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13 · *REPRESENTATIVENESS – Effectiveness of the global network of marine protected areas*

Camilo Mora

13.1 Introduction

Marine biodiversity is increasingly being lost due to human-related activities. Several marine ecosystems such as estuaries (Lotze *et al.*, 2006), mangroves (Valiela *et al.*, 2001), seagrasses (Waycott *et al.*, 2009), coral reefs (Gardner *et al.*, 2003; Pandolfi *et al.*, 2003; Bruno and Selig, 2007), and coastal and oceanic fish communities (Jackson *et al.*, 2001; Worm *et al.*, 2005) are rapidly losing populations, species, or entire functional groups due to threats such as exploitation, habitat loss, and climate change, among others (Jackson *et al.*, 2001; Hoegh-Guldberg *et al.*, 2007; Mora *et al.*, 2007; Mora, 2008). The rate of these losses and extent of these threats are expected to drive many marine species to collapse and possible extinction before the middle of this century (Worm *et al.*, 2006; Hoegh-Guldberg *et al.*, 2007; Donner, 2009). These losses, in turn, may impair the capability of ecosystems to cope with natural and anthropogenic impacts and harm the services that biodiversity provides to a growing human population that increasingly uses coastal habitats and marine resources (Worm *et al.*, 2006; Donner and Potere, 2007).

The accelerated decay of ecosystems is a modern concern to humankind and has motivated concerted global efforts such as the Convention on Biological Diversity, which was endorsed by more than 190 countries and aimed to reduce the rate of biodiversity loss by 2010 (Balmford *et al.*, 2005). In practical terms, one of the solutions that

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was proposed and that has received significant support to reverse the loss of biodiversity is the establishment of protected areas (Lubchenco *et al.*, 2003; Balmford *et al.*, 2005; Chape *et al.*, 2005; Lubchenco *et al.*, 2007; Wood *et al.*, 2008). The expected effect of protected areas is that by reducing pressures from harvesting and habitat loss, wild populations will recover if they have been impacted or will maintain natural levels of resilience to cope with natural and other human-related disturbances (Lubchenco *et al.*, 2003; Palumbi, 2003; Micheli *et al.*, 2004; Palumbi, 2004). The fact that such an expected effect has been documented (Halpern and Warner, 2002; Micheli *et al.*, 2004; Worm *et al.*, 2006) and that governments need to fulfill international agreements (Balmford *et al.*, 2005; Wood *et al.*, 2008), has resulted in a proliferation of marine protected areas (MPAs). Today, 4435 MPAs exist worldwide (Wood *et al.*, 2008) covering 0.65% of the world's oceans, although only 0.08% is inside no-take MPAs (Wood *et al.*, 2008). It may be understood, however, that the number and coverage of MPAs are the simplest proxies for biodiversity conservation and that "coverage effectiveness" is what ultimately will determine the real conservation of biodiversity (Chape *et al.*, 2005; Mora *et al.*, 2006). Unfortunately, global assessments on the effectiveness of MPAs are still limited, given the difficulties in collecting data that are patchy and changing rapidly (Mora *et al.*, 2006). Here I analyze a combination of databases to assess the effectiveness of the current global network of protected areas in ensuring the maintenance of populations and the likely constraints that humans pose to the effective management of MPAs.

13.2 World Database on Protected Areas

I used the most recent data on global MPAs, as provided in the 2009 release of the World Database on Protected Areas. That database contained the corrections done by Wood *et al.* (2008) and included polygons for 4705 MPAs and the geographical coordinates for the center points of 1796 other MPAs. Center points were converted to polygons by creating a buffer of the same size of the reported MPA. Most of the point MPAs are very small (Wood *et al.*, 2008) and creating such a buffer around them is known to introduce only small errors (Mora *et al.*, 2006). Using GIS, I removed the spatial overlap among MPAs. The final database contained 4363 independent MPAs (Figure 13.1). This reduction in the number of MPAs occurs because a substantial number of MPAs were duplicated in the original database and because the polygons of several MPAs overlap

