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Research Focus

No-take areas, herbivory and coral reef resilience

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Coral reefs worldwide are under threat from various anthropogenic factors, including overfishing and pollution. A new study by Mumby *et al.* highlights the trophic relationships between humans, carnivorous and herbivorous fishes, and the potential role of no-take areas in maintaining vulnerable coral reef ecosystems. No-take areas, where fishing is prohibited, are vital tools for managing food webs, ecosystem function and the resilience of reefs, in a seascape setting that extends far beyond the boundaries of the reefs themselves.

Managing coral reefs

The recipe for killing a coral reef is simple: distort food webs from the top down by overharvesting, or from the bottom up by adding nutrients, and add to the mix the stresses of climate change, emergent diseases and a myriad of other anthropogenic impacts. Overfishing and pollution have eroded the resilience of reefs, reducing their ability to absorb recurrent disturbances and remain coral dominated [1]. Consequently, tropical reef ecosystems worldwide are under siege, despite their enormous economic, social, cultural and aesthetic value. The key question arises: what should we do to protect and preserve the world's coral reefs? In a new paper [2], Mumby *et al.* highlight the trophic relationships between humans, carnivorous and herbivorous fishes, and discuss the potential role of no-take areas, where fishing is prohibited, in maintaining vulnerable coral reef ecosystems.

Herbivory and resilience

Traditionally, proponents of no-take areas have focused on their utility for managing targeted fisheries [3], rather than on their potential to regulate the ecosystem functions of harvested stocks, their prey and the resilience of reef ecosystems [4]. Mumby *et al.* [2] tested the potential importance of marine no-take areas for safeguarding parrotfish and their ability to control blooms of turf and fleshy seaweeds. Parrotfish (Figure 1) have several crucial roles in the dynamics of tropical reefs: they graze fleshy seaweeds that compete with juvenile and adult corals for space; they erode dead coral skeletons and generate reef sediments, and they are an important trophic link between their natural predators and algal primary producers [5]. Parrotfish also support subsistence fisheries on many coral reefs worldwide [4,5]. Logically, the density of parrot fishes will vary spatially and temporally in response to local rates of recruitment and mortality; the relative importance of mortality from fishing versus natural predation is also likely to differ substantially across the boundary of a no-take fishing reserve. Accordingly, Mumby *et al.* studied how parrotfish densities differ inside versus outside the Exuma Cays Land and Sea Park (ECLSP) in the Bahamas, a no-take area where fishing has been banned since 1986.

Similar to many reefs around the world, coral cover in the ECLSP was sharply reduced following bleaching associated with the 1998 El Niño-Southern Oscillation event [2]. Mumby *et al.* present data, collected after nearly 20 years of protection, on the number and size of grazing parrotfish, their predators, and the abundance of seaweed, both inside and outside the park. These data describe the outcomes of a long-term reduction of fishing pressure inside the ECLSP, compared with controls outside. Like any such comparison, there is a chance that differences ascribed to fishing could have been caused by other unrecorded factors, such as different levels of recruitment by fish inside versus outside the ECLSP. However, Mumby *et al.* minimized the potentially confounding effects of spatial variation by utilizing a multi-scale sampling approach, with multiple sites inside and at varying distances outside the ECLSP. Although no local management scheme can prevent regional-scale mortality of corals from global warming, this study illustrates convincingly that stewardship of marine parks by local communities can enhance grazing and help to prevent regime shifts from coral- to algal-dominated systems (Figure 2).

Fishing and trophic cascades

The biomass of parrotfish predators (groupers, barracuda, moray eels and large snappers) inside the ECLSP was double that of two adjacent reefs (Figure 3), and five times greater than more distant parts of the Bahamas archipelago. Spatial gradients in the density and size of harvested predatory fishes have been documented from other no-take areas, and have been attributed to the spillover of adults into nearby areas, providing a boost to local fisheries [6]. Similarly, groupers tagged within the ECLP have been located over 200 km away [7]. The elevated biomass of

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Figure 1. The Caribbean rainbow parrotfish *Scarus guacamaia*. Protection of parrotfish within no-take areas sustains both fish stocks and crucial ecosystem processes. The grazing activities of parrotfish can prevent algal overgrowth and enhance reef resilience. Reproduced with permission from M.J. Paddack.

predators inside the park might be expected to suppress the resident parrotfish that they consume, thereby reducing grazing and promoting macroalgae. However, to their surprise, Mumby *et al.* found precisely the opposite.

