Placing marine protected areas onto the ecosystem-based management seascape

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The rapid increase in the science and implementation of marine protected areas (MPAs) around the world in the past 15 years is now being followed by similar increases in the science and application of marine ecosystem-based management (EBM). Despite important overlaps and some common goals, these two approaches have remained either separated in the literature and in conservation and management efforts or treated as if they are one and the same. In the cases when connections are acknowledged, there is often little assessment of if or how well MPAs can achieve specific EBM goals. Here we start by critically evaluating commonalities and differences between MPAs and EBM. Next, we use global analyses to show where and how much no-take marine reserves can be expected to contribute to EBM goals, specifically by reducing the cumulative impacts of stressors on ocean ecosystems. These analyses revealed large stretches of coastal oceans where reserves can play a major role in reducing cumulative impacts and thus improving overall ocean condition, at the same time highlighting the limitations of marine reserves as a single tool to achieve comprehensive EBM. Ultimately, better synergies between these two burgeoning approaches provide opportunities to greatly benefit ocean health.

cumulative impacts | fisheries | global | no-take reserves | ocean health

Marine protected areas, including no-take marine reserves, have become key ocean conservation strategies around the world, with most nations agreeing to commitments made at the World Summit on Sustainable Development in 2002, the fifth World Parks Congress in 2003, and the eighth Conference of the Parties (COP 8) in 2006 to set aside 10–30% of their waters in MPAs by 2012 (1). Although few countries have yet to come close to meeting these goals (1), local and federal governments and conservation organizations around the world have already created or are in the process of creating hundreds of new MPAs. Interest in using MPAs as a conservation strategy is supported in part by a growing body of science showing the conservation benefits from no-take reserves (2, 3), and made more urgent by the increasing recognition of the dire condition of most of the world's oceans (4, 5). Despite the success of these efforts, it is also clear that MPAs are only part of the solution to protecting and restoring ocean health. MPAs cannot address all of the existing and emerging threats to marine systems, most notably land-based sources of pollution and threats from global climate change, nor can they achieve all management goals. MPAs typically support a single societal value—conservation—although they are also commonly established with the aim of benefiting fisheries. There is a growing range of objectives for ocean use and protection that extends beyond conservation and fisheries, and these different perspectives need to be included in management plans. In particular, we need to ensure that human well-being is part of our definition of ocean health if marine conservation is going to be effective in the long term.

In response to the increasing diversity and intensity of ocean uses and associated impacts, and the recognition that we need to more carefully and explicitly include human dimensions in our efforts to understand and manage the oceans, there has been a recent push toward ecosystem-based management (EBM) (6–8). Emerging from this development are numerous variations on the EBM theme, including area-based management, ecosystem-based fisheries management (EBFM), marine spatial planning, and ocean zoning, among others. Area-based management approaches encompass a wide range of tools, from no-take reserves and other types of MPAs, which focus primarily on restricting use for conservation or fisheries management purposes, to comprehensive marine spatial planning and ocean zoning, which account for both protection and multiple-use objectives. EBM and EBFM often include some area-based components, but can also include nonspatial regulations such as permits. More often than not, existing conventional management efforts lack a holistic focus on the breadth of activities and the range of ecosystem services that we seek from a particular place (9), and thus do not offer a path forward for EBM, much less integrate MPAs within a larger EBM framework.

This division between MPA and EBM science and implementation can be traced in part to the trajectories of the two concepts in time and the historical separation of biodiversity conservation from resource management (multiple use or otherwise). Peer-reviewed research on MPAs and marine EBM has rapidly increased in the past 15 years, with a 10-year lag in marine EBM research, yet the combined treatment of the topics is relatively sparse (Fig. 1). Furthermore, of those scientific papers addressing both management topics, many are actually focused on just one of the two topics—most commonly MPAs or marine reserves—and make only passing mention of the other. Thus, many researchers acknowledge the important connection between MPAs and EBM, but this offers little concrete guidance on how to use MPAs within an EBM context.

We expect there is much to be learned and gained through a direct comparison of the science and implementation of EBM and MPAs. Here we explore the role and limitations of marine reserves and other types of MPAs in achieving a key EBM goal—reducing cumulative impacts. Specifically, we aim to provide scientific guidance regarding the use of MPAs within an EBM approach and evaluate the potential for marine reserves to achieve specific EBM goals at global and regional scales, creating new bridges between these concepts.