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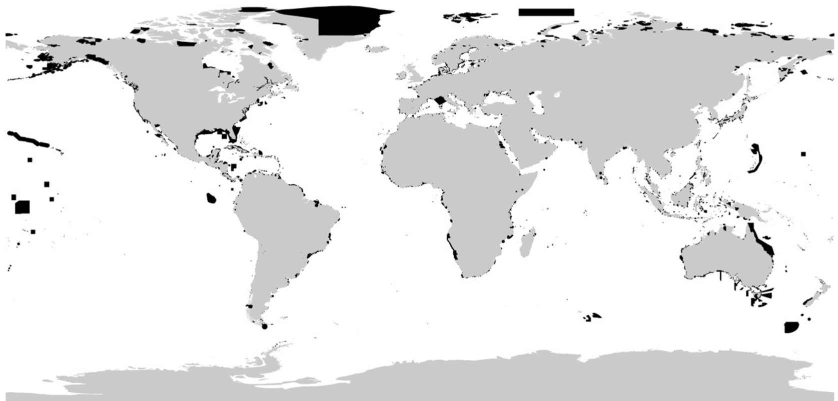

Figure 13.1 Global distribution of marine protected areas. Data from the 2009 release of the World's Database on Protected Areas. Map not to scale; I have bolded the borders of MPAs so that they would be visible at this global scale.

each other. These two problems in the World Database of Protected Areas have been documented before (Chape *et al.*, 2005; Wood *et al.*, 2008) but are easily resolved by dissolving the overlap among polygons, which maintains the same area of coverage which is the main purpose of conservation.

13.3 Maintenance of populations in the global network of marine protected areas

The stability of most marine populations is determined by metapopulation dynamics, in which local populations are seeded by a combination of locally and distantly produced propagules (Kritzer and Sale, 2006). These types of systems require a precise understanding of the home ranges where benthic individuals live and the spatial scales over which their propagules disperse (Mora and Sale, 2002; Palumbi, 2003; Palumbi, 2004; Sale *et al.*, 2005). In other words, extensive movement can expose benthic individuals to harvesting outside the boundaries of the MPAs (Kramer and Chapman, 1999; Palumbi, 2004; Sale *et al.*, 2005), whereas the arrival of new recruits can be favored if source populations are protected (Shanks *et al.*, 2003; Sale *et al.*, 2005). Additionally, it is expected that protected habitats are suitable for the maintenance of local populations (Jameson *et al.*, 2002). In other words, local habitats are not polluted, environmentally stressful, or dominated by exotic species

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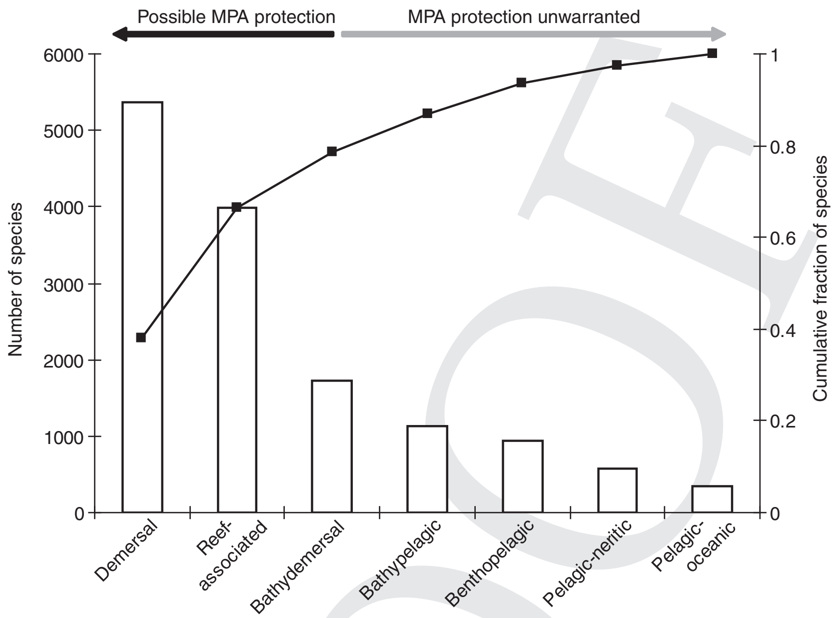

Figure 13.2 Frequency distribution of marine fish species by habitat types. The figure is intended to provide a rough quantification of the groups of species that may and may not be protected by MPAs. This quantification is based on the habitats of residence of marine fish species. If habitats of residence are too large, protected individuals may face mortality outside the boundaries of MPAs, such as for instance pelagic residing species. Data from FishBase (www.fishbase.org).

