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SHORT COMMUNICATION

Documenting hurricane impacts on coral reefs using two-dimensional video-mosaic technology

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Keywords
Acropora palmata; Florida; hurricane damage; reef framework damage; video-mosaics.

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Abstract

Four hurricanes impacted the reefs of Florida in 2005. In this study, we evaluate the combined impacts of hurricanes Dennis, Katrina, Rita, and Wilma on a population of *Acropora palmata* using a newly developed video-mosaic methodology that provides a high-resolution, spatially accurate landscape view of the reef benthos. Storm damage to *A. palmata* was surprisingly limited; only 2 out of 19 colonies were removed from the study plot at Molasses Reef. The net tissue losses for those colonies that remained were only 10% and mean diameter of colonies decreased slightly from 88.4 to 79.6 cm. In contrast, the damage to the reef framework was more severe, and a large section (6 m in diameter) was dislodged, overturned, and transported to the bottom of the reef spur. The data presented here show that two-dimensional video-mosaic technology is well-suited to assess the impacts of physical disturbance on coral reefs and can be used to complement existing survey methodologies.

Problem

During the summer of 2005, an unprecedented sequence of four hurricanes impacted the reefs of the Florida Keys. Damage patterns to coral reefs are commonly influenced by the strength, path, and duration of each storm event (Harmelin-Vivien 1994; Lirman & Fong 1997; Lirman 2000). In the case of sequential storms, damage patterns can be also determined by storm frequency and prior disturbance history (Witman 1992). When the time required for live coral fragments to re-attach to the bottom and for loose rubble to stabilize exceeds the interval between storms, physical impacts can be compounded as loose pieces of coral rubble are mobilized by subsequent storms (Lirman & Fong 1997). The impacts of storms on coral colonies are often influenced by colony morphology, and the branching morphology of corals like *Acropora* spp. makes them especially susceptible to physical disturbance (Woodley *et al.* 1981). In fact, hurricane damage and coral diseases have been identified as the main source of mortality to acroporids in the Caribbean region, where this taxon has undergone such a drastic decline in abundance that the U.S. NOAA Fisheries Service has proposed listing *Acropora palmata* and *A. cervicornis* as 'threatened' species under the U.S. Endangered Species Act (Bruckner 2002; Oliver 2005; Precht *et al.* 2005).

The cumulative effects of the 2005 storms on one of the last remaining populations of *A. palmata* in the northern Florida Reef Tract were assessed with a newly developed survey methodology that is used to construct spatially accurate, high-resolution landscape mosaics of the reef benthos. Video-mosaics provide a complement to

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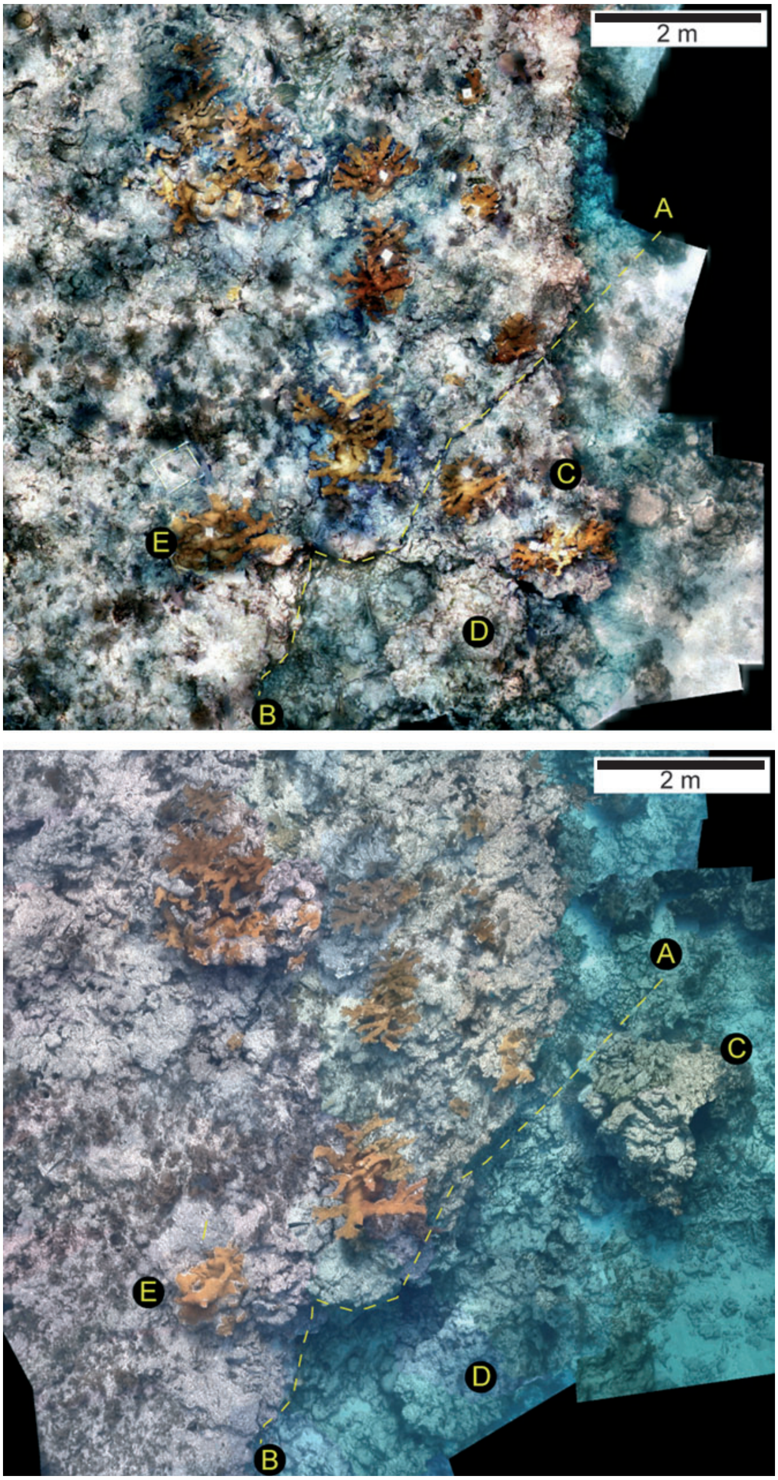