Results

Comparing and Contrasting MPAs and EBM. The overarching goal of EBM is to sustain the long-term capacity of marine ecosystems to deliver a range of ecosystem services, such as seafood, clean water, renewable energy (e.g., wave, tidal, and biofuels), protection from coastal storms, and recreational opportunities, with a focus on both ecosystem health and human well-being (10, 11). Accordingly, management at any particular location will have many goals, and a key aspect of EBM is to explicitly assess the necessary tradeoffs in achieving multiple, often competing, goals. EBM aims to consider the range of services that people care about and require from a particular ecosystem, the range of factors affecting the production and delivery of those services, and acknowledge connections between the focal

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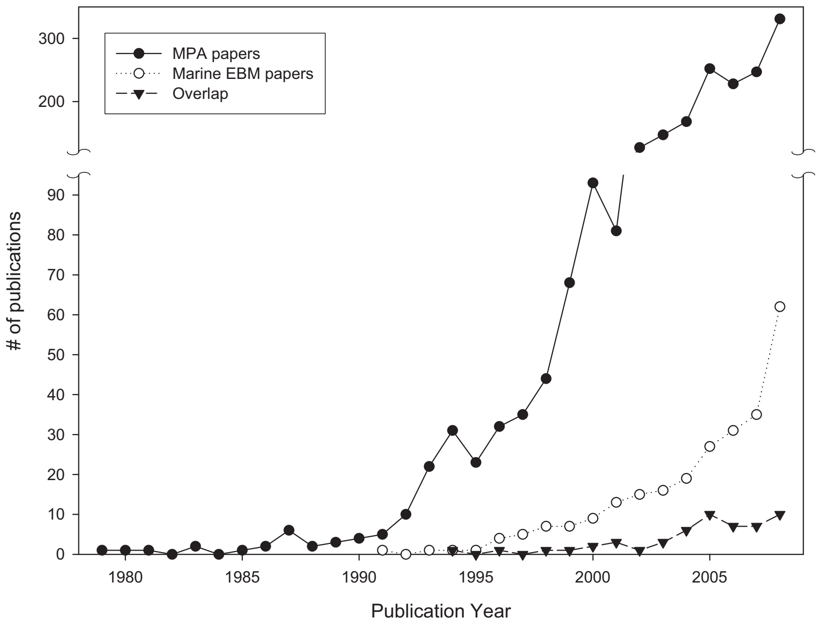

Fig. 1. Number of publications per year on MPAs or marine EBM, up until 2008, indexed on ISI Web of Science using a topic search. See *Methods* for search criteria. Note *y* axis break at 100 publications.

scale of management and both larger and smaller scales (i.e., management boundaries are ecologically "leaky"), including connections with upland ecosystems (12). Managing individual ecosystem services in isolation ignores the inherent synergies and tradeoffs among them.

This holistic focus of EBM represents an important distinction from the typical approach and intent of MPAs. Most commonly, MPAs are designed to exclude or limit some types of fishing and, in the case of no-take reserves, prohibit all fishing and extractive or destructive activities, except as necessary for scientific monitoring (13). Such a focus on limiting a single sector (fishing) and enhancing a single or possibly two objectives (biodiversity conservation and/or fisheries) is a small subset of what EBM is intended to address. Yet despite these differences, there is common ground between MPAs and an EBM approach, and potential for large overlap in scope and goals depending on the nature of the system being managed. All MPAs share the overarching goal of being designated to protect all or part of a particular ecosystem (14), and besides their primary objectives of sustaining fisheries and enhancing conservation, they can also be focused on preserving areas of cultural significance, protecting the aesthetic integrity of the system for recreation, tourism, or existence value, or promoting research and education (15). Furthermore, it is now widely recognized that MPAs need to be designed to address social and economic considerations as well as conservation goals, because without attention to socioeconomic issues, MPAs are less likely to succeed in the long run (16, 17).