(Jameson *et al.*, 2002). The extent to which these attributes are met in the global network of MPAs is poorly known and is the main objective of this paper.

13.3.1 Protection of benthic neighborhoods

One fact that needs to be understood about the use of MPAs is that they warrant the protection of species whose home ranges, at some point during their life history, are restricted to areas that could be reasonably protected as part of an MPA (Palumbi, 2004; Sale *et al.*, 2005). That excludes a large fraction of biodiversity, such as those species whose life cycles occur entirely in open water and large pelagic and benthic fishes whose home ranges are too large to be covered within the area of common MPAs. For marine fishes alone that may represent up to 22% of their global diversity (Figure 13.2).

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For species that have benthic habits at some point during their life cycle, MPAs provide protection depending on the ratio between the size of the species' home range and the size of the MPA (Kramer and Chapman, 1999; Palumbi, 2003; Palumbi, 2004; Sale *et al.*, 2005). This occurs because individuals can trespass the boundaries of the MPA and become vulnerable to mortality outside the MPA even if MPA enforcement is successful. This effect is known to create gradients in abundance around the borders of MPAs (Kramer and Chapman, 1999) and possibly cause extinction if the protected area is small and mortality outside the protected area is severe (Woodroffe and Ginsberg, 1998). Kramer and Chapman (1999) illustrate, for instance, that to reduce fishing mortality of a particular species inside an MPA to 2% of the mortality outside the MPA, the MPA has to be 12.5 times larger than the home range of the species. By using the previous calculation in combination with the home ranges of marine fishes (as scaled from their body size: Kramer and Chapman [1999]), I calculated that complete protection of fish assemblages is warranted in only 14.4% of the MPAs in the world (see Figure 13.3 for details). This suggests that at the global scale a significant fraction of the MPAs are too small to protect the large variety of species that may occur at any particular assemblage.

13.3.2 Ensuring propagule connectivity

The scale of propagule dispersal (I refer to propagules because the vectors of dispersal can be eggs, larvae, juveniles, and even adults in some species) is a critical, yet poorly known, characteristic for the effective design of MPAs, or, in other words, for ensuring that populations will remain viably interconnected within the network of MPAs (Shanks *et al.*, 2003; Palumbi, 2004; Sale *et al.*, 2005). Although data about the relative role of long-distance dispersal versus local retention remain limited (Mora and Sale, 2002), recommendations about the spacing between MPAs to ensure connectivity ranges from 10 to 20 km (Shanks *et al.*, 2003) and 20 to 150 km (Palumbi, 2003). In the global network of MPAs, the average distance from any MPA to its nearest MPA is 42 km (Figure 13.4A), with that distance increasing rapidly as more than one MPA is considered. For instance, the average distance from any MPA to the nearest 20 MPAs is 430 km (Figure 13.4B). If exploitation or habitat loss outside MPAs is severe, these results indicate that the life cycle of many marine populations can be truncated during the dispersal stage because viable or protected reproductive benthic populations are separated by distances larger than

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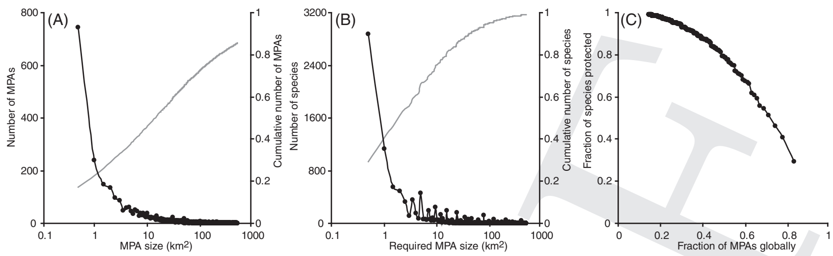

