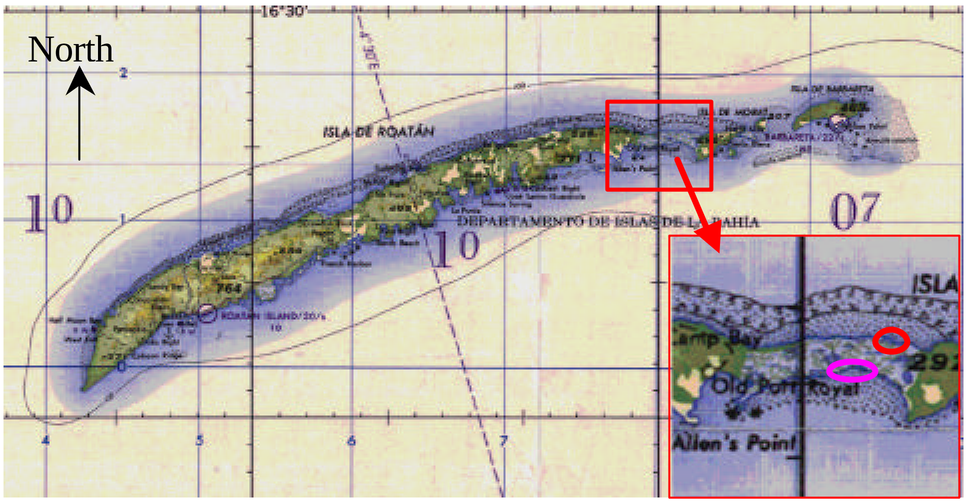


Figure 7. Map of Roatan (Bay Islands, Honduras) with inset showing the mangrove forests of Santa Elena, where mangrove census was taken. Approximate location of medium impact study sites is circled in red; location of low impact sites circled in purple.



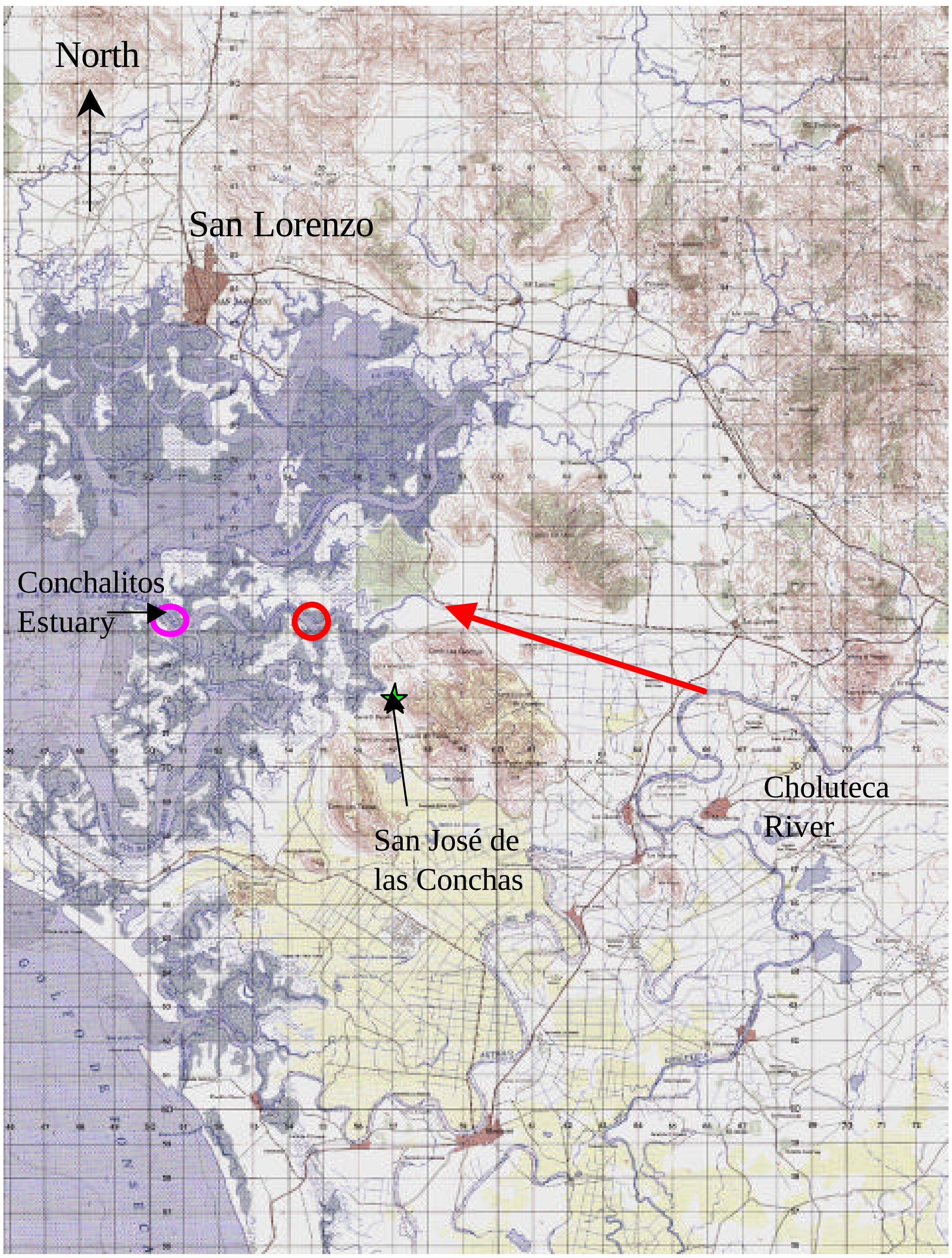
damage, although some local black mangrove stands suffered nearly complete mortality, similar in kind to what was seen in Guanaja. In total, 18 mangrove forest plots were thereby established in the Bay Islands in 2000. Within each plot, forest structure characteristics were obtained through a census of live and dead trees, mangrove species, canopy height, and trunk diameter. Seedlings and saplings were also surveyed. Measurements of forest structure were taken in January 2000 and again in January 2001, in order to gauge the recovery process.