The roles of MPAs within an EBM approach will depend on the spatial extent and type of stressors that need to be addressed by management. When the dominant stressors to a system are local scale and spatial in nature (e.g., fishing, energy extraction, shoreline modification), then MPAs are capable of mitigating those stressors and can be an effective management tool, albeit still not equivalent to EBM. However, such cases may not be common, and even in the best case scenario MPAs can address only a subset of EBM goals, primarily those dealing with extractive activities. As stressors become larger scale (i.e., external to the management area) or nonspatial (e.g., land-based pollution and climate change), MPAs alone will not be able to ensure the sustainable delivery of ecosystem services from a region or address the full range of uses, and therefore will be unable to meet all EBM goals.

The connections between MPAs and ecosystem-based fisheries management (EBFM) are more straightforward than those with a more comprehensive EBM approach. EBFM incorporates ecosystem considerations such as bycatch, trophic interactions, and habitat and climatic variation into decision making (18), and in this context MPAs have been recommended as a useful tool for rebuilding overexploited stocks (or acting as an insurance policy against overexploitation), protecting habitat, maintaining ecosystem functioning, buffering against environmental variability, protecting genetic diversity, providing reference points for conducting stock assessments and setting harvest limits, and serving as a precautionary approach to management (19–22). However, even in the case of fisheries, a single management sector, MPAs are most likely to be useful when embedded in a broader, multisector management plan. This is because, as noted previously, MPAs cannot be isolated from many of the activities and impacts occurring outside their boundaries. Thus, MPAs will be most successful at meeting fisheries (or other sector) goals when there is some degree of coordination among the management entities responsible for fisheries, coastal development, run-off and wastewater discharge into coastal waters, coastal and offshore oil and gas extraction, wave energy, mariculture, and shipping.

Though MPAs certainly fill important roles both for fisheries management and conservation, they cannot be viewed as a cure-all for all that ails ocean ecosystems. Given that MPAs vary so greatly in the intensity and types of activities permitted, it is not possible to make generalizations about the ability of MPAs to meet specific goals, let alone help to achieve the varied goals of comprehensive EBM. The success of MPAs in meeting EBM goals, and specifically in reducing cumulative impacts, will depend on the intensity and types of human activities occurring at a location, the nature and level of enforcement of regulations within the MPA, which species are affected by protection, and the values and goals of the human communities that use the marine resources from the location, among other factors. For example, not all species will benefit from MPA protection, particularly in the case of more mobile or migratory species (23). Additionally, effective enforcement and compliance are often problematic (15, 24). Though MPAs have been shown to result in positive ecological changes within their borders (e.g., ref. 25) and benefit nearby fisheries (26, 27), they may not always produce the same magnitude of effect as no-take marine reserves (28). Yet, the ability of no-take reserves to meet EBM goals will also depend on many of the same factors as MPAs. At present, MPAs and, particularly, no-take areas, represent a very small percentage of the global ocean (1, 29), suggesting that activities outside MPAs are likely to swamp the effects of protection in many cases.

Importantly, even if much larger portions of the global ocean were protected within MPAs, many EBM goals would remain unfulfilled (e.g., balancing multiple human uses and explicitly assessing tradeoffs among objectives). Furthermore, activities such as fishing may often be merely displaced, not reduced, by MPAs (15, 30), potentially leading to a more degraded ecosystem in unprotected waters. Such tradeoffs are beginning to be recognized and included in MPA network design (Gaines et al., in this issue of PNAS) and are an essential consideration if MPAs are to play a larger role in EBM. Lastly, if MPAs are not designed as part of a more comprehensive management plan, conflicts among different human uses or between use and conservation may often arise (15).

Unfortunately, there has been a tendency for marine EBM and MPA planning to be used interchangeably, reflecting a broader phenomenon of assuming the two are effectively synonymous. In other words, researchers, managers and conservation planners will refer to an MPA planning process as an EBM planning process, even if many of the goals and principles of EBM are not taken into account. This may in part derive from EBM being a "buzz word," and thus the focus of funding opportunities, policy agendas, and scientific meetings. Furthermore, many managers are being tasked with implementing EBM, but until quite recently there was very little practical scientific guidance on how to apply this approach (12, 31–33). As a result, MPAs are an easy fallback, with the argument that EBM is a place-based approach to management, and MPAs are a spatial management tool. When MPA planning processes are embedded within a larger marine spatial planning process, as in the case for the zoning of Australia's Great Barrier Reef Marine Park (34), these processes begin to converge on EBM. Such efforts remain rare, however, and there is risk in letting the misconception persist that MPA and EBM planning are one and the same.

