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Did the community structure of a coral reef patch affected by a ship grounding recover after 15 years? Merging historical and recent data sets

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A B S T R A C T

Shifts in dominance from coral to other benthic groups in coral reefs have raised concerns about the persistence of coral reefs and their ability to provide ecosystem services. Acute disturbances such as ship groundings offer the opportunity to examine the dynamics of successional processes in coral reefs, since understanding them is a prerequisite for their proper management. In this study, we investigated whether a ship grounding area in a reef located in a marine protected area in Cancún, Mexico, showed signs of recovery 15 years after the incident. We evaluated the reef's composition and structure by taking samples at three different scales (reef scale, 1 m^2, and 0.01 m^2). In these samples, we analysed coral density and recruitment, the abundance of five functional algal groups, and the abundance of the grazer sea urchin *Diadema antillarum*. If recovery had already occurred, we expected the impacted sector to have a community composition and structure similar to that of a contiguous, non-impacted sector. Using historical information, we found indications of a long-term phase shift, with *Porites astreoides* being the dominant coral species some time ago and at all scales of analysis; this species also showed intense recruitment. In agreement with previous studies of Caribbean reefs, architectural complexity was low. The algal cover was similar in impacted and non-impacted sectors though the density of sea urchins differed between them. Fifteen years after the ship grounding and despite the enforcement of the prohibition of tourism and fishing activities at the site, the impacted sector does not show signs of recovery. On the contrary, like other reefs in the Caribbean Sea, the non-impacted sector is becoming degraded due to the loss of reef builder key species and the increase of the algae-covered area, mirroring the path observed in the impacted sector.

1. Introduction

Around the globe, many coral reefs have lost their typical community structure and turned into a degraded condition. In the Caribbean, this situation has triggered the implementation of a number of strategies aimed at recovering the communities' original status (e.g., Jaap, 2000; Young et al., 2012). Common strategies include the establishment of marine protected areas (MPA), conceived as buffers against stressing factors and facilitators of coral recovery through the reestablishment of trophic cascade feedbacks (Mumby et al., 2006, 2007; but see Kramer and Heck,

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2007; Huntington et al., 2011). The populating of areas with sexual or asexual fragments (Johnson et al., 2011; Lindahl, 1998; Lirman, 2000; Young et al., 2012) is also a frequent strategy, and to a lesser degree, the implementation of land-based activities such as residual water treatment (Jackson et al., 2014) has been the selected tool. Among the factors contributing to coral reef deterioration, physical impacts, such as ship-groundings, are the most destructive of both the biological community and the reef framework (Gittings et al., 1990; Riegl, 2001).

Ship groundings are complex, acute disturbances that often reset coral reef communities almost to zero (Precht et al., 2001). The degree of damage caused by these disturbances depends on reef features (i.e., the reef zone that was affected), the environmental conditions at the time of the impact (tidal level, wave conditions), and ship-related features (vessel speed, load condition, ship heading angle) (Jaap, 2000; Nguyen et al., 2011). When a ship strikes a coral reef, it immediately removes the live cover, opening space for colonisation (Schroeder et al., 2008). The coral reef framework can be broken and crushed because of the ship's weight and impact strength, thus flattening the reef surface (Precht et al., 2001). Also, the site may be polluted if the hull brakes and fuel or cargo spill into the sea (Lirman et al., 2010; Precht et al., 2001). Rescue activities may increase the extent of damage. Ships towing off the grounded vessel may cause a new grounding or, in the worst case, the use of explosives may be needed (Smith, 1985).

Records of the effects of ship groundings on coral reefs around the world reveal contrasting community responses to these disturbances. After five years of the *Wellwood* grounding in Florida, the coral community showed increases in abundance from 0% to ca. 80% due to an intense recruitment process in the affected site, and an average recovery of ca. 20% cover was observed for hard corals dominated by *Favia fragum*, *Porites* sp. and *Agaricia agaricites* (Gittings et al., 1990). In contrast, no signs of recovery were observed in the *Evening Star* grounding four years after the impact (Lirman et al., 2010). In the Red Sea, several reefs affected by ship groundings showed a positive linear relationship between coral cover and time elapsed since the impact (Riegl, 2001). A common trend is that, after groundings, opportunistic species start preempting the space. For example, in Bermuda *Favia fragum* and *Porites astreoides* started to recolonise the site affected by the *Mari Boeing* in 1977 (Smith, 1985). The functional traits of *P. astreoides* (i.e., brooding species with several reproductive events in a year) enable it to rapidly colonise habitats subjected to physical damage that cause hard coral mortality (Alvarez-Filip et al., 2013; Green et al., 2008; Knowlton, 2001).