At Punta de Manabique (Caribbean coast of Guatemala), the red mangrove *Rhizophora mangle* (L.) lines sheltered back-barrier lagoons and brackish channels, as well as protected coastlines on the mainland side of the Punta de Manbique peninsula. Two hurricane impact levels were identified: 1) a high impact area on the northern (exposed) coast, where mangrove forests suffered serious damage from erosion as well as sediment burial, and 2) a low impact area located in Bahía la Graciosa, on the protected side of the peninsula (fig. 8). Three replicate 50 m^2 plots were randomly established in each of these two areas in August 2000 (total of six plots). Forest structure surveys were conducted in August of 2000 and 2001.

In the Gulf of Fonseca (Pacific coast of Honduras), the mangrove forests most severely affected by sediment burial and debris flows were located in the upper reaches of the Conchalitos estuary. Mangrove forests that received little or no hurricane impacts were identified near the mouth of the estuary (fig. 9). Within this area, mixed assemblages of red mangroves [*Rhizophora racemosa* (L.) and *Rhizophora mangle* (L.)] dominate the

Figure 8. Map of Punta Manabique, along Guatemala's Gulf of Honduras coast. Red circle shows the location of the high impact study sites; purple circle shows location of low impact sites.

Figure 9. Map of the central region of the Gulf of Fonseca (Honduras), where the study of Hurricane Mitch impacts to mangrove forests was conducted. Medium and high impact sites are encircled in red; low impact sites are encircled in purple. The red arrow corresponds to the path of the Choluteca River during Hurricane Mitch.



shorelines. The white mangrove *Laguncularia racemosa* (L.) Gaertn. f. has a patchy distribution along the more upstream shorelines. The black mangrove *Avicennia germinans* (L.) Stearn and *Laguncularia* dominate the (scrub) dwarf interior mangrove forests located behind the shoreline forests all along the coastline. Triplicate 50 m^2 plots were chosen in both shoreline and interior mangrove forests; in total, 18 plots were surveyed in the Gulf of Fonseca in January of 2000 and 2001.

