The Last Call for Marine Wilderness?

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Wilderness areas have been widely discussed in the terrestrial conservation literature, whereas the concept of marine wilderness has received scant attention. The recent move to protect very large areas of the ocean and thus preserve some of the final marine wilderness areas is a bold policy initiative. However, some important questions have remained unanswered, such as whether marine wilderness areas support a different composition and abundance of species than do the smaller marine no-take areas (NTAs) that are steadily dotting our coastlines. We present a case study from the world's largest wilderness coral reef NTA, the Chagos Archipelago, and demonstrate that fish biomass is six times greater than and composition substantially different from even the oldest NTAs in eight other Indian Ocean countries' waters. Clearly, marine wilderness does promote a unique ecological community, which smaller NTAs fail to attain, and formal legislation is therefore crucial to protect these last marine wilderness areas.

Keywords: coral reef ecology, fishery closures, governance, marine policy, marine protected areas

Wilderness areas **are defined as large areas (greater** than 10,000 square kilometers [km^2]) that host over 70% intact biodiversity and human densities of five people per km^2 or less (Mittermeier et al. 2003). This label has typically been restricted to terrestrial ecosystems, and little is known about marine wilderness areas. For example, are large, unfished marine wilderness areas different from small protected areas that are embedded within fished, human-dominated seascapes? A large number of national governments have embraced small (i.e., mostly less than 10 km^2) no-take marine protected area management, or *no-take areas* (NTAs), and there are now over 4400 NTAs, covering 2.35 million km^2 (Wood et al. 2008). Can these small NTAs protect a suite of species and ecological processes in a manner comparable to that of wilderness areas? These questions require urgent answers as we undertake an unplanned global experiment in population growth and climate change in which moral pragmatism and a shifting baseline are quickly withering any salient concepts of pristine, wild ecosystems.

In the western Indian Ocean, one of the poorest regions on Earth, a number of relatively large (up to about 30 km^2) NTAs have existed for more than 40 years, and some, such as those along the Kenyan coast, have received the best available protection. It has been argued that these NTAs are among the most pristine coral reefs in the Indian Ocean in areas inhabited by people (McClanahan et al. 2011), and the Kenyan NTAs have reached asymptotes in the recovery of fish biomass (McClanahan et al. 2007). However, in a recent study, these NTAs were compared with historical fish catch archived between the eighth and fourteenth centuries. An analysis of Swahili settlement trash middens showed that the species composition in these contemporary NTAs does not represent historical baselines (McClanahan and Omukoto 2011). Although many NTAs in the western Indian Ocean are relatively large by global standards, they are adjacent to dense human populations that influence the resources surrounding the protected areas, and in some of the region, there is weak compliance with NTA rules (Pollnac et al. 2010, Daw et al. 2011). In addition, the sizes of these NTAs are smaller than what may be necessary to create wilderness conditions (Mittermeier et al. 2003).

Chagos marine wilderness area case study

The Chagos Archipelago, also known as the British Indian Ocean Territory, is the largest unfished, uninhabited, and remote coral reef wilderness area in the Indian Ocean (figure 1). The previously sparsely populated northern atolls of Chagos have been uninhabited since the early 1970s and, in April 2010, the entire 640,000-km^2 archipelago and its associated exclusive economic zone was officially established as the world's largest no-take marine protected area (Sheppard et al. 2012). Consequently, to better understand the context of human impacts and the effectiveness of small NTAs in re-creating coral reef ecosystems comparable to wilderness areas, we surveyed reef fish biomass and composition in remote atolls of the Chagos Archipelago for the first time in 2010 and, here, compare this wilderness area with reef fish communities influenced by different management across the western Indian Ocean and in other large remote wilderness locations across the globe. We assessed fish biomass because fishing is one of the most pervasive threats to coral reefs in the Indian Ocean, and fish biomass has been shown to be a good proxy for a range of key

