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# The Effects of Hurricane-Deposited Mud on Coral Communities in Florida

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**Abstract.** Widespread accumulation of mud on nearshore hardbottom was recorded during biological monitoring surveys for beach nourishment projects from Cape Canaveral to Miami along the Florida Atlantic coast and from Naples to St. Petersburg along the Florida Gulf of Mexico coast following the hurricanes of 2004. Permanent video transects were used for this study along with in-situ measurements of mud layer thickness. The surveys have indicated deposition of a relatively thin layer of fine sediments over extensive areas of hardbottom and thick accumulations at the base of sharp relief features. Storms suspend this fine material, resulting in turbid nearshore waters for long periods. The high adhesive capacity of the mud particles has enabled sediments to survive as a compact layer through the winter storms of 2004 through 2008. The effects have been lethal for many filter-feeding species while photosynthetic activity and recruitment opportunities are reduced for most benthic species. The 2007 monitoring data suggests significant mortality of octocoral recruits due to the smothering effects of mud, indicating that octocorals are not surviving beyond two to three years in this environment. It is hypothesized that the sediments were transported by hurricane-generated waves and currents from the deeper parts of the shelf.

Key Words: hurricanes, mud, recruitment, corals, octocorals

## Introduction

Reefs and hardbottom communities with variable representation of scleractinian coral species and coral cover are widespread in the upper shelf of Florida. Between August 14 and September 26, 2004, four hurricanes (Charley, Frances, Ivan, and Jeanne) impacted the Florida shelf and coastline. Following these storms, widespread accumulation of mud on nearshore hardbottom and reefs was recorded from Cape Canaveral to Miami along the Atlantic coast and from Naples to St. Petersburg along the Gulf of Mexico (Gulf) coast. The nearshore distribution of mud is very wide with water depths ranging from 3 meters to at least 15 meters, and the offshore distribution ranges from approximately 50 to 60 meters to 1-2 kilometers from the shoreline. Very nearshore accumulation is characteristic of areas where vertical escarpments face the shoreline, such as Indian River County on the Atlantic side and Collier County on the Gulf side of Florida (Figure 1). Distant offshore accumulation was recorded in the Gulf of Mexico where the shelf is characterized by a very low gradient.

The mud has accumulated in a range of forms: relatively small pockets of a few decimeters in width in concave areas; attached to or perched on top of reefs and hardbottom ridges, subvertical to overhanging escarpments (ledges) and knolls; and a thin veneer of mud over sand, hardbottom and reefs. The thickness of accumulated mud varies from a few millimeters to over a meter. The content of the mud is variable with a visually higher carbonate component in south Florida in comparison to northern areas. For example, the mud in Indian River County is darker than the mud observed in Broward County.

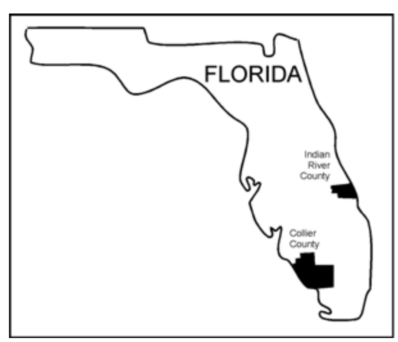


Figure 1. Location map of Florida counties mentioned in text.

The high adhesive capacity of the mud particles has enabled sediments to survive as a compact layer through the winter storms of 2004 through 2008. Shallow nearshore locations are characterized by high wave energy. Storms suspend this fine material, resulting in turbid nearshore waters for long periods. Mud accumulations persist in these areas, both as a thin veneer over hardbottom and hardbottom communities and as thick accumulations (Fig. 2a). In some locations along the Indian River County shoreline, (central Florida Atlantic coast), accumulations of more than 20 cm in thickness were observed along the inshore edge of hardbottom at the base of scarps and ledges. The surveys have also indicated the deposition of a relatively thin layer of fine sediments over extensive areas of hardbottom. As a result, the visibility in nearshore waters has been dramatically reduced for several years. The summer of 2007 was the first opportunity of adequate water clarity for aerial photography to discern the shallow water hardbottom features in Indian River County.