Results

The most glaring effect of Hurricane Mitch on mangrove forest structure in the Bay Islands was the virtually complete mortality of mangroves on Guanaja (high impact forest; fig. 2). No live trees were encountered within either shoreline or interior plots 15 months after the hurricane (total sample area 300 m^2). Damage was irrespective of tree size, genus and intertidal zone. As expected, the density of dead mangrove trees decreased significantly along the gradient from high to low impact levels ($P<0.0001$). The canopy of the medium impact fringe remained intact after the storm, and high mortality was confined to the smaller size classes (i.e., 0-1.9 cm). In contrast, the adjacent interior basin forest suffered higher mortality in canopy trees (50% in the largest size class). Within medium and low impact plots, there was no evidence that mortality was species-related ($P=0.981$). Mortality, however, was related to tree size, as both taller and wider trees enjoyed greater survivorship ($P<0.009$ and $P<0.09$ for canopy height and trunk diameter, respectively).

Severe chronic impact in Mangrove Bight was indicated by a lack of recovery within the high impact area in 2001, 27 months after the storm. This is in marked contrast to a strong post-hurricane recovery seen in the medium and low impact forests, where high recruitment into the seedling size class was observed in 2001 (table 1). High recovery was also noted in the black mangrove dead zone along the north shore of Roatan.

Table 1. Density of mangrove seedlings within study plots in the Bay Islands (Honduras).

		Impact levels					
		High		Medium		Low	
Intertidal Zone	Year	Live	Dead	Live	Dead	Live	Dead
Shoreline	2000	0	0	3	0	168	0
	2001	0	0	64	0	191	0
Interior	2000	0	0	9	0	122	0
	2001	0	0	364	0	416	0

Few mangrove trees remained along the exposed shorefront on the Gulf of Honduras side of Punta de Manabique, 22 months after Hurricane Mitch (average of four trees per 150 m^2). Those trees which remained standing were large-diameter red mangroves, and mortality among these was very high, likely related to burial by the eroded beach sands (table 2). Other trees, previously belonging to a back-barrier mangrove forest, had apparently been washed away by Hurricane Mitch-induced beachfront erosion. As a result, a new shoreline was now established where the previous back-barrier mangrove forest had stood.

Mortality was significantly lower along the protected Bahía la Graciosa (low impact plots) compared to the exposed coastline of Punta de Manabique (P=0.008). No clear hurricane-related damage was observed in these sheltered mangrove forests in August 2000: tree density was well distributed across most diameter size classes, and mortality was very low (table 2). Although the high and low impact forests shared the same mangrove species, comparisons between the two must be tempered by the fact that they have inherent differences in forest structure, due to their different locations (back barrier forest vs. bayside forest).

Table 2. Percent mortality of mangroves within experimental plots in Punta de Manabique, Guatemala. Data from August 2000.

	Impact Levels	
Diameter/Size Class	High	Low
Seedling	N/A	0
0 – 1.9cm	N/A	0
2 – 4.9cm	N/A	100[1]
5 – 9.9cm	N/A	0
10 – 19.9cm	N/A	9
20^{+}cm	50	0
Total Adult*	50	6

* Total Adult does not include contribution from seedlings or saplings (canopy <2m)
[1]Represents only one individual in the sample area (150m^2)

Chronic hurricane impacts were evident along the exposed, high impact coastline. No recruitment was recorded from 2000 to 2001, likely related to high sediment instability that characterizes this shoreline (Cahoon and others, 2002). Although total basal area (an expression of cumulative trunk cross-sectional area) increased in 2001 (suggestive of recovery), the change was not significant (P=0.405).

An extensive area of estuarine mangrove forests in the Gulf of Fonseca suffered high mortality as a consequence of Hurricane Mitch-related flooding and sediment burial (fig. 4). Within this area, the amount of damage to mangrove forests was very heterogeneous, as some forest patches survived quite well (medium impact shoreline plots), while others were almost decimated (high impact shoreline plots on the opposite bank of the Conchalitos estuary; table 3). Significant differences in mortality rates among these plots were related to both impact level (P<0.0001) and intertidal zone (P<0.0001). Mangrove species showed differing sensitivities to hurricane impacts, as the white mangrove *Laguncularia* experienced significantly lower mortality than *Rhizophora* spp. over all impact levels and intertidal zones (P<0.0001).

Despite high mangrove mortality, gradual recovery was apparent between 15 and 27 months after the initial impact. No mangrove forest plot (including those at high and medium impact levels) was devoid of live mangroves in January 2000, and a trend of recovery was suggested in the increasing live mangrove densities in January 2001 (e.g., figs. 9 and 10). This recovery, however, was limited to *Laguncularia*: there were no live *Rhizophora* in either the medium impact interior or any of the high impact plots in

2000 and 2001, underlining the degree to which *Rhizophora* forests were decimated by Hurricane Mitch.

