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Designing, implementing and managing marine protected areas: Emerging trends and opportunities for coral reef nations

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ABSTRACT

Coral reefs are in dire need of effective governance, yet the science and planning of coral reef protected areas largely stem from wealthy, developed nations, with very different social, economic, and cultural characteristics than the nations in which most coral reefs occur. Much has been written about coral reefs and the use of marine protected areas (MPAs) as a management tool, but emerging trends and recommendations have not been adequately synthesized for the context of developing nations. We found that 60% of studies on MPA design and planning are from North America, Australia, Europe and the Mediterranean. As a result, many recommendations about how best to design, implement and manage coral reef protected areas may need to be adapted to address the needs of other nations. Based on the literature and our experiences, we review three emerging trends in MPA design and management, and relate these to the context of coral reef developing nations. First, MPA design is evolving to merge community (usually bottom-up) and regional (usually top-down) planning approaches. Second, the increasing recognition that social and ecological systems are tightly coupled is leading to planning and management of MPAs that better incorporate the human dimensions of reef systems and their linkages with reef ecology. Finally, there has been a trend toward adaptive management of MPAs and the emergence of related ideas about adaptive planning. These three trends provide crucial and much needed opportunities for improving MPAs and their effectiveness in coral reef nations.

Contents

1. Introduction

The many threats facing biodiversity and ecosystem services of coral reefs from overfishing, climate change, pollution, and other sources are well documented (e.g., Bellwood et al., 2004; Carpenter et al., 2008; Hoegh-Guldberg et al., 2007). In response, marine protected areas (MPAs) are often recommended as a management tool for coral reefs and other marine systems, and the potential benefits of no-take MPAs are widely recognized (e.g., Halpern and Warner, 2002; Lester et al., 2009; McCook et al., 2010; Russ et al., 2004). MPAs are not a panacea, but rather one management tool among many, and therefore MPAs need to be used within a broader

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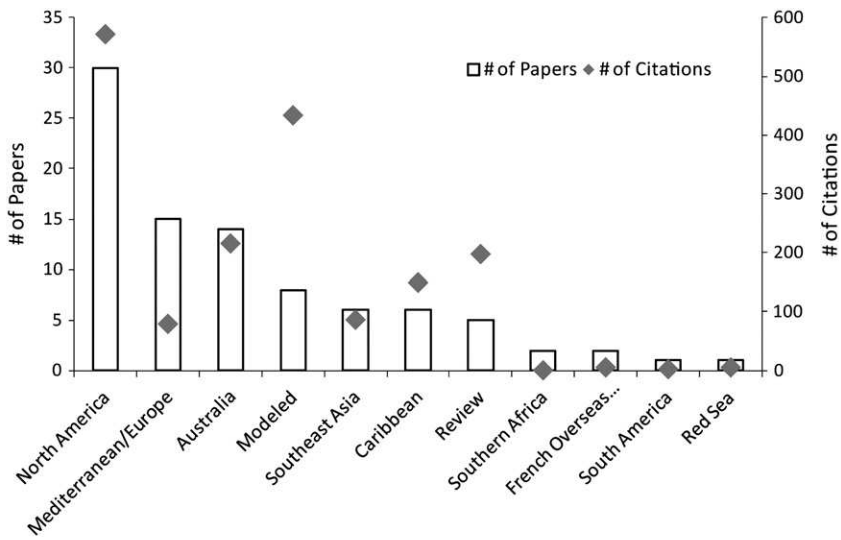

Fig. 1. Papers indexed in Web of Knowledge that advise on MPA design. Search terms used were: (“marine protected area*” OR “marine reserve*” OR MPA* OR “no-take”) AND (design OR planning). Titles rather than topics were searched to ensure that only the most relevant papers were captured. A total of 90 relevant papers were found, with 1742 citations. Papers were binned by geographic location or as modeling or review papers. Because the focus was on ISI-indexed literature, much of the work done within developing countries that is not published in indexed journals is excluded. The many relevant presentations at recent conferences (e.g., the 2010 Asia Pacific Coral Reef Symposium) by developing-country scientists and managers indicates that the trend may be shifting, or at least that work is being done in developing countries even if it does not reach ISI-indexed journals.

context of general seascape and ecosystem-based management (EBM) approaches (Allison et al., 1998; Halpern et al., 2010; McCook et al., 2010). In this paper, we review the literature and synthesize our experiences to explore emerging trends in the design, implementation and management of MPAs in the context of the developing nations that contain most of the world's coral reefs.