**Methods**

Annual measurements of mud accumulation were performed from 2006 through 2008 on a nearshore artificial reef constructed as mitigation for impacts to nearshore hardbottom from a beach restoration project in Indian River County. Permanent transects were established for the evaluation of benthic community succession on the artificial reef. Monitoring methods involved permanent video transects and photo surveys with *in-situ* measurements of mud layer thickness to study the dynamics and effects of mud on benthic succession.

Two types of artificial reef were constructed as mitigation for impacts to nearshore hardbottom habitat: high-relief, high-complexity (HRHC) reef and low-relief, low-complexity (LRLC) reef. The high-relief, high-complexity artificial reef was designed to have a vertical relief of 0.9 to 1.8 m. Limestone boulders were partially stacked to achieve this vertical relief. The low-relief, low-complexity mitigation reef was designed to mimic a vertical relief of 0.3 to 0.6 m using a single layer of limestone boulders. The mitigation reef was constructed between May and September 2004; however, artificial reef placement could not be completed due to the passage of hurricanes Frances and Jeanne in September 2004. Therefore, a portion of the high-relief reef and the main portion of the low-relief reef were constructed in the summer of 2005. This phased construction enabled us to compare the influence of mud on benthic ecological succession.

**Results**

Accumulations of mud up to 30 cm in thickness were measured along the inshore edge and within spaces between boulders of the pre-hurricane artificial reef during the Year 1 baseline survey in August 2006. A thin cover of mud was also observed on the subhorizontal surfaces of the boulders. During the July 2007 survey, the mud persisted and was redistributed in a slightly thinner layer throughout the artificial reef, migrating into areas which had not been previously affected by mud. During the 2006 baseline survey, mud was not recorded on the post-hurricane high-relief reef; however, in July 2007, mud accumulations were recorded on this portion of the artificial reef. In July 2008, mud pockets increased to 15 cm in thickness along the portions of the post-hurricane reef constructed in 2005. Overall, mud accumulation is deeper along the western edge of the mitigation reef as compared to the eastern (i.e. seaward) edge.

The persistence of the mud layer on the pre-hurricane high-relief reef has led to the extensive development of cyanobacterial mats (Fig. 2b). The development of cyanobacterial mats is a very typical feature of mud accumulation throughout the study area. Mud-related cyanobacterial growth has had a dramatic smothering effect on octocoral recruits (*Leptogorgia* spp.) on the artificial reef. The total number of octocorals along the permanent transects decreased from 56 in 2006 to 16 in 2007. The surviving colonies suffered from partial coverage of cyanobacterial mats, and tissue loss and mortality were observed under epiphytic overgrowth (Fig 2c). A similar effect was observed in southeast Florida; however, a small number of *L. virgulata* colonies survived for several years despite partial burial by mud.

In 2006 and 2007, the dominant functional group on the post-hurricane artificial reef was fleshy macroalgae. Overall percent cover of macroalgae at the post-hurricane high-relief reef in July 2007 was 77.6% compared to an overall average of 5.3% at the pre-hurricane high-relief reef (Fig 3). The macroalgal community on the pre-hurricane reef was initially dominated by calcareous algae due to its ability to survive under a veneer of sediments. A turf algae/cyanobacteria matrix replaced calcareous algae as the dominant functional groups on the pre-hurricane artificial reef in July 2007.