Figure 13.3 Protection of fish neighborhoods in the global network of marine protected areas. Plot (A) depicts the frequency distribution of MPA sizes globally. Plot (B) depicts the required MPA size to protect the described marine fishes of the world. The required MPA size was calculated based on the calculations of Kramer and Chapman (1999). In their analysis, for a particular species, reducing fishing mortality inside a MPA to 2% of the fishing mortality outside the MPA requires MPAs 12.5 times larger than the home range of the species. The home ranges of the species were calculated from the escalation of home range with body size (Kramer and Chapman, 1999). In this analysis, I included only the subset of species with discrete habitats of residence that can be protected by MPAs (i.e., the groups of species outlined in Figure 13.2). In total 9830 fish species were considered and data on their body size were obtained from FishBase (www.fishbase.org). Given that local pools of species are random subsets of the species seen at regional scales (Karlson *et al.*, 2004), Plot (B) is intended to provide a relative view of the frequency distribution of the MPA sizes required to protect particular fractions of species at local communities. Plot (C) depicts the fraction of species protected, according to the criteria of reducing fishing mortality to 2%, by the different MPAs in the world. To exemplify how to read the figure, note the dotted lines in the plot. According to that example protecting 99.9% of the species in a given community is warranted in only 14.4% of the MPAs in the world.

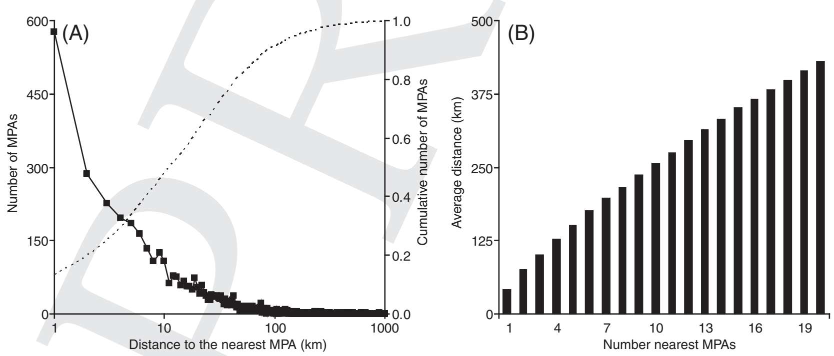

Figure 13.4 Protection of connectivity in the global network of marine protected areas. Plot (A) depicts the distance between any MPA and its nearest MPA in the global network of MPAs. Plot (B) depicts the global average distance from any MPA to increasingly higher numbers of nearby MPAs.

the ones at which their propagules can connect them. In other words, the entire metapopulation dynamics expected from MPAs alone may be endangered due to low connectivity resulting from distant MPAs (Kritzer and Sale, 2006).

13.3.3 Habitat suitability inside the network of marine protected areas

There are a large number of human threats such as pollution, invasive species, ocean warming, acidification, and many others that are hard to regulate as part of the management plan of an MPA (Aronson *et al.*, 2003; Birkeland, 2004; Jameson, 2006). Unfortunately, many of these threats can have deleterious effects on the viability of populations, including extinction (Myers, 1995; Walther *et al.*, 2002; Aronson *et al.*, 2003; Parmesan and Yohe, 2003; Perry *et al.*, 2005; Halpern *et al.*, 2007; Hoegh-Guldberg *et al.*, 2007; Mora *et al.*, 2007; Portner and Knust, 2007; Caitlin Mullan *et al.*, 2008). Consequently, populations can still be vulnerable and possibly at high risk of extinction inside even well-managed MPAs or where threats of fishing and habitat loss are minimum (Jones *et al.*, 2004; Graham *et al.*, 2006; Coelho and Manfrino, 2007; Monaco *et al.*, 2007; Graham *et al.*, 2008; Russ *et al.*, 2008). To provide a global overview of this problem, I overlapped the MPAs of the world with the recent Ocean Human Footprint developed by Halpern *et al.* (2008), which combined a variety of human threats into a single score. According to this analysis, over 70% of the MPAs in the world are in areas of high human impact (i.e., over areas with human footprint scores larger than 12: see Halpern *et al.* [2008])(Figure 13.5). Clearly, the possible imperilment of populations inside MPAs due to threats other than fishing and habitat loss are significant worldwide. Unfortunately, the extent of human threats, other than fishing, is very pervasive in the oceans worldwide, which certainly reduces the areas of the ocean where MPAs can be minimally affected by such threats (Halpern *et al.*, 2008).

