ECOLOGY

Coral Reefs and the Global Network of Marine Protected Areas

Existing marine reserves are largely ineffective and as a whole remain insufficient for the protection of coral reef diversity.

Camilo Mora,[1,2]* Serge Andréfouët,[3] Mark J. Costello,[1] Christine Kranenburg,[4] Audrey Rollo,[1] John Veron,[5] Kevin J. Gaston,[6] Ransom A. Myers[2]

Coral reefs worldwide are suffering massive declines in their diversity in response to human activities (*1*, *2*). The accelerating decay of this and other marine and terrestrial ecosystems has motivated multinational efforts to reduce biodiversity loss such as the 2002 World Summit on Sustainable Development (*3*) and the 2003 World Parks Congress (*4*). The latter recommends that 20 to 30% of all major ecosystems should lie within strictly protected reserves by 2012 (*4*).

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Protected reserves should reduce pressure from harvesting and other human activities, which should in turn facilitate the ability of species to cope with natural disturbances (*5*–*7*). Although much discussion has surrounded the success of protected areas at small spatial scales (*7*), little evaluation has been done at the global scale (*5*, *8*). Here we provide a global assessment on the extent, effectiveness, and gaps in the coverage of coral reefs by Marine Protected Areas (MPAs).

A major challenge to quantifying the extent of coverage of any ecosystem by a network of MPAs is the dynamic nature of the network itself and of information about it. To address this problem, we built a database of coral reef MPAs for every country (*9*), contacted local managers and researchers, and used recent published reports (*2*, *10*, *11*) to ensure that verification was available for each country. This process resulted in the deletion of 521 MPAs from a previous standard list, and the addition of 157 further MPAs. The final verified database contains 980 MPAs and covers 98,650 km^2 (18.7%) of the world's coral reef habitats. We will provide general conclusions in the text; detailed methodology and data can be found in the supporting online material.

[1]Leigh Marine Laboratory, University of Auckland, Post Office Box 349, Warkworth, New Zealand. [2]Department of Biological Sciences, Dalhousie University, Halifax, NS, Canada, B3H 4J1. [3]Institut de Recherche pour le Développement, Boite postale A5-98848, Noumea cedex, New Caledonia. [4]Institute for Marine Remote Sensing, University of South Florida, St. Petersburg, FL 33701, USA. [5]Australian Institute of Marine Sciences, Townsville 4810, Australia. [6]Biodiversity and Macroecology Group, Department of Animal and Plant Sciences, University of Sheffield, Sheffield, S10 2TN, UK.

*Author for correspondence. E-mail: moracamilo@hotmail.com

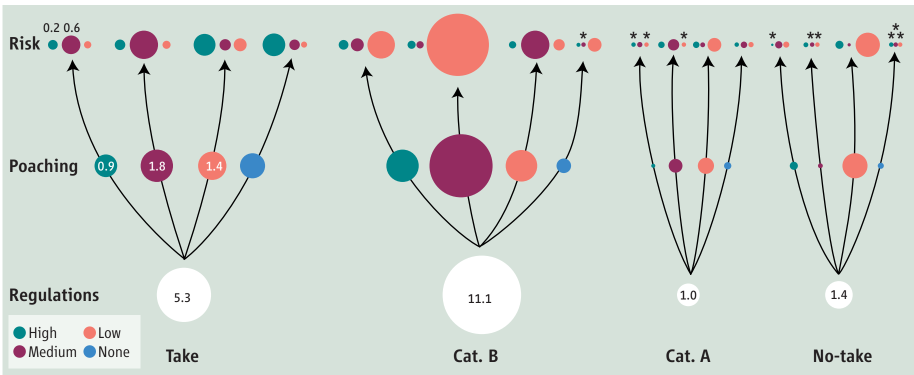
Protected areas are managed for different purposes, and, therefore, this protection can have varied effects on particular taxa. Growing evidence for coral reefs suggests that their resilience is strongly dependent on the presence of a range of functional groups, including large herbivorous and predatory fishes (*1*). Consequently, those areas used for harvesting may be of limited benefit (*1*, *7*). Of the world's roughly 527,072 km^2 of coral reefs, 5.3% lie inside extractive MPAs, 12% inside multipurpose MPAs, and 1.4% inside no-take MPAs (see figure, this page). Regional coverage of coral reefs by multipurpose and no-take MPAs ranges from 69% in Australia, to 7% in the central Pacific and western Indian Ocean, to ~2% in the central Indian Ocean (fig. S1A, table S1).