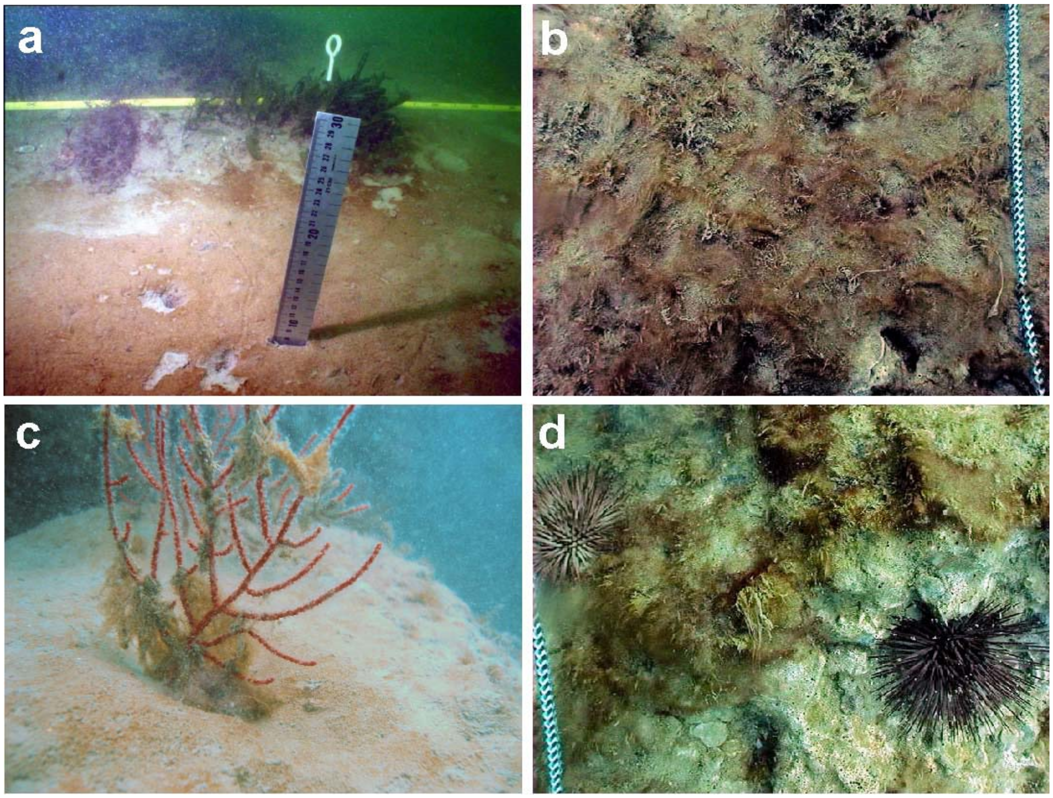


Figure 2. a) Mud layer of 8-10 cm covers extensive areas of hardbottom at depth of 5 m, offshore of Sarasota County, FL; b) Cyanobacterial mat over a thin layer of mud covering both substrate and algae on the pre-hurricane artificial reef, Indian River County, FL; c) Accumulation of mud flakes on octocoral, *Leptogorgia hebes,* stimulate growth of cyanobacteria and algae which smother octocoral tissue; d) Sea urchins scrape mud and cyanobacteria, exposing clean limestone surface for recruitment opportunities.

The 2007 survey revealed a three-fold increase in the sea urchin population on the artificial reef in comparison to 2006 (118 versus 37). The number of urchins (*Arbacia punctulata* and *Echinometra lucunter*) along the six permanent transects increased to 296 in 2008.

The increase in the urchin population is positively correlated with the increase in coral recruitment between 2006 and 2008. Ten small coral colonies (<2 cm in diameter) were recorded during the 2007 survey compared to two colonies in 2006. Twenty-one *Oculina* sp. colonies were counted along the six video transects during the 2008 survey. *In situ* counts along one of the 20-meter monitoring transects on the pre-hurricane reef documented 32 *Oculina* sp. recruits <2 cm in diameter during the July 2008 survey.

**Discussion**

The 2006 and 2007 annual surveys have demonstrated that mud deposition has had a greater effect on benthic succession and community composition than the difference in vertical relief in the Indian River County artificial reef. The continual resuspension and deposition of mud on the benthic community on the reef constructed in 2004 (pre-hurricane) has resulted in recurrent disturbance events which limit macroalgal colonization and growth.