There is a disconnect between the geographic origins of scientific knowledge about MPA design and management and the location of most of the world's coral reefs. A search on Web of Knowledge for articles providing guidelines and recommendations on MPA design or planning reveals that almost 60% of these studies are from North America, Europe and the Mediterranean, and Australia and were often conducted in temperate ecosystems (Fig. 1). Another 15% of relevant papers are theoretical models or reviews. In contrast, about 70% of coral reefs occur in developing nations (here defined as nations that are not designated high income by the World Bank) (Spalding et al., 2001), where people have high dependence on reef resources for subsistence (Donner and Potere, 2007). Our review focused on ISI-indexed literature, and thus much of the work done within developing countries that is not published in indexed journals is excluded. The many relevant presentations at recent conferences (e.g., the 2010 Asia Pacific Coral Reef Symposium) by developing-country scientists and managers indicate that there is research and capacity originating within developing nations. Another explanation for the limited scientific literature originating from developing nations is that there may be a preference for disseminating information through social learning networks such as the Locally Managed Marine Areas network and gray literature.

Another disconnect is between knowledge about design and experience in implementation of conservation actions. Most of the literature on conservation planning stops short of the transition from design to action (Knight et al., 2010). Even the few success stories about marine applications, such as the rezoning of the Great Barrier Reef (Fernandes et al., 2005), are from situations that are globally atypical: untenured inshore marine waters managed by one or a few authorities. These provide little guidance for situations where inshore waters are covered by a plethora of finely textured ownership and management boundaries and support subsistence and small cash economies.

These disconnects mean that policy may need to be adapted to the social, economic and political realities of developing countries with coral reefs (Cinner, 2007; Johannes, 2002). In particular, general recommendations for MPA design are that larger MPAs are better, that 20–50% of any region should be designated as no-take areas, and that networks of MPAs should be comprehensive, adequate and representative (McCook et al., 2009b; Roberts et al., 2003). In contrast, in many developing countries, coral reef MPAs are numerous but small with variable representation of habitats. MPAs are typically not planned to contribute to representative, connected networks (McCook et al., 2009b; TNC et al., 2008; Weeks et al., 2010a; Wood et al., 2008), and management effectiveness is low (Christie and White, 2007). The political, social and economic reasons underlying these tendencies limit the relevance of approaches in developed countries to developing nations.

The goal of this paper is to review emerging trends in MPA design, implementation and management, and relate these to the context of developing nations with coral reefs. We focus on three emerging trends, which we believe are most important for advancing coral reef conservation. These are: (1) integration of community MPA initiatives with systematic conservation planning; (2) consideration of tightly coupled social and ecological systems; and (3) adaptive MPA management and planning. We selected these trends based on our interpretation of recent literature and our experience in the field.

2. Integrating community-based MPA initiatives with systematic conservation planning

Approaches to designing and implementing MPAs lie on a continuum between systematic planning at regional (or national) scales with top-down implementation, and community-based, bottom-up implementation (also called opportunistic, ad hoc, or local) (Roberts, 2000; Pressey and Bottrill, 2008) (Table 1). We refer to “regional” as any spatial extent that provides broad perspective for decisions about

Table 1
Different foci when working at local and regional scales in MPA planning and implementation. Local and regional situations are described here as extremes. A range of approaches exists along a continuum between these extremes.

	Continuum from		
	Local	To	Regional
Stakeholders	Communities or local stakeholder groups (e.g., fishing cooperatives).		Groups representing different marine resource industries, relevant leaders from different spheres of governance (e.g., government, church and traditional), community representatives.
Data	Reflect local values (e.g., cultural sites, important nesting sites), threats (e.g., point source pollution) and socio-economic considerations (e.g., livelihood, local fisheries). Traditional knowledge may provide relevant ecological and social information. The cost of this detail is that data are patchy and inconsistent across planning regions.		Usually extend across whole regions but at the cost of coarse resolution and use of surrogates (e.g. approximations of opportunity cost) that can be remote from the variables of most concern. Consistency can provide a better understanding of the relative importance of different areas for representation of habitats and the persistence of regional-scale processes (e.g. connectivity).
Objectives	Reflect values and concerns important at a household and community level (e.g., livelihood, well-being).		Reflect regional or national concerns (e.g. fisheries or biodiversity) of governments, major non-government organizations (NGOs), or aid organizations.
Governance	Community or multi-community level with traditional leaders, community groups (e.g., churches, businesses, councils of traditional leaders) and local government representatives.		Representatives of provincial and national level government or major NGOs.
Applying actions	Communities implement and enforce conservation and management actions.		Regional/national government regulations requiring large-scale enforcement.

individual MPAs. Typically, this includes provincial or ecoregional extents. We refer to "local" as the extent of one or a few MPAs. In many developing countries with coral reefs, these can be very small (e.g., in the Philippines, 90% of MPAs are less than 1 km^2, Weeks et al., 2010a).