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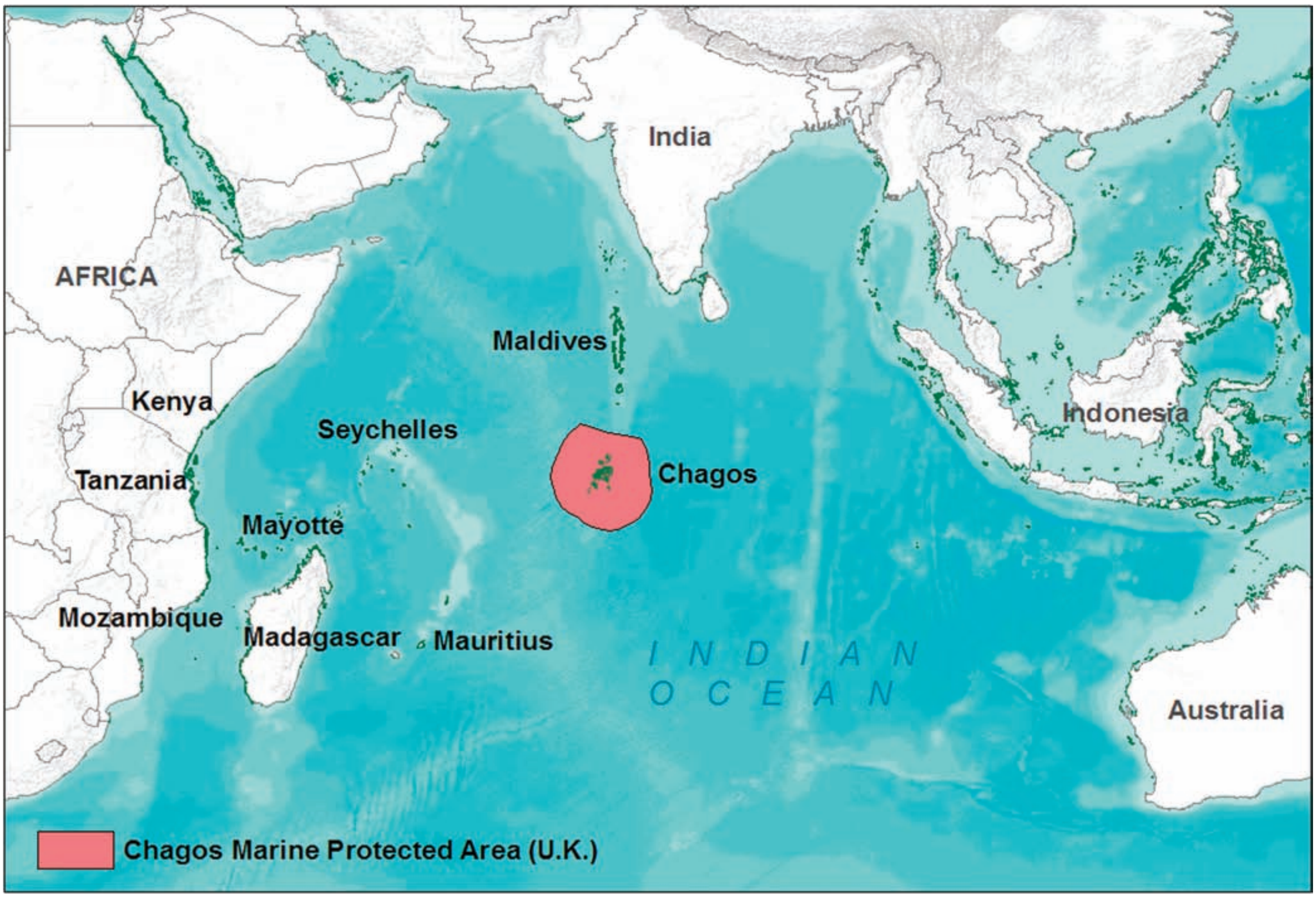

Figure 1. Location of the approximately 640,000-square-kilometer Chagos no-take marine protected area in the central Indian Ocean and the other countries in which coral reef fish communities were sampled. The green dots denote coral reefs. Abbreviation: U. K., United Kingdom.

functional groups and ecological processes across the region (McClanahan et al. 2011).