Table 3. Percent mortality of mangroves within experimental plots in the Gulf of Fonseca, Honduras. Data from January 2000.

	Impact levels					
	High		Medium		Low	
Diameter/Size Class	Shoreline	Interior	Shoreline	Interior	Shoreline	Interior
Seedling	N/A	N/A	0	0	7	0
0 – 1.9cm	53	100	0	82	0	0
2 – 4.9cm	89	0	19	75	0	0
5 – 9.9cm	N/A	N/A	18	N/A	0	0
10^{+}cm	N/A	N/A	0	N/A	50	N/A
Total Adult*	22	67[1]	2	82	1	0

* Total Adult does not include contribution from seedlings or saplings (canopy <2m)
[1]This was a previously-abandoned shrimp pond, under an uncertain amount of post-hurricane human disturbance.

Discussion

Three different geographic regions were investigated in this study to gain insight into mechanisms of hurricane damage, levels of damage and the associated recovery trajectories. Wind-induced defoliation and uprooting of mangroves associated with the center of the storm track caused the most severe acute and chronic impact, as 97% of Guanaja's mangrove forests were destroyed (LeBigre and others, 2000). Over 27 months after the hurricane, severe chronic impacts remain evident, as recovery had not progressed to any significant amount. Wave-induced erosion and sedimentation at some 200 km away from the hurricane track also caused significant mangrove mortality, although some evidence of recovery is apparent despite continued high sediment mobilization (Cahoon and others, 2002). Massive sedimentation on mangrove surfaces in the Gulf of Fonscea destroyed extensive mangrove forests, yet recovery, especially in *Laguncularia racemosa*, is apparent despite chronic impacts of high sediment elevation.

A very small percent of mangrove forests on Guanaja survived Hurricane Mitch, most of which is currently located around a canal that separates the two largest massifs of the island. Due to the very small number of mangrove survivors in Guanaja, the reliance on surviving mangroves for recovery is tenuous at best, especially given the fact that previous mangrove surfaces are rapidly collapsing (Cahoon and others, 2002). Local hydrology will also limit the dispersal of potential mangrove propagules from the canal area. Local ocean currents (east to west) effectively isolate Guanaja from the neighboring island of Roatan, which would otherwise offer a potential source of viable propagules (fig.1). Rapid recovery is essential given the rate of peat collapse suggested by Cahoon and others, 2002; the only way to ensure successful recovery would therefore be to implement a very intensive replanting effort. Although the work of LeBigre and others (2000) suggest that predation by crabs may cause very high mortality among planted seedlings, logistical as well as financial constraints would make measures to reduce predation unreasonable or unaffordable. It is likely that the most efficient mechanism of restoration in Guanaja would be massive mangrove planting with propagules from Roatan as well as the mainland, undertaken by local NGOs in addition to local community groups (e.g., ESNACIFOR, Unidad Municipal Ambiental de Guanaja).

Although mangrove mortality was evident in the nearby island of Roatan, impacts of forest structure were rather minimal compared to Guanaja, and were limited to an area outside the survey plots (the dead zone dominated by *Avicennia*). Furthermore, recovery in this dead zone was apparent, especially in 2001. However, despite signs of recovery, there may be some concerns over the long-term stability of this part of the forest (Cahoon and others, 2002), which might make active recovery of this area a priority. If this area is to be restored, care should be taken to mimic prior species composition, which was likely a result of local hydrology.

The hurricane-associated erosion and deposition of shorefront sands have caused continued chronic impacts along the Caribbean coast of Guatemala. Although some recovery is suggested by this study, the continued reworking of eroded and deposited sands will preclude the successful establishment of new mangrove recruits. Recovery of this area will therefore hinge on shoreline stability. Once the shoreline has been stabilized, local sources of propagules may be enough to naturally restore these mangrove forests without the need for active restoration.