Can MPAs Achieve Specific EBM goals? Because so few MPAs have been designed within the context of an EBM approach, or monitored to assess how they are affecting a range of ecological and socioeconomic factors, it is difficult to draw on empirical data to answer the question posed in the title of this section. There does not exist, to our knowledge, an explicit evaluation of whether existing MPAs are achieving specific EBM goals. However, we can infer the answer: on a global or regional scale, it is unlikely that existing MPAs are playing a significant role in advancing EBM because there simply are not enough, in number or in size, to ensure the long-term sustainable delivery of the full suite of marine ecosystem services. Globally, MPAs comprise only 1.6% (and no-take reserves, 0.2%) of the area within exclusive economic zones (1). When examining the representativeness of this protection by biogeographic classifications, an imbalanced picture emerges, further revealing the limitations of existing MPAs. Half of all ecoregions have less than 1% of their waters protected, and only 18% of ecoregions have MPA coverage that exceeds 10% (35). Similar results are seen in more local scale case studies. For example, in Hawaii, an emerging MPA network is part of an attempt to move toward a more ecosystem-based approach to management, but these MPAs do not currently protect a significant portion of the coast (36). Of course, though increasing the extent and representativeness of MPAs will help to limit cumulative impacts in the oceans, even a perfectly designed network of global MPAs cannot replace the need for a more comprehensive EBM approach. In particular, MPAs cannot directly address the many external stressors to a system, such as land-based sources of pollution and climate change, or those that do not have a clear spatial or consumptive component, such as marine invasive species.

Similarly, it is difficult to find empirical data on EBM efforts that include MPAs that could be used to assess how important MPAs are for meeting EBM goals. There are many places around the world that are working toward EBM, and many are using MPAs as a key management tool. However, most of these case studies are nascent, and thus more time is required to adequately assess whether MPAs are effective for achieving specific EBM goals, such as the reduction of cumulative impacts. For example, along the coast of California, a statewide network of MPAs is being established under the Marine Life Protection Act (37), paralleling an effort to move the state toward marine EBFM and EBM as articulated in the state's Marine Life Management Act and the California Ocean Protection Act (38, 39). The ecological benefits of some of these areas are already being demonstrated (Hamilton et al., in this issue of PNAS), but there has yet to be adequate time to assess whether these areas advance broader ecosystem goals. A more advanced example is the Great Barrier Reef Marine Park, which has adopted a sophisticated and extensive marine zoning scheme. In this case, socioeconomic evaluations are being coupled with ecological assessments to truly evaluate the role of these MPAs in achieving some EBM goals (McCook et al., in this issue of PNAS). The Great Barrier Reef Marine Park Authority successfully developed and used MPAs within this broader planning context, but that must be at least partially attributed to the comprehensive zoning of the park as a whole. The lessons from this region will be incredibly useful as other regions around the world consider comprehensive ocean zoning.

Given the absence of more extensive case study examples, we evaluate the potential for MPAs, specifically no-take marine reserves, to achieve the EBM goal of reducing cumulative impacts, assuming (*i*) reserves are designed and implemented within an EBM framework and (*ii*) the cumulative impact of human activities serves as a reasonable surrogate for ocean health. As we have discussed, where fishing is a dominant driver of overall ocean health, marine reserves should be able to more effectively contribute to meeting specific EBM goals. We estimate ocean condition and the relative contribution of fishing to that condition by assessing the current cumulative impact of human activities (i.e., the sum effect on ecosystem condition resulting from overlapping human uses) (4) and calculating the change in cumulative impact when hypothetical MPAs are established. For simplicity, we focus on no-take reserves where all fishing is prohibited. When calculating the percent of the cumulative impact on ocean condition contributed by all types of fishing, we found large areas where fishing (artisanal and commercial) is responsible for more than 50% of the overall impact (Fig. 2). These areas are primarily in nearshore coastal regions, and greatest in the South and East China Seas and much of the Coral Triangle, the waters off of Argentina, and the North, Norwegian, Bering, and Okhotsk Seas. In some patches within these regions, fishing contributes to more than 80% of the cumulative impact on ocean health. By diminishing cumulative impacts within their boundaries, well-designed and enforced no-take reserves in these regions could dramatically improve overall ocean health and likely enhance the delivery of a suite of ecosystem services.