The respective benefits and limitations of regional and local approaches have been debated and contrasted in the literature (Ban et al., 2009; Pressey, 1994; Pressey and Bottrill, 2008). Regional approaches emphasize ecological principles of complementarity, representativeness and connectivity, and generally result in recommendations for relatively large (~10 km in diameter) MPAs. In contrast, local approaches generally emphasize practical considerations of governance, management and livelihood considerations, and usually result in small MPAs with limited negative impact on people's livelihoods. Perhaps nowhere is the contrast more apparent than between the usually top-down, systematic planning approach of developed nations in MPA design (e.g., Airamé et al., 2003; Fernandes et al., 2005), and the opportunistic community-based, usually bottom-up implementation of MPAs in coral reef regions in developing countries (Alcala and Russ, 2006; Christie et al., 2002; Weeks et al., 2010a; White et al., 1994, 2006a). Both considerations are crucially important for effective conservation actions, and hence integration of ecological theory with local realities and constraints is necessary.

One of the emerging trends in MPA design is the integration of community-based opportunities with systematic conservation planning to leverage their respective benefits (Lowry et al., 2009). Planners are realizing that regional, systematic approaches present implementation challenges, while community-based MPAs alone may not be sufficient to achieve ecological and social objectives (e.g., enhancement of fisheries, protection of biodiversity). To illustrate these potential limitations, we modeled hypothetical expansions of community-based MPAs and contrasted the results with a hypothetical systematic approach (see Box 1, Figs. 2 and 3).

Explicit consideration of community goals and information is critical in developing countries because local communities and local governments often have control and/or jurisdiction over the use and management of reefs. They also have major influence over compliance (e.g., through tenure areas; Cinner, 2005; Foale and Manele, 2004; Johannes, 2002). Given the high reliance on coral reef resources for subsistence and survival in these countries, consideration of community objectives is also morally the right thing to do. Implementation of conservation actions in many developing nations is therefore most appropriate at the local, community scale (Govan, 2009; White et al., 2006a). The benefits of explicitly working at this scale include facilitation of implementation, improved compliance, and decreased costs (social, monetary, enforcement, etc.), all of which result from greater local buy-in (Pollnac and Pomeroy, 2005). There may be synergies between potentially differing community goals (e.g., food security, locally-important subsistence/artisanal fisheries) and regional goals (e.g., biodiversity, regionally-important commercial fisheries), or differences may result in conflicting priorities. Any differences can only be identified and reconciled by integrating regional and local perspectives.

Reconciling these two scales of operation requires regional designs to be scaled down (Mills et al., 2010) and local actions to be scaled up (Lowry et al., 2009). Scaling down inevitably involves adjustment of regional designs to accommodate local objectives and preferences. On the other side, while implementation may be most appropriate at the community and local government scale, building MPA networks from the bottom up without a regional perspective may fail to achieve regional goals (Weeks et al., 2010a). Therefore the integration of community and regional planning and implementation is an important avenue for improving the effectiveness of MPAs in coral reef nations.

Several examples of approaches to integrating community-based MPAs with regional goals exist. Fiji is currently attempting to scale up its Locally Managed Marine Area (LMMA) network by encouraging communities to work with adjacent communities (Mills et al., in press), with the spatial scale of collaboration varying from a couple of small islands to whole provinces. In the Visayas, Philippines, six local municipal governments have formed a common management unit to guide the development of an ecological and institutional network of about 40 no-take MPAs within their jurisdictions (Eisma-Osorio et al., 2009). In these examples, communities approached NGOs and local governments requesting assistance on MPA placement and how to "network" their existing MPAs. In Choiseul, Solomon Islands, as MPAs became more popular, there were more requests for implementation assistance than could be handled, and NGOs started to evaluate these requests based on regional goals relating to biodiversity, opportunities and threats (Game et al., 2011).

Clearly both community and regional perspectives are necessary, but these have not yet been adequately integrated. There is a need for more guidance from the scientific literature on how to scale-up and speed up local actions, and how to scale down regional plans, and importantly whether working in these two directions produces similar conservation outcomes (but see Lowry et al., 2009). An opportunity for successful MPA design and implementation lies in finding synergies between regional and local scale objectives, and to implement MPAs in an iterative process, with progressive adjustment of regional designs and local actions, informed by both perspectives.

Box 1
Comparing local, community-based implementation with regional, systematic planning using simulated expansions of MPAs.

The respective benefits of community-based implementation of MPAs and systematic planning with a regional perspective have been much discussed in the literature. Nonetheless, a clear illustration is still lacking of how community-based implementation of MPAs, without the guidance of a regional conservation design, may be insufficient. To address this, we simulated the expansion of local, community-based MPAs in three scenarios (Fig. 2) and added a scenario to reflect top-down establishment of MPAs.

We designed a test region that is similar to island nations in the Coral Triangle. We selected five islands of variable size and shape and assumed that local tenure boundaries were evenly distributed in segments of coastline 10 km long and 3 km wide, giving a total of 138 coastline units. We calculated the distance between the center of each unit and assumed that any unit within 50 km of another unit was ecologically connected (Almany et al., 2009). We also assumed a linear decreasing connectivity strength with 0 km fully connected (connectivity between units of 1.0) and units 50 km or more apart not connected (connectivity between units of 0). For four scenarios of MPA establishment, below, we measured two forms of connectivity (between MPAs and between MPA and non-MPA units) through time.