Massive sediment burial within the Gulf of Fonseca not only caused acute mangrove mortality, but has also caused chronic impacts, which might limit mangrove recovery in the short term. In the area of greatest impact, mangrove sediment surfaces are at a much higher elevation than before the hurricane (McKee and McGinnis, 2002). Although water and salt stress may be apparent within these mangrove forests, recovery was very evident, especially in *Laguncularia*. It is likely that these chronic hurricane impacts will confer a selective advantage to *Laguncularia* in the short term, at least until elevations and sediment dynamics are returned to pre-hurricane conditions.

Hurricanes represent only one of several factors that impinge on mangrove forests and the environmental services they offer. Despite tangible mangrove-derived benefits (e.g., fisheries catches, sediment retention and storm protection), this ecosystem has witnessed an important decrease in acreage due to human activities over the recent past (Lindén and Jernelöv, 1980; Mazda and others, 2002). Broader-scale, chronic impacts may now impinge on mangrove communities in the form of global climate change, including sea level rise (Church and others, 2001), increased mean temperatures, and increased hurricane frequency and intensity (Giorgi and others, 2001).

The long-term sustainability of mangrove forests affected by Hurricane Mitch, therefore, depends on the extent and frequency of other impacts, both future and current. The Caribbean region is one of high tropical storm recurrence (Reading, 1990); the occurrence of another storm in the near future could severely compromise any current recovery. In addition, the widespread expansion of human activities within the coastal zone, for example shrimp mariculture, agriculture, and tourism, may have already limited the extent of mangrove forests and may eventually place limits on the ability of mangrove forests to withstand future storm impacts.

Literature Cited

Cahoon, D.R., Hensel, P., Rybczyk, J. and Perez, B.C., 2002, Hurricane Mitch: impacts on mangrove sediment elevation dynamics and long-term mangrove sustainability: Reston, Va., U.S. Geological Survey Open File Report, in press.

Church, J. A., Gregory, J. M., Huybrechts, P., Kuhn, M., Lambeck, K., Nhuan, M. T., Qin, D., and Woodworth, P. L., 2001, Changes in Sea Level, *in* Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. and Johnson, C.A., eds., Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change: Cambridge, U. K., Cambridge University Press, p. 639 – 693.

DeSomviele, B. 1999. Etude de la reforestation de l'île de Guanaja après l'ouragan Mitch: Paris, France, Ecole National de Génie Rural, des Eaux et des Forêts, 42 p.

Giorgi, F., Hewitson, B., Christensen, J., Hulme, M., Von Storch, H., Whetton, P., Jones, R., Mearns, L., and Fu, C., 2001, Regional climate information – evaluation and projections, *in* Houghton, J. T., Ding, Y., Griggs, D. J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K. and Johnson, C.A., eds., Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change: Cambridge, U. K., Cambridge University Press, p. 583 – 638.

Guiney, J.L., and Lawrence, M.B., 1999, Preliminary report: Hurricane Mitch 22 October-5 November 1998: Miami, Fla, National Hurricane Center, 8 p.

LeBigre, J-M., Portillo, P., and Thompson, W., 2000, Quel avenir pour les mangroves de l'archipel de la Bahía (Honduras)?, *in* Conference of the Commission de Geographie de la Mer et du Littoral, Dunkerque, France, 2000, Espace Littoraux en Mutation, 10 p.

Lindén, O., and Jernelöv, A. 1980. The mangrove swamp – an ecosystem in danger: AMBIO, v. 9, p. 81-88.

Mazda, Y., Magi, M., Nanao, H., Kogo, M., Miyagi, T., Kanazawa, N., and Kobashi, D., 2002, Coastal erosion due to long-term human impact on mangrove forests: Wetlands Ecology and Management, v. 10, p. 1-9.

McKee, K.L. and McGinnis, T.E., II, 2002, Hurricane Mitch: effects on mangrove soil characteristics and root contributions to soil stabilization: Reston, Va., U.S. Geological Survey Open File Report, in press.

National Climatic Data Center, National Oceanographic and Atmospheric Association, 1999, Mitch: The Deadliest Atlantic Hurricane Since 1780: http://lwf.ncdc.noaa.gov/oa/reports/mitch/mitch.html, accessed 3 December 2001.

Reading, A.J., 1990, Caribbean tropical storm activity over the past four centuries: International Journal of Climatology, v. 10, n. 4, p. 365-376.

World Conservation Monitoring Center, 2000: http://www.wcmc.org.uk/cgi-bin/mp_countryquery.p, accessed 4 December 2001.