The biomass and size of parrotfish within the ECLSP differed significantly from adjacent areas that support a mixed-species reef fishery (Figure 3). For all species combined, the biomass of parrotfish was reduced by 30–60% on adjacent reefs, compared with the no-take area (Figure 3). Smaller-bodied species of parrotfish showed no difference in density in- or outside the park. By contrast, larger bodied species were twice as numerous inside the park, a difference that Mumby *et al.* attribute to protection from fishing and escape in size from predation. The frequency distribution of mouth size within the protected grouper population is consistent with the hypothesis that predation on large-bodied adult parrotfish is rare. The measured biomass of one large species, the queen parrotfish *Scarus vetula*, which is particularly vulnerable to trap fishing, was almost seven times greater inside the reserve, despite the elevated biomass of its predators. Co-incident with the elevated biomass of parrotfish, their estimated grazing intensity was six times higher, and the cover of seaweed within the park was five times lower, 14% compared with 75% on adjoining reefs (Figure 3). When grazing is impaired, chronic algal blooms can smother corals, particularly juveniles, and prevent the replenishment of coral populations (Figure 2). Hence, the ECLSP appears to regulate herbivory, a crucial ecosystem process that is an essential component of the resilience of reefs [1].

Mumby *et al.*'s conclusion, that the biomass of parrotfish grazers could also be enhanced within well-managed no-take areas elsewhere, is supported by the particular nature of the ECLSP, which is unusual for the relatively low level of fishing nearby. In most parts of the Caribbean, parrotfish are a major component of reef fisheries, especially where their slower-growing predators have long been depleted. The biomass of parrotfish varies tenfold among heavily versus lightly fished sites across the Caribbean [8], with values from the Bahamas being close to the top of the range. Therefore, the twofold difference in biomass of large parrotfish inside the ECLSP compared with adjacent reefs