Scleractinian corals are a minor component of the nearshore hardbottom community in Indian River County and are generally represented by only three species, *Siderastrea siderea*, *Oculina varicosa* and *Phyllangia americana*. Recruitment and survival of small colonies has been inhibited by mud deposition on both the natural nearshore hardbottom and artificial reef in Indian River County. However, the proliferation of sea urchins on the artificial reef between 2006and 2008 has increased recruitment opportunities. Sea urchins remove the mud and cyanobacterial mats while grazing, exposing clean limestone surface available for coral recruitment (Fig. 2d). The high density of *Oculina* recruits in the 2008 survey was observed in areas of bare substrate scraped clean of mud by urchin activity. In comparison, no coral recruits were observed along this transect during the 2007 survey.

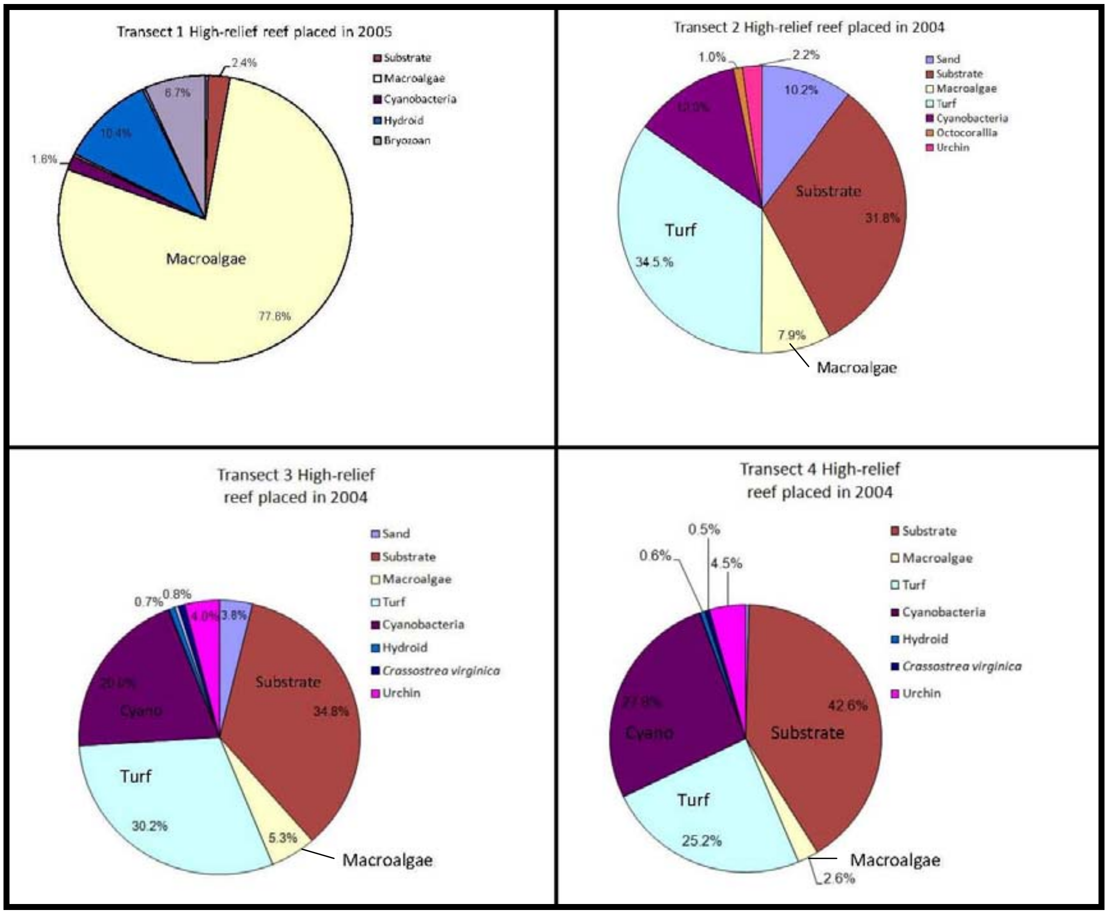


Figure 3. Percent cover of the major functional groups on the Indian River County artificial reef. Note dominance of macroalgae on the post-hurricane reef versus substrate and cyanobacteria on the pre-hurricane reef. Survey date is July 2007.