13.4 Human imperilment of marine protected areas

Humans play a critical role in the biological success and management viability of MPAs. Human populations on the edges of MPAs can increase the chances of conscious (i.e., poaching) and unconscious intrusions inside MPAs, which cause mortality of populations inside MPAs (Kritzer, 2004). Even if MPAs are strongly enforced, fishing pressure

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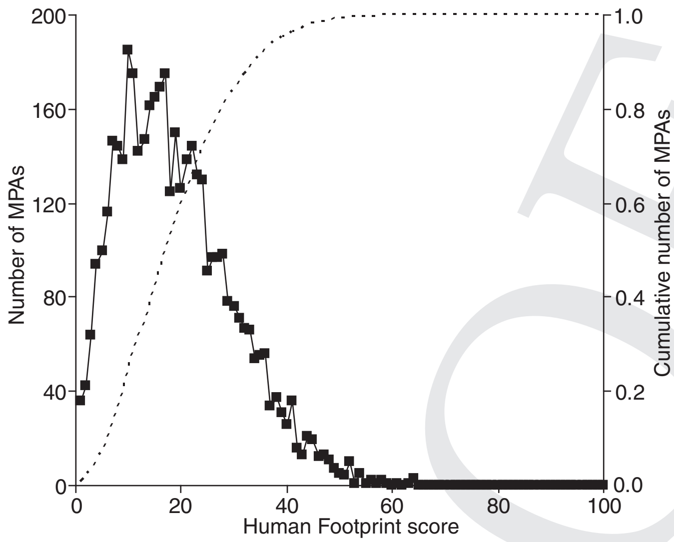

Figure 13.5 Suitability of habitats inside the global network of marine protected areas. Here I show the frequency distribution of MPAs along the gradient of combined human stressors. As measure of combined human stressors, I used the original data of the Ocean Human Footprint score developed by Halpern *et al.* (2008). The human footprint inside each MPA was determined by overlapping the MPAs of the world with the human footprint and calculating the mode score inside each MPA. Some of the threats considered in the Halpern *et al.* (2008) footprint include climate change, ocean acidification, invasive species, pollution, and overfishing.

outside MPAs can create density gradients inside MPAs (Kramer and Chapman, 1999) and possibly cause extinction due to edge effects (Woodroffe and Ginsberg, 1998). Conflicts between MPA objectives and local residents can reduce compliance with MPA regulations, which can increase poaching (Kramer and Chapman, 1999; Christie *et al.*, 2003; Christie, 2004), or alternatively increase the operation cost of surveillance of the MPA (Balmford *et al.*, 2004). As indicated, there are different effects on MPAs that can be triggered by the effects of human settlements inside or around the borders of MPAs. Although we lack a direct quantification of these issues for each MPA globally, the number of people inside or around MPAs provides a suitable proxy for their likely effect on MPAs. To provide a global overview of the likely difficulty of managing MPAs due to human settlements, I overlapped the global network of MPAs with the gridded Human Population of the