Our three community-based scenarios (see Fig. 2 caption), with MPAs established in six coastal units per time step, involved: 1. random establishment of MPAs; 2. linear, uni-directional spreading of MPAs; and 3. radial, bi-directional spreading of MPAs through time. The fourth scenario was a simulated regional network of MPAs designed with a ‘top-down’ approach in which 25% of coastal units were selected for conservation, after which management of these areas was implemented in a single time-step (similar to processes such as the re-zoning of the Great Barrier Reef Marine Park, Fernandes et al., 2005). The ‘top-down’ network was selected to optimize the number of connections from MPA to non-MPA coastal units. This reflected the conservation goal that the MPA network should help to sustain the regional coral reef ecosystem by acting as a source of larvae of harvestable fish species.

We compared the performance of the ‘top-down’ network and the three community-based MPA scenarios by measuring connectivity both between MPAs (“internal” to the MPA network) and between MPA and non-MPA units (external) (Fig. 3). For both internal and external connectivity, the top down scenario was equivalent to year 6 of the bottom-up expansion scenarios in covering 25% of coastal units. For comparison with this scenario and to compare connectivity values arising from different percentages of coastal units in MPAs, we allowed the bottom-up scenarios to proceed to 100% participation by communities (all coastal units in MPAs at time step 23).

For internal connectivity (defined as the sum of connectivity strength between pairs of MPAs, Fig. 3a), the radial and linear expansions gave the highest values while random expansion gave much lower values for any number of MPAs. To achieve the same level of connectivity as the regional network took the radial expansion 2 years, the linear expansion 3 years, and the random expansion about 6 years. This reflects the close grouping of MPAs with radial and linear allocations. All three community-based scenarios had the same endpoints but connectivity for the linear and radial scenarios increased linearly because neighboring local units were always selected for MPAs. Also, neighboring units each had roughly equal connectivity values because they were equally spaced along the coastline. The regional network had relatively low internal connectivity because it was designed to maximize external connectivity by dispersing MPAs throughout the islands.

For external connectivity (defined as the sum of connectivity strengths between pairs of MPA and non-MPA units, Fig. 3b), the regional network and random expansion of MPAs performed best. The regional network achieved the optimal number of external connections by design. Random expansion took about seven years longer to achieve the performance of the regional network. The random expansion performed better than the linear and radial scenarios because the local units selected for MPA expansion were well dispersed among non-MPA units.

In these simulations, we assumed complete and simultaneous implementation of all the MPAs in the regional network, as is generally assumed in the literature. However, we recognize that any top down regional design is unlikely to be implementable without adjustments to accommodate community goals, unforeseen opportunities and constraints, or errors in regional-scale data. Therefore, our simulations represent a dichotomous depiction of regionally designed versus expanding community MPAs. As discussed in the text, we believe there is much scope to guide community-based actions to meet regional goals more quickly (e.g., scenarios b and c in Fig. 2) by integrating community-based implementation with a regional perspective.

Linking community and regional perspectives could advance design, implementation and management of coral reef MPAs in several ways:

1. When MPAs are first implemented, any management action that reduces the loss of biodiversity will help to achieve goals of biodiversity representation and persistence. Opportunistically placing MPAs where there is community buy-in may be an effective way of building a foundation for later, more strategic management actions (Alcala and Russ, 2006; Govan, 2009; McCook et al., 2009b). Ongoing degradation of coral reefs means that establishing opportunistically placed MPAs now may be more beneficial than implementing, or perhaps failing to implement, a more optimal design in the future. As the process of planning and implementation progresses, managers can continually re-evaluate how community MPAs are contributing to community and regional goals, and take appropriate action to fill gaps, a process dubbed “informed opportunism” (Noss et al., 2002).
2. Identifying gaps in achievement of regional goals requires clear articulation and quantification of these goals (e.g., representation, connectivity, etc.). Managers and planners should also be prepared to modify regional plans based on community-scale information on conservation values and threats, as well as fine-scale information on opportunities for and constraints on action (e.g., when communities are unwilling to cooperate). Furthermore, practitioners who want to achieve regional objectives will have to provide incentives for communities to do at least some things more extensively and in different places. Scaling up is, to some extent, about changing local priorities to better co-ordinate actions between communities, extending management constraints over larger areas than those covered spontaneously (e.g., in Fiji), and spreading management across the full range of habitats, not only those with little scope for extractive use.
3. Iterative implementation of MPAs to achieve community and regional goals requires a stable institution to oversee and manage the process of generating, refining and implementing plans. Such an institution, formal or informal, depends on financial resources, time and human capacity, and its personnel need to understand the strengths and limitations of regional plans and local actions.