Scleractinian corals are a considerably larger component of hardbottom communities in southwest Florida; however, scleractinian coral diversity is low. The most common species are *Siderastrea siderea*, *Solenastrea bournoni* and *S. hyades*, *Cladocora arbuscula* and *Phyllangia americana*. The impact of mud on corals varies considerably for the same species with colony size, shape, location in nannorelief features and depth of mud layer.

*Siderastrea siderea* and *Solenastrea* spp. are notorious for their tolerance to turbid water and sedimentation. However, this mud event has resulted in an overwhelming accumulation of fine material which has remained within hardbottom areas for several years. Larger, vertically-developed colonies exhibit higher survivorship than encrusting and flat colonies, which can undergo fission and partial mortality. Corals are actively removing mud from their surface, and mud particles are continually resuspended by wave and current action. Continuous active sediment removal slows growth rates since energy is diverted to mucus production and particle removal rather than feeding and photosynthesis/ symbiosis, potentially resulting in coral death (Riegl and Branch, 1995).

*Cladocora arbuscula* forms small colonies less than 10 cm in diameter. *C. arbuscula* colonies are typically less than 5 cm high in Collier County. Several colonies of *C. arbuscula* were observed buried and dead while some were partially buried and dead. The cryptic species, *Phyllangia americana*, settles and grows mostly on subvertical and overhanging features, avoiding sedimentation impacts associated with horizontal surfaces. During our three years of post-hurricane surveys in Collier County, the only coral species observed recruiting within the areas of nearshore mud accumulation was *P. americana*.

The effects of mud deposition have been lethal for many other filter-feeders while photosynthetic activity and recruitment opportunities have been reduced for most benthic species. Small sponges (for example, *Cinachyra alloclada,*), zoanthids, Actiniaria, tunicates, etc. were observed dead under mud cover throughout the study area on both the Gulf and Atlantic sides of Florida. For example, 30 tunicates were recorded on the pre-hurricane high-relief artificial reef in Indian River County in 2006, while in 2007, only 5 tunicates were recorded along the same permanent transects. Under normal conditions, exponential growth of cover by tunicates during the first few years of succession is a characteristic feature of artificial reefs in South Florida.

**Conclusions**

It is hypothesized that the mud was transported by hurricane-generated waves and currents from the deeper parts of the shelf, where this material normally accumulates. We cannot suggest any other source for such an enormous amount of mud to be transported during such short-term events such as hurricanes. Large accumulations of mud were observed in southeast Florida in 1960 after Hurricane Donna at depths of 25 to 45 meters. These accumulations were later removed by currents and waves (E. Shinn, personal communication). Shinn et al. also described the deposition of mud layers over ooid sands in the very shallow realm of banks south of Joulters Keys and Cat Key in the Great Bahama Bank after Hurricane Andrew in August 1992 (Shinn et al., 1993).

Our observations of mud in Collier County and Palm Beach County are similar to the descriptions of interlacing mud with coarse post-hurricane sand described by Shinn et al. (1993). It is possible that the impacts of mud on reefs and hardbottom communities are more widespread than suggested by our observations and surveys. It is not possible to evaluate the extent and consequences of this impact on benthic communities and individual groups of organisms without considerable additional study. However, it is clear that the effects are long-lasting.

We have observed that mud masses are able to move along or around features; however, we are uncertain if the sediments are moving as liquid, gel-like body or are resuspended and accumulate in adjacent areas in the leeward side of relief features. The latter appears to be more plausible; however, the sediment dynamics have not been studied. The redistribution and accumulation of mud in the areas of the Indian River County artificial reef constructed after the hurricanes of 2004, which were previously unaffected by mud deposition, are clear evidence that the mud masses are mobile in the nearshore environment.

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