To better explore among- and within-region variation in the extent to which no-take reserves might contribute to EBM goals, we also calculated the percent change in overall cumulative impact within each marine ecoregion (40) when setting aside increasing amounts of the region in marine reserves. To provide a sense of the range of possible outcomes, we evaluated two scenarios for each ecoregion assuming that increasing amounts (in 5% increments) of the area of the ecoregion are included in reserves. Under the first scenario, we enclosed the areas with the greatest impact from fishing; under the second scenario we enclosed the areas with the least impact from fishing. We found that among ecoregions, marine reserves can play highly variable roles in improving ocean health and therefore in helping to meet specific EBM goals (Fig. 3 *A* and *B*). Because some ecoregions experience relatively minimal impacts from fishing, the range of possible outcomes, even with 100% closure to fishing, includes very minimal change in overall cumulative impact. In contrast, some ecoregions are dominated by fishing impacts, such that setting aside 10–30% of the area can improve overall ocean health by reducing total cumulative impact up to 15–20%, and setting aside larger proportions of the area could

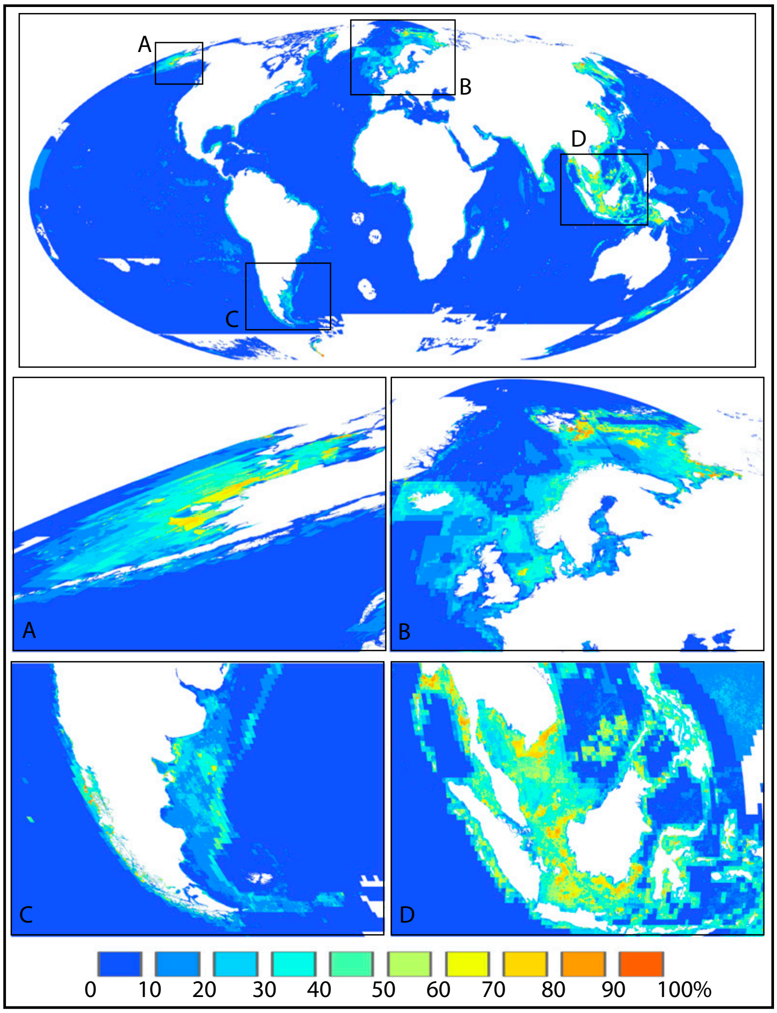

Fig. 2. The percent contribution of six types of fishing to cumulative impact scores. The cumulative impact of all fishing was divided by the cumulative impact of 17 human activities (including fishing) to illustrate where MPAs are more likely to significantly contribute to meeting EBM goals. Insets show zoomed-in views of four regions where fishing plays a particularly large role in driving overall cumulative impact.

improve ocean health by up to 50% (Fig. 3 *A–D*). Furthermore, it is possible that these predicted improvements in ocean health are underestimates for cases where MPAs are designed to act as networks, where connections among reserves could help rebuild populations and ecosystems faster or to a greater extent than MPAs designed solely based on local conditions (in our case, local levels of cumulative impact).