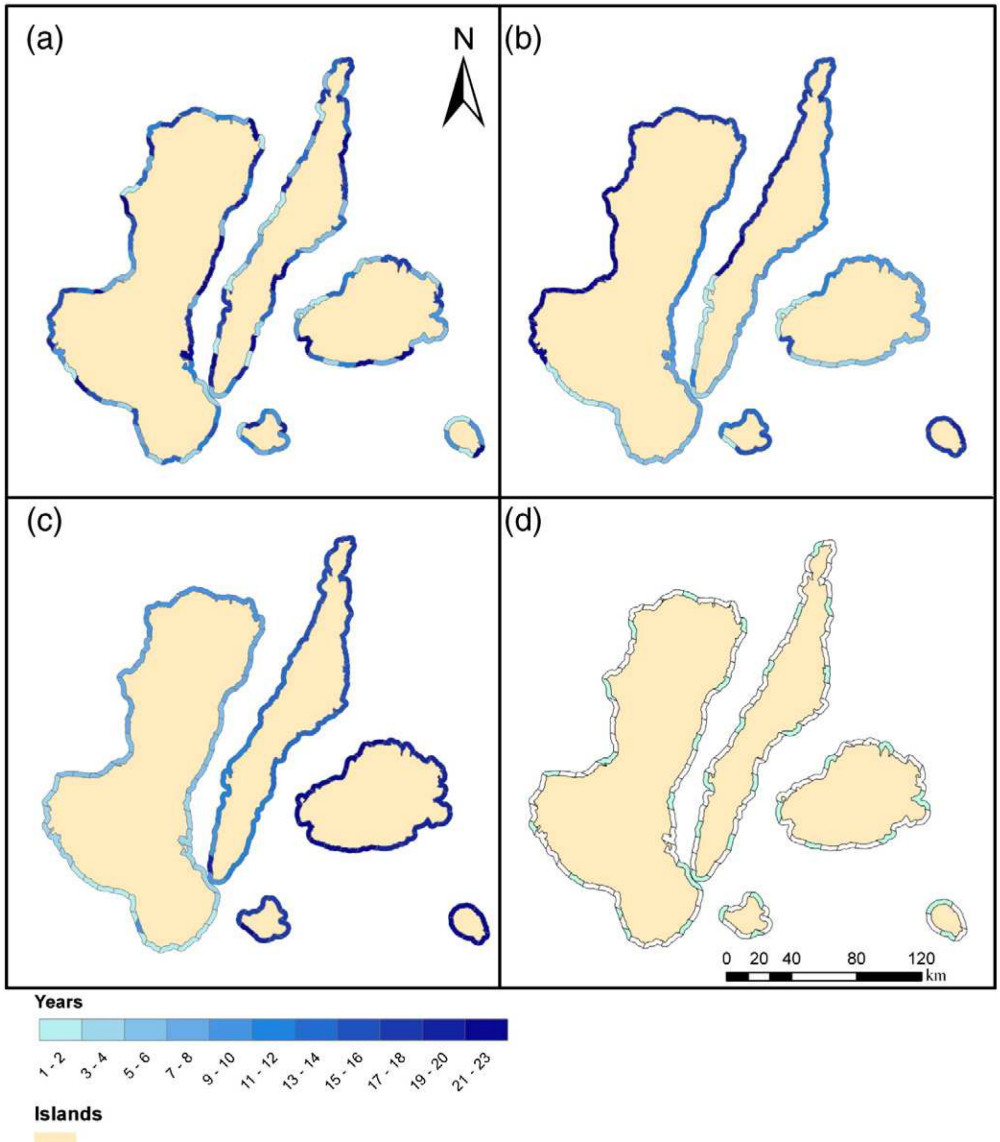

Fig. 2. Simulated expansion of MPAs, with three scenarios of incremental expansion of MPAs and one top-down regional network scenario with simultaneous application of management in the selected areas. Simulated inshore MPAs are shown for segments of coastline around islands. a) Random establishment of MPAs through time to approximate spontaneous, uncoordinated implementation of MPAs through community-based action. b) Linear, uni-directional expansion of MPAs through time to approximate communication between local communities about MPA establishment. c) Radial outflow or bi-directional expansion of MPAs through time to approximate a different form of communication between local communities. d) Top-down implementation of a regionally designed MPA network, consisting of 25% of coastal segments, in a single time-step, as reflected in some recent case studies in developed countries.

4. Decision support tools (e.g., Marxan, C-Plan), often used to assist with systematic conservation planning, need to be tailored to allow for community participation in the planning process without implying that the computer's modeling or data are superior to people's knowledge. Once communities relinquish decision making to technical experts, they may surrender responsibility and ownership of resulting management plans. That said, if appropriately used, decision support tools can assist and empower communities to make decisions about where to establish MPAs that contribute to community and regional objectives (Game et al., 2011).
5. Social networks (e.g., local governance associations, church groups, ethnic groups) can play an important role in scaling up community actions. Such networks may foster collaboration for MPA implementation and help to distribute the costs and benefits of MPAs more equitably (Aswani and Hamilton, 2004). However, certain aspects of social networks can also act as barriers to cooperation where communities which have little in common are requested to work together (e.g., different language groups).