Reef fish biomass in Chagos dwarfs that of the rest of the NTAs in the western Indian Ocean ($p < .001$; see supplemental table S1, available online at *http://dx.doi.org/10.1525/bio.2013.63.5.13*), with a mean biomass at a 9-meter (m) depth of more than 7500 kilograms per hectare (kg/ha)—six times that of the most successful small NTAs in the region (figure 2a). This probably highlights a huge exploitation gap, whereby extraction across the rest of the region has reduced biomass, and the small spatial scale of most NTAs within exploited seascapes does not approach the true potential of these ecosystems. Furthermore, the contribution of higher trophic levels to the standing fish biomass is far greater in Chagos than elsewhere in the Indian Ocean, with over half of the biomass consisting of fish with a mean trophic level of more than 3.5. The small proportion of these higher-trophic-level species across the rest of the Indian Ocean points to trophic downgrading of ecosystems at large scales (Estes et al. 2011). Biomass at a 3-m depth in Chagos, where extreme wave energy results in low reef complexity (figure 3), is much lower than that at 9 m but is still higher than that of many sites across the western Indian Ocean, where no effect of survey depth on biomass was apparent (figure 2a; supplemental tables S2 and S3). It is possible that geographic or oceanographic factors contributed to the differences in fish biomass across the region, but much of the data come from islands and atolls with similar geomorphology. Exploitation is the most likely driver, given the differences in the numbers of high-trophic-level fish between NTAs and the Chagos wilderness.

The family-level biomass community composition of the fish assemblages also differs substantially between Chagos and the rest of the Indian Ocean (figure 2b). Crucially, of the 10 reef fish families that make up 70% of the difference between Chagos and the rest of the Indian Ocean, all had a higher biomass in Chagos than elsewhere or were present only in Chagos (supplemental table S4). This suggests that fish diversity and composition in coral reef wilderness areas are also substantially different from those in locations dominated by humans. The most likely explanation for the inability of small NTAs to mimic wilderness areas is the spatial scale over which some larger marine fish range (Heupel