The degree of spatial variance in fishing impacts differs markedly across ecoregions (Fig. 3 *E* and *F*), such that the strategies of enclosing areas with the least versus greatest impact from fishing can produce dramatically different outcomes (when fishing impacts are highly variable across space, as in the Black Sea; Fig. 3*C*) or much more similar results (when fishing impacts are relatively uniform across space, as in the South China Sea; Fig. 3*D*). The shapes of these curves also provide valuable guidance on how much area needs to be set aside in reserves to efficiently reduce impacts to ocean health. In the Black Sea ecoregion, if one were to focus on setting aside the most impacted areas, 20–30% of the area within marine reserves would nearly maximize the possible improvement in ocean health. In contrast, in the South China Sea ecoregion there is a nearly linear increase in the improvement in ocean health with increasing area set aside in reserves. Importantly, within-ecoregion variation in the cumulative impact from fishing leads to much greater differences in scenario results (greatest versus least impacted areas placed into no-take reserves) when enclosing 30% of each ecoregion compared with enclosing only 10% (Fig. 3 *E* and *F*). As we move toward greater amounts of area being placed into MPAs, the placement of those MPAs becomes much more important if we aim to more effectively reduce cumulative impacts. This is particularly true for the ~20 ecoregions that show >10% difference between the two scenarios (Fig. 3*F*).

Discussion

Results from our scenario analyses suggest that marine reserves can play a key role in achieving the broader goals of EBM in many regions of the world. However, reserves are not synonymous with EBM and in no case will be entirely sufficient to achieve all EBM goals. A critical assumption of our analyses is that the reduction in cumulative impact resulting from establishing these hypothetical marine reserves would significantly improve ocean health and in turn lead to increases in the production of a suite of ecosystem services. This is likely the case in areas where fishing is the major contributor to the cumulative impact score and where fishing and fishing-related impacts (e.g., habitat damage from destructive fishing practices and bycatch of nontarget species) are compromising the ability of the ecosystem to produce diverse ecosystem services. Yet, even these locations likely experience some impacts from other anthropogenic stressors that would require additional management tools. Currently there are no empirical data to suggest how common or rare such fishing-dominated instances are, but it is a reasonable assumption in cases where fishing methods significantly alter habitat structure (e.g., dynamite fishing and most bottom-trawling), and such fishing methods are widespread (4, 41). A true test of these assumptions would require social and economic impact assessments to demonstrate that a reduction in cumulative