Each year over the past 10 years, about 40 new MPAs have been created worldwide that include coral reefs (fig. S2A). Unfortunately, the establishment of MPAs is rarely followed by good management and enforcement (*10*, *11*), which means that the numbers of MPAs and their coverage can be misleading indicators of effective conservation. Using levels of poaching as an indirect measurement of management performance (*9*), we found that only 88 coral reef MPAs (fig. S1B), covering 1.6% of the world's coral reefs (table S1), are managed in such a way as to prevent such activities. Less than 0.1% of the world's coral reefs are within MPAs classified as no take with no poaching (see figure, this page). Management performance varies worldwide but, troublingly, it is particularly low in areas of high coral diversity such as the Indo-Pacific and the Caribbean (fig. S1B, table S1) (*10*, *11*).

MPAs are specifically intended to limit human activities at particular locations. However, many coral reefs still remain vulnerable to risks that arise from beyond their boundaries, such as sedimentation, pollution, coastal development, and overfishing (*7*, *12*). Using a risk index of these threats (*9*), we found that 147 coral reef MPAs (fig. S1C), covering almost 10.8% of the world's corals (table S1) are at low risk from such threats. Less than 0.01% of the world's corals are within MPAs defined as no take with no poaching and at low risk (see figure, below).

One of the main impacts of effective MPAs on marine organisms is the prevention of harvesting, which reduces mortality and which, in turn, should generate larger body sizes, increases in abundance, and greater fecundity (*6*, *7*). However, populations can also be influenced by the movement of their individuals (*6*). Extensive movement can expose juvenile and adult individuals to harvesting outside the boundaries of the MPAs (*6*, *7*, *13*), whereas the arrival of new recruits can be favored if source populations are protected (*6*, *14*). Therefore, the scales of adult movement and propagule dispersal can be critical to the effectiveness of an MPA network (*6*, *7*).

Data on species' home ranges is improving, particularly for coral reef fishes (*13*). Although, for most species, home ranges are small (<1 km^2), for large herbivorous and predatory fishes,



Effectiveness of the global network of coral reef MPAs. The area of coral reefs covered by the network of MPAs (18.7% of the world total) was classified by their regulations on extraction as either no take, take, or multipurpose. Multipurpose MPAs were divided into those that prohibit commercial harvesting (category A) and those that do not (category B). The subdivision of reefs on each of those MPA categories was then analyzed according to attributes of poaching and risk (according to the combined threat risk index described above). Sizes of circles indicate percentage of world coral reef area; in a few cases, numbers are shown within the circles to indicate sizes and method of subdivision. Asterisks indicate percentages smaller than 0.01.

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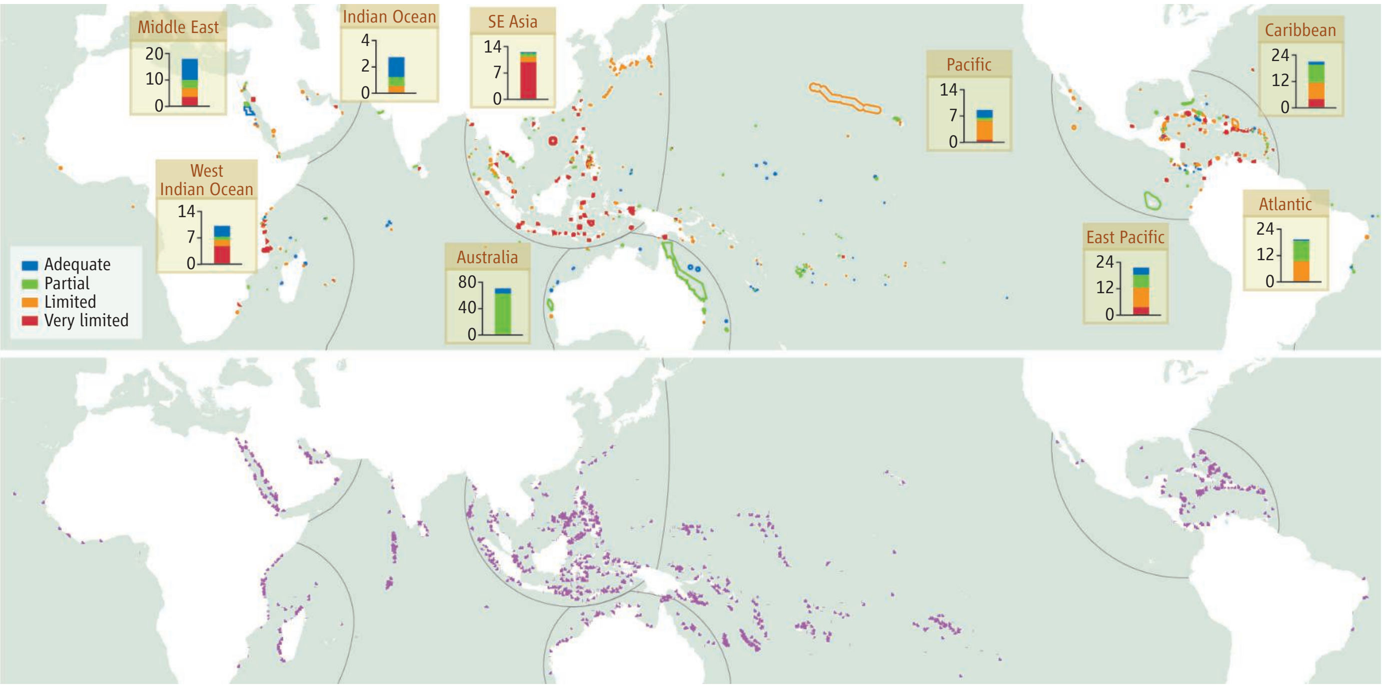