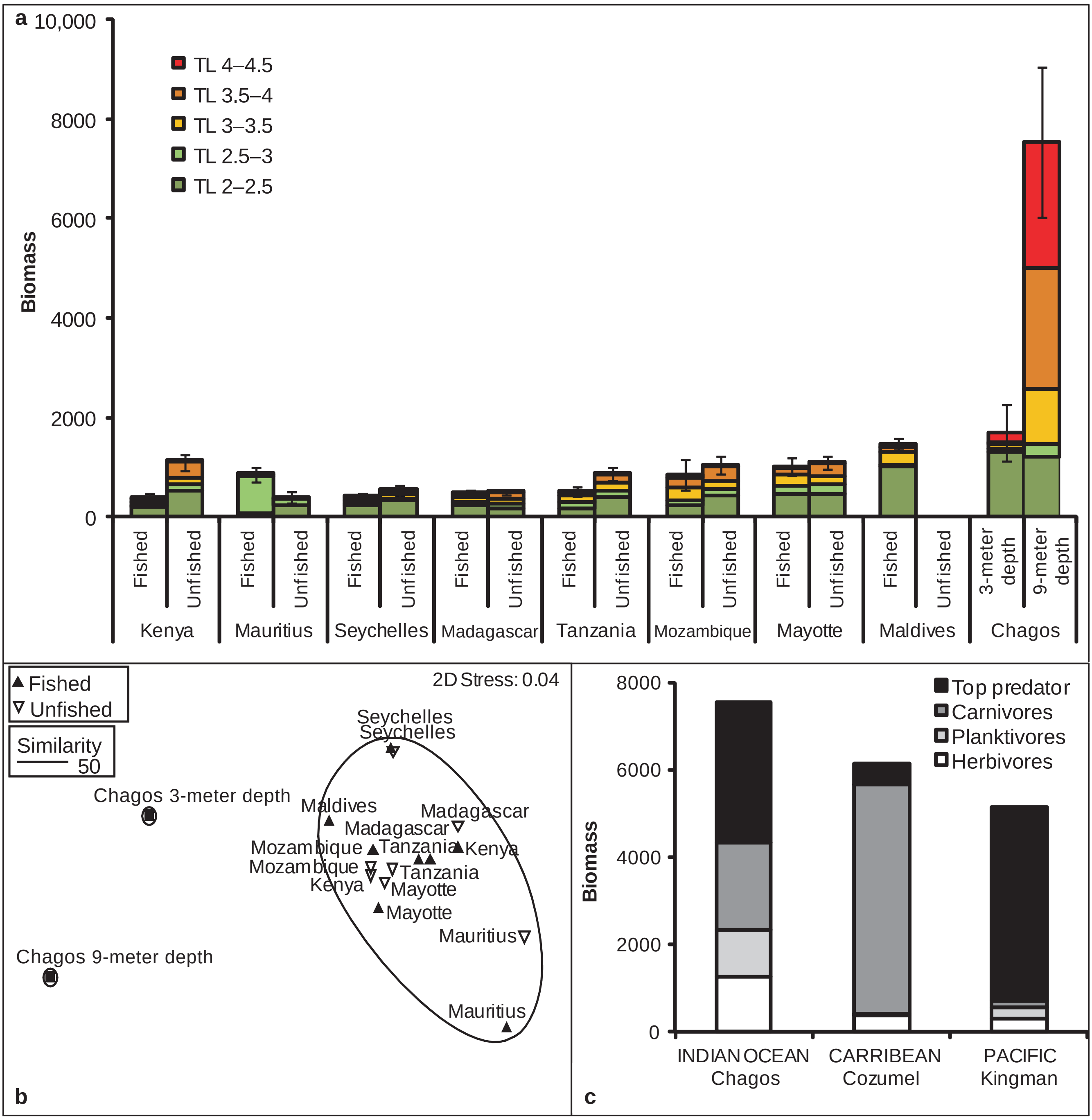

Figure 2. (a) Total reef fish biomass (in kilograms per hectare [kg/ha]) as a function of trophic level (TL), management, and depth in nine countries across the central and western Indian Ocean. The error bars represent the standard error. (b) Multidimensional scaling plot of reef fish family biomass composition in nine countries across the central and western Indian Ocean. (c) Comparison of biomass trophic group composition for the highest reported reef fish biomass estimates (in kg/ha) from the Indian Ocean, the Caribbean, and the Pacific Ocean. Unfished *refers to no-take marine protected areas. The data for the Caribbean are from Newman and colleagues (2006), and those for the Pacific Ocean are from Sandin and colleagues (2008).*

et al. 2010), which exceeds the size of most small NTAs and exposes these populations to fishing pressure.

The highest reported reef fish biomass estimates from remote reefs of the Pacific Ocean, the Caribbean, and the Indian Ocean are comparable, ranging from 5500 to 7500 kg/ha (figure 2c). These three areas represent locations that are extremely remote from human habitation or that have had unusually large well-enforced NTAs for some time. However, the composition of the fish communities varies greatly among the three locations ($p < .001$), with