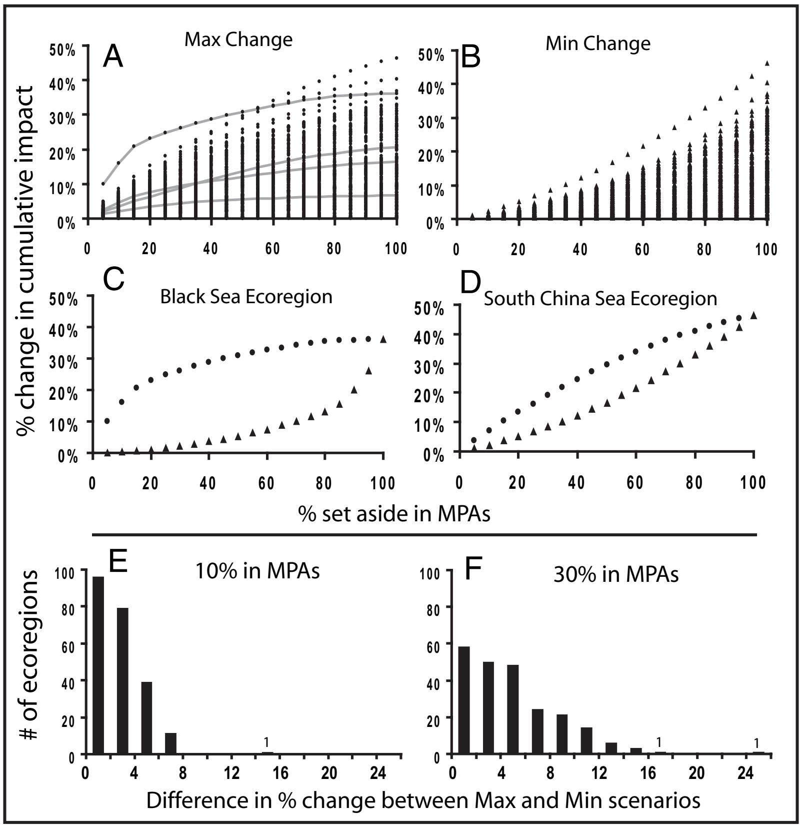

Fig. 3. Change in ecoregion-scale cumulative impact under different portions of area are set aside in no-take reserves (i.e., all fishing is prohibited within those areas). In each of 232 ecoregions (identified by each point), scenarios were analyzed with the portions of the region with the greatest (*A*) and least (*B*) impact of fishing were converted to no-take reserves. Results for four example ecoregions are connected with gray lines (*A*) to illustrate different shapes and magnitude of change with increasing proportion of no-take reserves. (*C* and *D*) Results for two specific ecoregions illustrate differences when no-take reserves are designed to include the greatest (circles) and least (triangles) impacted areas. (*E* and *F*) Histograms show the difference in the change in total cumulative impact between the scenarios where no-take reserves are placed in the areas with greatest and least impact from fishing within each ecoregion, at 10% (*E*) and 30% (*F*) total area set aside in no-take reserves. Histogram bars with a single ecoregion are noted with "1" to aid in identification.

impact significantly increases not only the production, but also the delivery of a spectrum of services, and that these increases better support healthy human communities. In locations where these assumptions do not hold, marine reserves may make important contributions to conservation, fisheries, or other EBFM goals, but not to broader EBM goals. In particular, where fisheries are sustainable and well managed, marine reserves may lead to little benefit in ocean health while simultaneously leading to a large cost for those reliant on the fishery (i.e., for income or food). We argue, however, that evaluating MPAs in the context of their contribution to reducing negative impacts to ocean ecosystems is an important first step in viewing MPAs as a key component of EBM rather than only a conservation and fisheries management tool.

Reducing the cumulative impacts of threats to ocean health is clearly only one piece, albeit a critical one, in achieving comprehensive EBM. To be effective components of an EBM approach, these hypothetical marine reserves would need to be designed with full consideration of the changes in and tradeoffs among a suite of ecosystem services and would need to incorporate socioeconomic costs and benefits in the planning process. Furthermore, ideally we would have evaluated existing, rather than hypothetical, marine reserves. Unfortunately, as already mentioned, only 0.2% of the world's oceans are protected in no-take reserves, and thus their contribution to improving ocean condition is negligible, at least at global and regional scales. A slightly larger percentage of the world's oceans are protected within all types of MPAs, but to evaluate the role of all MPAs is far more complicated, because MPAs encompass a wide spectrum of regulations on fishing and other uses. An important avenue of future research is to determine how real MPAs are contributing to EBM goals. These types of analyses may also reveal that the connection works in both directions—not only can marine reserves reduce impacts to ocean health, but poor ocean health can limit the ability of reserves to meet their intended ecological, social, or economic outcomes. Indeed, marine reserves have been shown to produce highly variable ecological effects (3), and relatively small percentages of this variance are explained by characteristics of the species (taxonomy, life history, target status) or reserve (size, age), suggesting that the context of the reserve, including activities occurring in surrounding waters, may play an important role in determining reserve effectiveness.