Fig. 1. Two-dimensional video-mosaics from a study plot at Molasses Reef in the Florida Reef Tract (depth 3.5–4.5 m). (Top) Mosaic from May 2005 was constructed prior to the start of the 2005 hurricane season. (Bottom) Mosaic from February 2006 following the passage of four hurricanes. The yellow line A–B shows where the reef framework was dislodged during hurricane Rita causing sections of the reef marked C and D to collapse. The section labeled C also appears in Fig. 2A. The *Acropora palmata* colonies located on section C are shown in Fig. 2B. Close-ups of the *A. palmata* colony labeled E appear in Fig. 2C and D.

standard diver-based survey methods, which require a high level of training and extended time underwater. Moreover, two-dimensional mosaics cover larger areas than one-dimensional 'strip' mosaics (Jaap *et al.* 2003) thereby allowing new types of analyses such as measuring the sizes of coral colonies and visualizing large features on the reef (Lirman *et al.* 2006).

Material and Methods

In this study, we used video-mosaic technology to document hurricane impacts on a population of the branching coral *A. palmata* at Molasses Reef (25° 0.609 N, 80° 22.397 W, depth = 3.5–4.5 m). Mosaics of the study plot (approximately 10 m × 10 m) were constructed from underwater video collected at 2 m from the bottom using a Sony TRV900 DV camcorder. The mosaicing algorithm is described in detail by Gracias *et al.* (2003), Negahdaripour & Madjidi (2003), and Lirman *et al.* (2006). Briefly, the method has four steps: (1) acquire the video in a series of parallel, overlapping swaths covering the study area; (2) estimate the image-to-image motion between pairs of sequential images to calculate an estimate of the camera trajectory; (3) refine the estimated camera trajectory by estimating motion between non-sequential but overlapping images; and (4) produce a single image by blending contributions from the individual frames. The mosaics constructed for this study have a ground resolution of 1–2 mm per pixel and coral colonies or fragments >5 cm in diameter are easily identified within each image.

Video data were collected before the passage of the hurricanes at Molasses Reef in May 2005 and again in February 2006 after hurricanes Dennis (dates of influence over the Florida Keys = July 9–10, 2005, peak wind gusts at Molasses Reef (C-MAN station) = 90 km h^{-1}), Katrina (August 25–26, 2005, 116 km h^{-1}), Rita (September 19–20, 2005, 100 km h^{-1}), and Wilma (October 24–25, 2005, 147 km h^{-1}). The video required to build the mosaics of the study plot was collected in <30 min, and production of the mosaics required approximately 10 h using a standard personal computer.

Landscape video-mosaics such as the ones produced in this study have high spatial accuracy (standard deviations of the residues = 4–5.5 cm, maximum distance error <14 cm) and thereby provide the capability to measure distances and sizes directly from the images once a scale has been established (Lirman *et al.* 2006). The scale in these mosaics is provided by PVC segments and ceramic tiles scattered throughout the images. The size of the *A. palmata* colonies found within each mosaic was measured as: (1) the maximum colony diameter (to the closest cm); and (2) the projected surface area of live tissue. The image-analysis software ImageJ was used to calculate these metrics.