3. Social–ecological systems perspective

Research in natural resource management is increasingly recognizing that MPA design and implementation must account for critical linkages in social and ecological systems. This perspective focuses on documenting and understanding interconnections between healthy ecosystems and social conditions, institutions, and governance arrangements, which is particularly important in developing nations where reliance on reefs for subsistence is high (Berkes and Folke, 1998; Pollnac et al., 2010). These factors can play a critical role in the success of MPAs (McClanahan et al., 2006; Pollnac et al., 2010). Recognition of humans as part of the system has led to multi-disciplinary approaches to understanding how social systems affect ecological systems and vice versa. For example, in response to different socio-ecological conditions such as subsistence needs and high population densities in developing countries, there has been a move away from considering MPAs as strictly no-take to a broader definition that includes other management regimes (e.g., temporal closures, gear restrictions, and zoning schemes

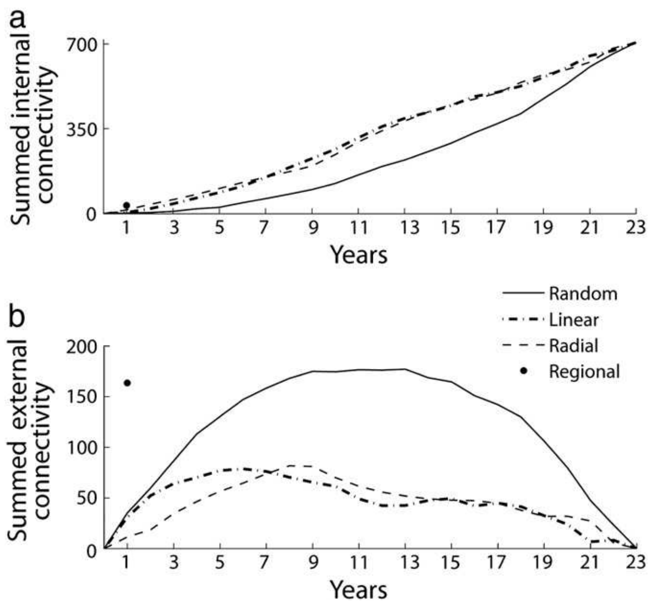

Fig. 3. Connectivity values for a regional (top down) conservation design, implemented in a single time-step, and three scenarios of expansion of community-based (bottom up) MPAs. (a) Internal connectivity, the sum of connectivity strengths between all possible pairs of MPAs within 50 km of one another (the maximum distance over which ecological connectivity was assumed). (b) External connectivity, the sum of connectivity strengths between all possible pairs of MPA and non-MPA units within 50 km of one another. The regional network is indicated by a single point because we assumed that 25% of coastal units were selected for MPAs and that all of these MPAs were implemented in a single time-step. In (b) note that, because we only considered connections between MPA and non-MPA units, connections between units progressively change from external to internal (the latter not measured in this graph) as more MPAs are implemented. Therefore, the curves reach their respective maxima of external connectivity before decreasing as connections between units become increasingly internal.

that allow for a range of controlled uses and limitations) (e.g., Cinner, 2005; Game et al., 2009b; McClanahan et al., 2006). This trend allows planners and researchers to better address the realities of many coral reef nations.

The change in focus from ecological to social–ecological systems in the last 10 years is demonstrated by the changed perspective on key stages of systematic conservation planning discussed by Margules and Pressey (2000). These were biologically focused, as compared to the addition of five new stages by Pressey and Bottrill (2009), most of which concern the social, economic and political context for planning. Initially, the focus in systematic conservation planning was to ensure that biodiversity was represented and the planning process was transparent (Margules and Pressey, 2000). In recent work, there is also recognition of the crucial role that social dimensions (e.g., involving stakeholders throughout the process) play in conservation planning (Pressey and Bottrill, 2009). These perspectives have been strongly developed for terrestrial environments in South Africa (Cowling et al., 2008) but are nonetheless highly relevant to marine planning and coral reef nations.