As marine management becomes increasingly spatial, the issue of context is a particularly important one with respect to the roles of MPAs for EBM. Within a given region (which may vary from an individual estuary to a large marine ecosystem), EBM is an attempt to integrate the full spectrum of goals, management entities, and constituents within that region to design a management strategy that explicitly considers the necessary tradeoffs among various activities and services. At relatively small scales, such as that of an individual estuary, MPAs may not be a viable option, and instead EBM efforts must focus on the interplay among the range of objectives and host of actors in that system. At larger regional scales, EBM efforts seek to balance a wide range of objectives that will include both protection and use. For social and political reasons, reserves will likely always be relatively small, and yet it is important to focus management on large swaths of ocean space, especially as climate change becomes an increasingly powerful driver in ocean ecosystems. Thus, at larger scales, spatial management tools will need to include multiple types of areas that cover a range of objectives, from no-take marine reserves to areas in which most or all activities are permitted. One key advantage of using MPAs within the context of EBM (rather than implementing MPAs in isolation) is to deliberately plan for spatial configurations that minimize negative impacts to particularly sensitive species, habitats, or ecosystems, and minimize externalities that could reduce the effectiveness of the MPA. The concept of buffer zones around MPAs with lower levels of protection but with some limits on use is one strategy to minimize the impacts of such externalities (e.g., not allowing dredging next to a no-take reserve). As emerging uses of the oceans expand, such as wind and wave energy and offshore aquaculture, MPA planners are increasingly faced with the need to consider the potential downstream effects of these activities on MPAs.

As MPA planning processes move toward better inclusion of socioeconomic concerns and focus on larger scales, they are moving toward an EBM approach. However, MPAs can never be a substitute for EBM. Even when the goals of an EBM effort include the reduction of fishing impacts on ecosystem health, MPAs will not be adequate for addressing the cumulative impact of and tradeoffs among the full suite of benefits people want and need from ocean ecosystems. Our analyses highlight that fishing is the dominant impact in many areas of the oceans, but there are also many other factors, including climate change, land-based pollution, and commercial shipping, that make significant contributions to overall cumulative impact. In short, MPAs will almost always be a necessary component of EBM (the exception being EBM efforts occurring at very small spatial scales). However, MPAs alone will rarely, if ever, be sufficient to achieve the range of goals inherent in comprehensive ecosystem-based management.

Methods

Literature Search. We searched ISI Web of Science for papers, through the year 2008, that addressed any topic related to marine protected areas (MPAs) or marine ecosystem-based management (EBM). MPA papers were found searching the topics "marine protected area(s)" or "marine reserve(s)." Marine EBM papers were found searching topics "marine" and one of the following: "ecosystem-based management," "ecosystem-based fisheries management," "ecosystem management," or "ecosystem approach to management." Papers that were returned from both of these searches were counted as overlap papers.

Global Impact Analyses. To assess the potential for MPAs to achieve EBM goals, we used the methods and data compiled by Halpern and co-workers (4), who produced a global map of cumulative impacts on marine ecosystems, to evaluate where and how much no-take marine reserves (i.e., one type of MPA) could improve overall ocean health. We conducted three analyses. First, we calculated the fraction of the cumulative impact of human activities (from the 17 human stressors included in that analysis, which included six types of fishing) by just the six types of fishing (artisanal shore-based fishing and five types of commercial fishing, differentiated by gear type) in each 1-km^2 pixel of the ocean. This analysis shows the per-pixel potential for no-take reserves to affect overall ocean health (i.e., reduce total cumulative impact scores). Second, we simulated placing increasing portions (5% bins) of each of 232 marine ecoregions (biogeographic regions that extend to the 200-m isobath) (40) into no-take protection and calculated the percent change in total cumulative impact that would result from this amount of reduction in all fishing types within the no-take reserves. In other words, we turned off all six types of fishing within the simulated reserve network and then recalculated the new overall cumulative impact score for the ecoregion, and then divided this new value by the original total score to produce a percent change. This analysis addressed the among-ecoregion variation in the extent to which no-take reserves may be able to address EBM goals. We focused on scenarios that closed the portion of each ecoregion with the greatest and least impact from fishing to capture the full range of possible outcomes. The scenario that encloses 100% of the ecoregion within an MPA has only one result (the greatest and least impact options are the same). Finally, for each ecoregion we calculated the difference between the greatest- and least-change scenarios to illustrate the within-ecoregion variation in the extent to which no-take reserves may be able to address EBM goals.

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