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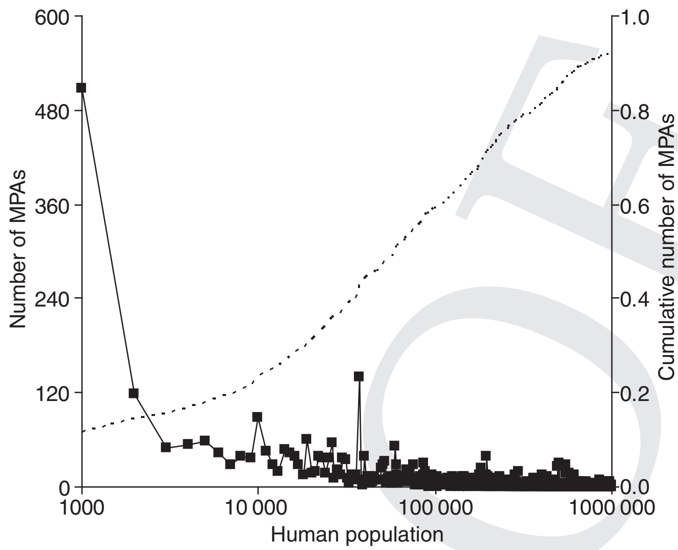

Figure 13.6 Likely imperilment of marine protected areas by humans. Here I show the frequency distribution of MPAs by the number of people in or around their borders. As mentioned in text the number of people was used as proxy for the different effects that humans can have on the biological and management effectiveness of MPAs. Some of these effects may include poaching, increases in the surveillance cost of the MPAs, and/or harvesting outside the borders of MPAs, which could create density gradients in protected populations inside MPAs. For this analysis I created a 50-km buffer around each MPA and then calculated the maximum number of people found inside the MPA as well as its buffer. Data on human population were obtained from Gridded Population of the World, version 3 (http://sedac.ciesin.columbia.edu/gpw/).

World (http://sedac.ciesin.columbia.edu/gpw/) to quantify the number of people living inside or around each MPA. Caution: it is certainly possible that the mechanistic effects of the number of people on MPAs may vary due to different social and economical backgrounds, but the net results may be very similar. For instance, in poor communities, fishing can be used as a source of food and income, in which often labeled as "artisanal fishing." In richer communities, the same fishing can be used as a source of recreation, in which is named "recreational fishing." Interestingly, the extent of these two types of fishing almost balance each other out when comparing fishing in poor and rich countries (Mora *et al.*, 2009). Worldwide there are only 136 MPAs located in areas where no humans are located within a 50-km radius of their borders. For the rest of

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the MPAs, human population density averages 308 940 people per cell of 25 × 25 km, although they are almost evenly distributed along the entire gradient of human density (Figure 13.6). Clearly, humans pose a significant challenge to the management of MPAs worldwide and this is only likely to worsen given the expected major increase in the world's human population in the coming few decades (e.g., the United Nations Global Human Population Prospects: http://esa.un.org/unpp/).

13.5 Concluding remarks

Marine protected areas are created for different purposes, including the protection of species under imminent risk of extinction, protection of unique habitats, and enhancement of local fisheries. Under many of these circumstances, MPAs are an immediate and practical solution and although they may provide an umbrella effect for the protection of overall biodiversity, it is clear that the escalation of this strategy with the aim of protecting global marine biodiversity is unrealistic. The results presented in this chapter reveal the still limited coverage of the world's oceans by MPAs, the failure to warrant the viability of most metapopulations, and the increasing challenge of MPA success given the pervasive distribution of the human population on coastal areas. While increasing funding for the deployment of new MPAs and improvement of existing ones remains a possibility, the reality is that MPAs have been largely operating at a loss (e.g., the deficit for the adequate operation of existing MPAs is calculated at 44.8%: Balmford *et al.*, 2004) and this situation is only likely to get worse given the current global economic crisis. At the global scale, a concerted effort to reduce the extent of human impacts, which are likely to be related to the increasing size of the human population and its excessive use of natural resources (Wackernagel *et al.*, 2002; Kitzes *et al.*, 2008), is likely to provide a more ultimate solution to a variety of human stressors including those not controlled by MPAs. Achieving this will require ecologists to re-evaluate our view of the role of MPAs in protecting global marine biodiversity and our recommendations when it comes to protecting the world's ocean biodiversity.

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