Broader recognition of MPAs as linked social–ecological systems has led to three important trends in conservation planning. First, scientists and managers are beginning to consider the social impacts of conservation actions. The biggest advances have been in incorporating ‘conservation costs’ of MPAs. Costs of conservation action have been broadly explored by two parallel tracks of research: static cost metrics such as profits in fisheries, and qualitative costs in social studies such as displacement and human health (Gjertsen, 2005; Mascia and Claus, 2009; McClanahan, 2010). Consideration of social and economic perspectives in conservation planning is demonstrated by the rapid increase in use of socio-economic data in marine conservation planning since the first study in 1999 (Ban and Klein, 2009). However, to date most of these studies have either assumed that socio-economic costs are uniform or have considered only opportunity costs to fisheries (30 of 42 studies; Ban and Klein, 2009). In reality, costs are almost never spatially uniform across planning regions, and estimates of opportunity costs are rarely comprehensive, usually reflecting only one or a few groups of stakeholders (Adams et al., 2010a). Other studies (e.g., Green et al., 2009) have approached ‘costs’ in a broader context, including the ecological impacts of humans, community preferences, and priority ecological areas in combined metrics. This approach shifts attention to perceived conservation opportunities, by promoting areas of interest for either social or ecological reasons, and away from perceived constraints in areas of high impact or human use.

A second important trend related to social–ecological systems is the incorporation of broader social values and potential benefits of MPAs into the design and implementation of MPAs. In many countries with coral reefs, community priorities concern consistent flows of ecosystem goods and services. Conservation of biodiversity may be a secondary benefit rather than the primary goal. These utilitarian aspirations may result in different approaches to implementing MPAs than a sole focus on conservation of biodiversity. For example, in parts of Melanesia, communities periodically harvest MPAs to provide food for traditional feasts (Bartlett et al., 2009). Likewise, in Madagascar, the Velondriake MPA employs a system of rotational closures to build up octopus stocks, which are then harvested after 2–6 months (Cinner et al., 2009a). In some sites in other countries, the attraction created by a well-managed MPA for diving tourists is a primary incentive among local communities to set up permanent no-take MPAs. This attraction is typically due to financial incentives from direct payment for ecosystem services (e.g., user fees) and indirect benefits (e.g., employment at resorts). While there may or may not be overlap between priority areas identified for ecosystem services and biodiversity conservation, MPAs that allow some use (managed extraction or viewing) can be as effective ecologically as no-take areas, especially considering that compliance with strict no-take areas is low in some areas (McClanahan et al., 2006).

Thirdly, in addition to the use of flexible strategies such as periodic harvests, there is an emerging trend toward incorporating local knowledge and constraints in the design and placement of MPAs. For example, in the Solomon Islands, local ecological knowledge was used to map vulnerable benthic habitats for integration into an MPA network plan (Aswani and Hamilton, 2004). In Fiji and the Philippines, where enforcement capacity rests largely with communities, most MPAs are located near communities so that they can be easily monitored.

We see the incorporation of social considerations into MPA planning and management probably leading to three future directions for researchers and spatial planners:

1. The increasing recognition of multiple needs from, and aspirations for, MPAs will see a shift toward planning for flows of ecosystem goods and services, as well as biodiversity. For example, researchers will have to ask: will increased biomass within MPAs result in benefits to fisheries (i.e., improved catches outside the MPA), and if so, how much? (Samonte-Tan et al., 2007). Likewise, recreational benefits from the cultural services provided by MPAs are sometimes measured (e.g., willingness to substitute, Ditton and Sutton, 2004), but there is considerable room to improve incorporation of other non-commercial values, such as those related to esthetic (beauty of a seascape) or intrinsic (right of species to exist) characteristics.
2. Incorporating social values and socio-economic costs into conservation plans and strategies will require creative applications of decision support tools. However, there are many unresolved research questions about how to define – and particularly how to quantify – the many dimensions of costs for effective use in decision support tools, and how to integrate potential benefits from MPAs (Table 2). Qualitative, social and economic costs and

Table 2
Unresolved issues in measuring and incorporating social and economic costs and benefits into conservation planning.

Issue	Recommendation	References
Incorporating different types of MPAs (e.g., no-take zones, rotating closures, seasonal, gear restrictions) and their costs and benefits	Include variable costs and benefits associated with different types of MPAs explicitly in the planning process. For example, Marxan with Zones provides a tool that can be used with explicit costs and benefits associated with different types of MPAs.	Watts et al. (2009)
Incorporating economic costs and benefits to multiple stakeholders	Incorporate economic costs and benefits to different stakeholders independently to analyze impacts on each stakeholder group and explicitly acknowledge tradeoffs between them. How stakeholder groups are defined will reflect local contexts (e.g., stakeholders defined by gear type to reflect different fisheries).	Adams et al. (2010a) and Ban and Klein (2009)
Management costs of different kinds of MPAs	Include estimates of management costs of different scenarios in MPA design (management costs cannot be accurately identified a priori because they depend on the location, size and other characteristics of selected areas). Considering management costs explicitly allow planners and managers to design MPAs so that these costs are minimized. However, minimizing management costs may result in increased opportunity costs. Evaluating these trade-offs requires consideration of both types of costs, perhaps with iterative versions of regional designs.	Ban and Klein (2009) and Ban et al. (in review)
Resolution of data depicting costs and benefits	Use cost and benefit data with appropriate resolution and quality. For example, country-scale data are unlikely to be useful for local community planning. Likewise, catch per unit effort (CPUE) data that only reflect current effort may not be appropriate where future fishing effort is likely to be heavily influenced by changing gears or markets.	Adams et al. (2010b)
Tenure	Traditional tenure boundaries should be considered explicitly to ensure that costs and benefits are allocated equally across communities. This can be achieved by defining each community as a stakeholder group and considering costs and benefits to those groups independently.	Weeks et al. (2010b)
Including other social dimensions such as community attitudes, beliefs, leadership	Considering social dimensions in addition to economic cost could make MPAs more locally relevant. For example, prioritizing areas where there are conservation opportunities (i.e., communities who want to implement a MPA), or where there are strong leaders might lead to quicker implementation of MPAs.	Example from terrestrial research (Knight et al., 2010)