Results and Discussion

The direct physical damage caused by hurricanes and tropical storms can vary significantly across scales, ranging from minimal to severe (Harmelin-Vivien 1994). Whereas changes in coral cover, abundance, and condition can be easily discerned from traditional before-and-after surveys, changes to the structure of reefs are harder to quantify. The video mosaics created in this study provide a unique view of the reef benthos that facilitates the

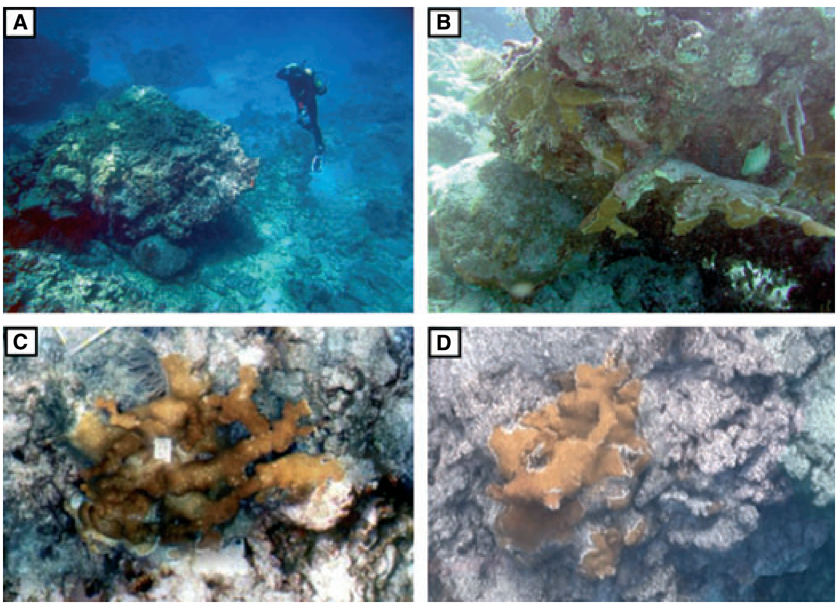

Fig. 2. A: Photograph of the reef section (labeled C in Fig. 1) that was dislodged during Hurricane Rita. B: Photograph of two *A. palmata* colonies attached to the dislodged reef section shown in A. These colonies ended up facing the sediments and died shortly after the storm. C: May 2005 and D: February 2006 photographs of an *A. palmata* colony (labeled E in Fig. 1) that experienced fragmentation and tissue losses due to the 2005 hurricanes.

documentation of colony-level impacts as well as large-scale structural changes to the reef framework.

If only coral cover and colony-based information such as abundance and size-structure had been collected prior to the onset of the 2005 hurricane season, the damage report for the *A. palmata* population at Molasses Reef after the passage of four major storms would have revealed, unexpectedly, only limited damage considering the intensity and frequency of the 2005 hurricanes. A total of 19 *A. palmata* colonies were identified from the video mosaic from May 2005, prior to the onset of the 2005 hurricane season, and 17 of these colonies remained, in the same location, in the study plot in February 2006 (Fig. 1). The two colonies that were removed from the plot were located on one of the sections of the reef framework that was dislodged during Hurricane Rita (Fig. 2A). These two colonies remained attached to the dislodged reef section but ended up in contact with bottom sediments and died shortly after this storm (Fig. 2B). The tissue on these large colonies (110 and 155 cm in maximum diameter) represented 14% of the total live *Acropora* tissue on the plot prior to the storms. For those colonies that remained, the net tissue losses between surveys were only 10%. Fifty-two percent of colonies lost live tissue, the maximum tissue loss for an individual colony was 46%. The mean diameter of colonies decreased slightly from 88.4 cm (SD ±70.1) to 79.6 (±63.3) cm. Tissue losses were mainly attributed to the removal of branches (Fig. 2C and D).

An increase in the abundance of colonies through fragment formation and reattachment after storms has been documented previously for *A. palmata* in Florida (Fong & Lirman 1995) but was not observed within the study plot at Molasses Reef. Fragment reattachment requires a minimum amount of time (Lirman 2000) and the succession of storms during the summer of 2005 may have impeded this process.

Considering the limited impacts documented for coral colonies at Molasses Reef, one of the most remarkable impacts of the 2005 hurricanes was the damage caused to the reef framework. Within the study plot, a large section of the reef (surface area = 12.7 m^2, diameter = 6 m) was dislodged and deposited on the sand at the bottom of the reef spur (Figs 1 and 2A). The shift in orientation of these sections resulted in the smothering and burial of coral colonies and the exposure of reef framework that may be further weakened by the future activities of bioeroders (Glynn 1988). The precise documentation of such large-scale modifications to the structure of the reef was only possible because of the landscape view provided by the video-mosaics.

The methods used to assess damage and recovery patterns of reef communities commonly entail the construction of underwater maps of the benthos based on diver-collected distance measurements and drawings, and the deployment of survey markers and permanent tags for coral colonies within plots. Assessing the impacts of severe physical disturbance on coral reefs can be especially challenging when large-scale modifications to the reef structure and the removal of both coral colonies and survey markers take place, as is commonly seen not only after storms but also after ship groundings (Hudson & Diaz 1988; Jaap 2000). The data presented in this study show that landscape video-mosaics provide the tools needed to accurately assess reef damage and recovery patterns and provide a significant addition to the existing survey techniques.

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