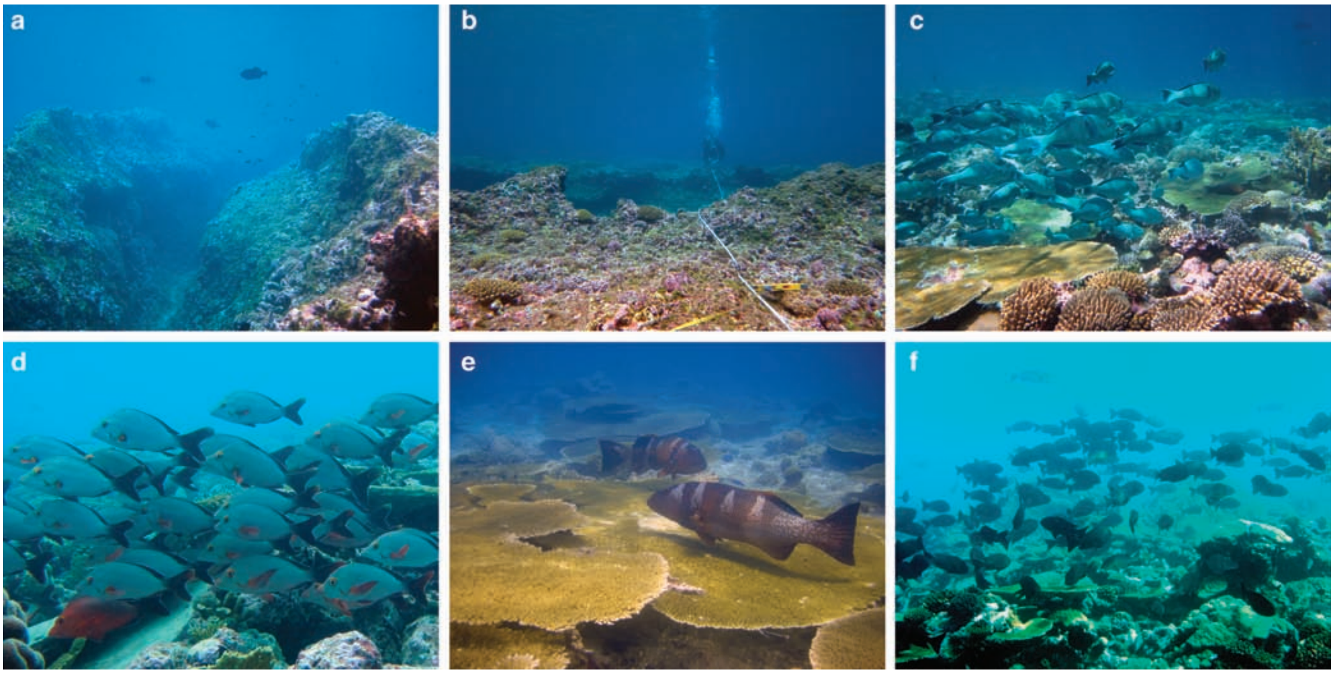

Figure 3. Many reef sites at a depth of 3 meters in Chagos experience extreme wave energy through much of the year, which reduces the small-scale structure of the reef and causes it to form spur and groove features (a, b). Fish biomass was still fairly high, particularly where the sites were less exposed to wave energy, and was dominated by lower-trophic-level species, such as parrotfishes (c). At a depth of 9 meters in Chagos, very high fish biomass was recorded, with large schools and very large individuals of species that are heavily targeted elsewhere in the Indian Ocean (d, e, f). Photographs: Nicholas A. J. Graham.

sharks and other top predators dominating Kingman atoll in the Pacific (Sandin et al. 2008), generalist carnivores dominating in Cozumel (Newman et al. 2006), and a more balanced composition of all four feeding groups (i.e., top predators, generalist carnivores, planktivores, and herbivores) contributing in Chagos. It is notable that reef sharks declined in numbers by 90% in Chagos between the 1970s and 2006 because of poaching (Graham et al. 2010), and so the potential biomass of top predators at Chagos is likely to be substantially higher. It is currently unknown whether the reduction in sharks would have had much impact on the biomass of other groups. Because shark populations typically show slow recovery rates, it will probably take many decades of stricter enforcement to reinstate the ecological processes that they provide.

The case for protecting marine wilderness

It is clear that the fish biomass that can be attained in remote coral reef wilderness areas far outstrips the levels that are seen in populated coastlines, including within small NTAs. Similar findings of exceptional fish biomass have been documented in a comparison of the remote northwest Hawaiian Islands with the populated main Hawaiian Islands (Friedlander and DeMartini 2002) and in a comparison of the unpopulated northern Line Islands with the populated atolls to the south (Sandin et al. 2008). Remoteness from many direct human influences and high biomass of fish populations are likely to provide important processes for the wider ecosystem (McClanahan et al. 2011). For example, the general reef condition in terms of coral cover and recovery from disturbances is high in Chagos and the northern Line Islands relative to that in many other reef locations (Sandin et al. 2008, Sheppard et al. 2008, Ateweberhan et al. 2011). Furthermore, microbial communities that can cause coral disease and associated declines in reef condition are in lower densities in the more pristine remote reefs of the northern Line Islands than in the populated atolls to the south (Dinsdale et al. 2008). Wilderness areas will not be immune to some longer-term threats, such as ocean warming and acidification, but their expanse may help mitigate some of the impacts by protecting certain oceanographic and habitat features necessary to provide some species with refuge.