Ship groundings, when limited to physical impact, represent an opportunity to explore and understand community resilience and stability. Community resilience [i.e., the capacity to absorb changes on state variables while relationships among them persist (Holling, 1973)] depends on the biological legacies of the pre-disturbance elements (i.e., coral fragments), the nature and intensity of the relationships among them after disturbance (Carpenter, 1990; Fung et al., 2011), and the connectivity with other communities or ecosystems (Mumby and Hastings, 2008). In terms of stability, an ecological system is more stable when its post-disturbance dynamics induces the development of a community structure that is similar to that existing previously (Holling, 1973). In Caribbean coral reefs, resilience relies mainly on three biotic drivers of coral reef succession: (1) hard coral species (reef builders), which confer physical complexity and thus create, for many species, habitat and refuges from predators or harsh environmental conditions (Precht et al., 2001; Idjadi and Edmunds, 2006; Precht and Robbart, 2006); (2) algal groups, which either facilitate or deter coral recruitment, depending on their identity and environmental conditions (Birrell et al., 2008; Box and Mumby, 2007; Kuffner et al., 2006; Ritson-Williams et al., 2009); and (3) grazers such as herbivorous fish and sea urchins, among which *Diadema antillarum* is a prime example, which reduce algal cover, freeing space for potential coral recruitment (Edmunds and Carpenter, 2001; Idjadi et al., 2010; Myhre and Acevedo-Gutierrez, 2007). Herbivore impact depends largely on spatial feeding patterns; for example, fish can move between reefs and are less likely to feed at the same place, whereas *Diadema antillarum*, due to its limited migrating ability between-reefs, feeds more frequently at the same location; thus its ability to free space locally is greater than that of fish (Carpenter, 1986; Kellner et al., 2010). Once space is free and coral larvae establish, the fate of the potential coral community is determined mostly by the identity of the established colonies rather than by competition between algae and corals (Sandin and McNamara, 2012).

In this work, the benthic structure of a Mexican Caribbean reef affected 15 years earlier by a ship grounding is examined. The study aimed to determine whether the sector affected by the ship grounding was similar, based on reef community structure, to that observed in the adjacent non-impacted sector one decade and a half after the grounding damage. Recognising that the distribution of any species is patchy across a range of scales (Levin, 1992) and that coral communities can respond to disturbance by changing its structure in terms of dominance (Holling, 1973), a multi-scale spatial approach was applied to contrast community structure patterns between impacted and non-impacted sectors. We hypothesised that the ship-grounding could potentially facilitate a change of state. If this was the case, we anticipated that the structurally-complex hard coral species should be absent, or if present, that their abundances or cover would have lower values compared to the non-affected sector.

2. Materials and methods

2.1. Study site

This study was carried out from October 2012 to January 2013 in Cuevones within the Costa Occidental de Isla Mujeres, Punta Cancún y Punta Nizuc National Park, hereinafter Cancún National Park (CNP). Cuevones is an elongated patch reef located ca. 2.5 km north of Punta Cancún (UTM 526909, 2340046, WGS84 16N). The patch reef is approximately 180 m long, 25 m wide and 4–7 m deep (Fig. 1), and has an overall NW–SE orientation. Across the patch reef, there is an apparent change in coral type dominance from hard coral species on the windward side to soft coral species on the leeward side (Fig. 1). Throughout the hard coral (windward) section, architectural complexity appears to decrease from SE to NW. Within the soft coral (leeward) section, architectural complexity does not show an equivalent strong variation, except for the impact that occurred at the SE end. Based on this apparent variation in coral type dominance and physical complexity, the patch reef was divided into four sectors, one impacted (Imp) and three reference non-impacted sectors (R1-R3) (Fig. 1). The impacted sector runs, on the leeward side, from the south-eastern edge of the reef through the soft coral-dominated sector. The second sector included the more architecturally complex hard coral-dominated sector (R1) on the windward side, contiguous to the impacted area. The third sector was located on the leeward side and corresponds to the area dominated by soft corals (R2), where architectural complexity is minimal due to the shape of the holdfast of soft coral colonies. The fourth sector (R3), located on the windward side, was the least complex hard coral-dominated area.

2.1.1. The ship-grounding

In December 1997 the Norwegian Cruiser *Leeward* hit Cuevones