Conservation of MPAs. (**Top**) Status of the global network. Location and shape of all 980 MPAs are shown. Categorization of MPAs was based on the average of the attributes analyzed (*9*). The percent of coral reefs per region covered by MPAs in those categories is shown on the bar charts. (**Bottom**) MPAs needed for an optimum coverage of the world's coral reefs. Dots represent MPAs of 10 km^2 and spaced at 15 km from each other.

which are often the targets of fishermen, these can cover several square kilometers (*6*, *7*, *13*). About 40% of the areas in the current global network of coral reef MPAs are smaller than 1 to 2 km^2 (fig. S2B). This suggests that in a large portion of the network, vagile, and usually also key, species can be lost directly to harvesting because they can move beyond the boundaries of small MPAs. Such losses can also trigger negative indirect effects on resilience of coral reefs through trophic cascades (*1*).

Propagule dispersal in coral reef organisms may be on scales on the order of a few tens of kilometers (*6*, *14*, *15*). Thus, it has been recommended that MPAs should be 10 to 20 km in diameter and/or in spacing from each other to ensure exchange of propagules among protected benthic populations (*14*). At the global scale, there are only a handful of MPAs sufficiently large to accommodate such dispersal within their boundaries (fig. S2B), while their average spacing (63 km) is too broad for this network to be functional in this regard (fig. S2C). Given the scattered distribution of coral reefs, an optimum global network of MPAs, each 10 km^2 in area [to protect the "neighborhood" of a broad group of vagile species (*6*)] and spaced 15 km apart from one another [to ensure "safe" levels of larval connectivity (*14*)], would require 2559 MPAs in addition to those that already exist (see figure, this page, top). These results suggest a major need for expanding and establishing new MPAs. This expansion of MPAs only requires the protection of 25,590 km^2, or ~5% of the world's coral reefs distributed over a sparser network.

The different attributes of MPAs discussed so far are likely to interact to different extents in determining the overall effect of a given MPA. Finally, we combined all the attributes analyzed in this study (i.e., regulations on extraction, poaching, external risks, MPA size, and MPA isolation) into a single index of overall conservation status (*9*). From this, we found that only 2% of the world's coral reefs are within MPAs that combine adequate conditions of the analyzed attributes. No one regional network covers more than 10% of its regional coral reefs within MPAs with such quality (see figure, page 1750, and table S1). Our analysis of the performance of the global network of MPAs in protecting coral reefs reveals that this network is very inefficient.

We have identified major discrepancies between the quantity and the quality of efforts invested toward minimizing biodiversity loss in coral reefs. Even if all existing coral reef MPAs are considered effective, as a whole, it is troubling that they are still insufficient for the global protection of coral reef diversity. Recent studies have also indicated important gaps in the global coverage of terrestrial vertebrates by protected areas (*8*); our analysis suggests that these shortcomings are worse than previously anticipated if the effectiveness of protected areas is taken into account. Given the current worldwide decline of coral reefs (*1*, *2*), our report highlights the serious vulnerability of this ecosystem and the need for immediate reassessment of global-scale conservation strategies.

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