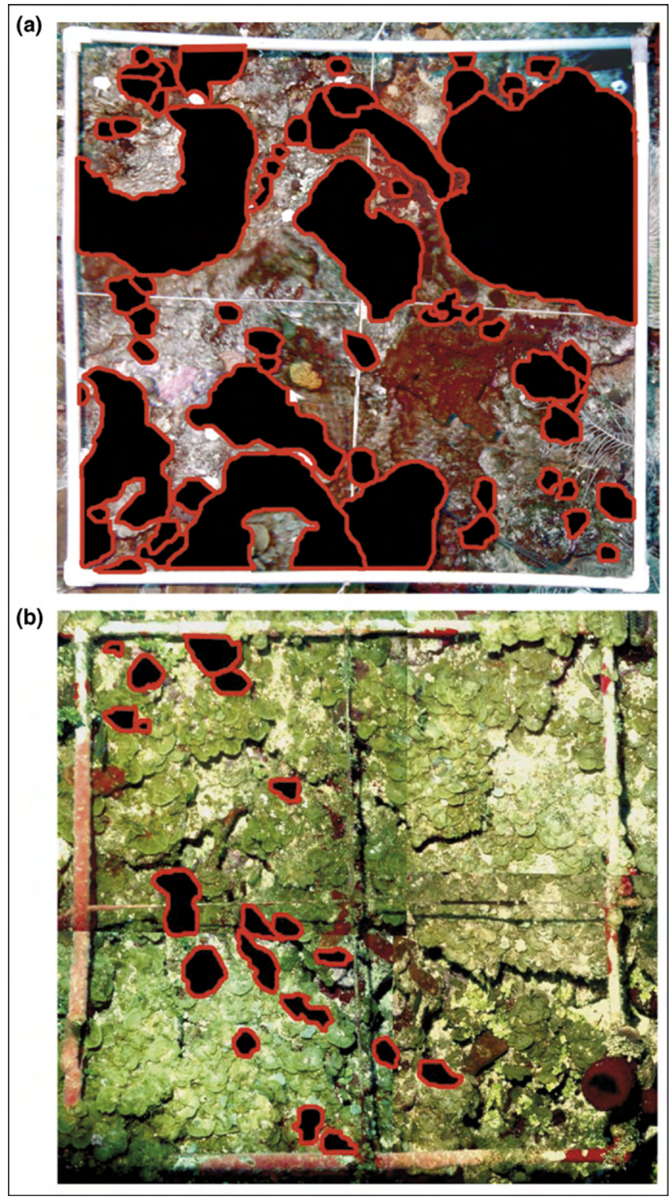

Figure 2. Changes in Caribbean coral reefs over the past 20–30 years, especially those that are chronically overfished. Here, a before **(a)** and after **(b)** sequence of photographs from Jamaica, of the same permanently attached 1-m^2 quadrat at a depth of 35 m, illustrates the replacement of corals (black with red outlines) by seaweeds over a 16-year period. The corals in (b) are shrunken remnant colonies that are partially smothered by seaweed, and are not newly recruited juveniles. Reproduced with permission from T.P. Hughes.

is probably modest compared with what might be expected for no-take areas established in the more heavily fished areas that typify much of the Caribbean. So long as fishing mortality outside remains higher than predation inside, Mumby *et al.*'s results indicate that no-take areas should enhance the biomass of parrotfish.

Future research

One limitation of Mumby *et al.*'s study is the lack of information through time. The best available time-series on the build-up of predatory fish in coral reef no-take areas comes from long-term studies of 15 reserves in the Philippines, where the biomass of large predatory fish has increased exponentially at an average annual rate of 12%, to more than six times the biomass of adjacent

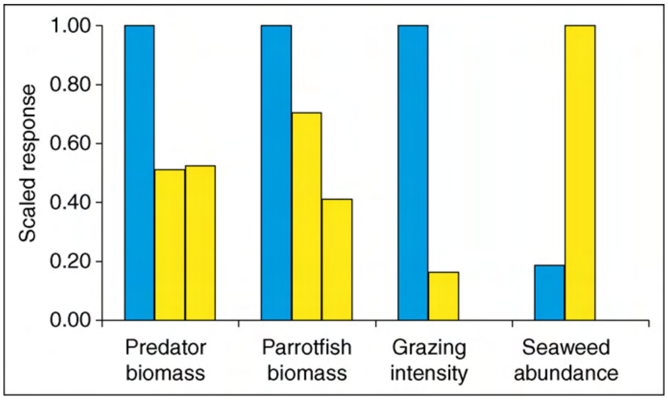

Figure 3. Biomass of parrotfish predators, parrotfish, their estimated grazing intensity and the abundance of seaweeds on areas of reef in the Bahamas that are no-take area reserves (blue bars) and non-reserves (yellow bars). The multiple yellow bars for predator and parrotfish biomass represent two non-reserve locations. Modified with permission from Ref. [2].

non-reserves [9]. Importantly, the build-up of fish stocks shows no sign of levelling off after 19 years of protection, a time frame that is almost identical to the age of the ECLSP. Future work at ECLSP should also focus on the trajectory of recruitment and abundance of corals following the bleaching mortality of 1998, both inside and outside the no-take area. Crucial issues include larval transport, the extent to which production of larvae by Caribbean corals has already been compromised by the widespread loss of brood stock, and the longer-term response of reef assemblages to global warming.

Building on Mumby *et al.*'s biological insights, an important issue for future research is the social, economic and political reasons why the ECLSP has successfully enhanced its fish stocks (Figure 3), compared with many marine parks that have failed to achieve their potential [10]. Many of these have been established by central governments or foreign NGOs, but they remain ineffective because they lack local support [11]. An improved integration of the scientific and social aspects of no-take areas is urgently needed to create appropriate institutions and governance systems that can confront the coral reef crisis at local and regional scales [10–12].

Importantly, the success or failure of any no-take area will depend on areas outside the park that are part of the same highly connected reef system. Therefore, in a broader seascape setting, integrated management of both no-take and harvested reefs will be crucial for their long-term sustainability. Globally, a greater emphasis is needed for coordinated stewardship of much of the coastal habitat worldwide that largely remains open to fishing, in tandem with the establishment and management of no-take areas. Thus, no-take areas are an important element of the global response to the coral reef crisis, but they are not a panacea.

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