It is evident that wilderness areas in the oceans offer unparalleled ecosystem conditions at a time when the majority of the discourse describes the declining state of the world's oceans (Halpern et al. 2008, Hoegh-Guldberg and Bruno 2010). Indeed, there seems little doubt that formal legislative protection of some of the world's last remaining marine wilderness locations, such as the Chagos NTA, is a crucial step to maintaining some near-pristine legacy areas in the oceans (Pew Environment Group 2010). Similar moves have been made with the 360,000-km^2 Papahānaumokuākea Marine National Monument in the northwest Hawaiian Islands and the 408,000-km^2 Phoenix Islands Protected Area, both of which were established in 2006. Although these locations were already in a relatively pristine condition prior to formal protection, this protection is expected to increase the likelihood of their long-term preservation.

We focused on coral reef ecosystems in our case study from the Indian Ocean. It is likely that large wilderness areas encompassing other marine ecosystems will also represent exceptional ecological communities worthy of protection (Estes et al. 2011). Large-scale assessments of the status of those ecosystems in comparison with exploited and managed areas should be conducted to evaluate the importance of marine wilderness for a range of other marine ecosystems. For example, one possible avenue for large protected areas is in the open ocean: harnessing knowledge of fixed or dynamic oceanographic features (Game et al. 2009). Most large protected areas to date have been delineated on the basis of political boundaries, such as countries or exclusive economic zones. If these large areas are instead designed on the basis of biological features and seascape processes that might be associated with larger-scale oceanographic features, international partnerships and governance will be required. This may be achieved through the strengthening of existing frameworks, such as the United Nations Environment Programme's Regional Seas Programme, or through building other, more sustainable regional governance structures among partnering nations.

Is small-scale management also necessary?

Does the unique condition of wilderness areas and the increasing trend toward their formal protection mean that we are wasting resources establishing small NTAs elsewhere? In reality, as far as coral reefs are concerned, there are few opportunities for protecting large wilderness areas, because there are not many large coastal areas in the tropics that are uninhabited or governed in such a way that would allow their effective protection. Furthermore, care needs to be taken not to make the same mistakes in the oceans that were made on land: protecting remote areas of little current commercial value at the expense of biodiversity and ecosystem service declines in areas of greater human use (Margules and Pressey 2000). These two points suggest that smaller-scale management actions in human-dominated seascapes are also of great importance.

Although small NTAs may not build fish biomass to the levels seen in wilderness areas, if compliance is high, they can substantially enhance fish biomass and diversity relative to adjacent fished areas (Lester et al. 2009, Graham et al. 2011) and may export a disproportionate number of larval fish to unprotected sites (Harrison et al. 2012). Furthermore, a number of key ecosystem processes, such as predation, herbivory, and bioerosion, can be substantially altered in small coral reef NTAs (Mumby et al. 2007, Stockwell et al. 2009, McClanahan et al. 2011), which suggests that local management in human-dominated seascapes can have important effects on ecosystem function. In terms of ecosystem services, small NTAs can enhance the profitability of adjacent fisheries (McClanahan 2010) and can attract dive tourism (Peters and Hawkins 2009).

However, regulations in many small NTAs are often not well complied with, and in these cases, there may be few biological benefits (figure 2a; Pollnac et al. 2010). Indeed, governance and poverty challenges may mean that NTAs are not always the most appropriate policy or management tool. Management in resource-dependent socioecological (often called *social-ecological*) settings requires much more innovative stewardship (Chapin et al. 2010) to engender some of the ecosystem function and service benefits at larger spatial scales that are seen in the more successful NTAs while still maintaining the livelihoods and nutritional needs of the many people who rely on reefs. This will require bold initiatives, such as expansions of gear-based management (Johnson 2010), the devolvement of governance structures in order to empower local stakeholders (Cinner et al. 2012), appropriate aid that leverages escape from socioecological traps that are often driven by poverty (Cinner 2011), and broadening the nutritional portfolio.

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