benefits need to be integrated in more meaningful ways to resolve explicitly the tradeoffs between economic goals. For example, it will be important to consider the aggregate impact on stakeholders and the distribution of impacts on different stakeholders (Adams et al., 2010a; Klein et al., 2010) as well as social values and social opportunities and constraints (Knight et al., 2010).

3. The social context for MPA effectiveness has generally been examined with case studies (Cinner, 2007) but is being increasingly approached with larger-scale comparative studies (McClanahan et al., 2006; Pollnac et al., 2010). While case studies provide valuable lessons, researchers need to undertake case studies in a manner that allows consistent comparisons between them (Ostrom, 2007, 2009). Understanding links between characteristics of the resource (e.g., fish reproduction) to those of governance systems (e.g., lack of sanctioning) or resource users (e.g., number of fishermen) will help to identify trends in interactions between social and ecological dimensions of coral reef areas. In turn, this will provide decision-makers with a greater understanding of how complex social–ecological systems can be managed (Ostrom, 2007).

4. Adaptive MPA management and planning

The need to integrate community-based MPAs with systematic conservation planning, and the increasing focus on social–ecological systems, mean that MPA design and management have to become more adaptive to incorporate these additional considerations (Gerber et al., 2007; Grafton and Kompas, 2005; McCarthy and Possingham, 2007; McCook et al., 2010). Adaptive management is an iterative process of decision making in the face of uncertainty, whereby management goals and methods will be expected to change over time as new information is obtained and new challenges develop (Walters and Hilborn, 1978). Passive adaptive management implies learning from past successes and failures, whereas active adaptive management means deliberate experimentation and carefully designed monitoring to measure and improve management effectiveness.

Adaptive planning is a less familiar term than adaptive management, and we use it here to refer to the need for the design of MPA systems to be approached adaptively. There are at least three reasons why this is important. First, conservation planning is increasingly focusing on marine dynamics such as movements of animals or spatio-temporal variations in sea surface temperature or chlorophyll (Hobday and Hartmann, 2006; Lombard et al., 2007). Our understanding of these dynamics is inevitably limited to short periods, perhaps 20 years at most, of observations. As this understanding improves, prescriptions for static or dynamic MPAs (Game et al., 2009a) will have to adapt accordingly. Second, lessons from later parts of the planning process can feed back to improve subsequent decisions (Pressey and Bottrill, 2009). For example, decisions made about the location and configuration of MPAs could lead unexpectedly to difficulties in managing those areas, perhaps because of present or future runoff from adjacent catchments or contested access to natural resources. These lessons can then improve subsequent decisions about design. Third, the transition from design to action must involve progressive adjustments to design as mistakes (e.g., errors in data) and surprises (e.g., unexpected constraints on conservation action) come to light (Mills et al., 2010), often over long periods required to put effective conservation actions into place. This means that designs should be seen as evolving, not static, if they are to remain relevant. Like adaptive management of MPAs, adaptive planning can be both passive and active.

Adaptive management has a rich history in many coral reef developing nations (Cinner et al., 2006), whereas it has proven more difficult to achieve in developed countries (Walters, 2007). The small size of many MPAs in developing nations means that adaptive management can be done by communities and decisions can be made and implemented rapidly. For example, coral reef areas are often managed adaptively through periodic closures, sometimes based on specific triggers (Cinner et al., 2006). In the Philippines, a user-friendly system for monitoring MPA management effectiveness has been adopted that provides feedback and rapid improvement of management effectiveness within an adaptive framework (White et al., 2006b). In developed countries where management tends to be more centralized, responses of management to new data are generally slower (McCook et al., 2010; Walters, 2007).

Perhaps one of the most important impetuses for adaptive MPA management and planning is climate change, a major threat to coral reefs (e.g., Carpenter et al., 2008). Climate change can be considered in design either by using rules of thumb on configuration to enhance the robustness of MPAs (McCook et al., 2009b) or by revisiting and iteratively improving MPA design as the effects of climate change become apparent. Several recommendations have been made to make MPA networks more robust to climate change: setting a minimum MPA size (e.g., minimum 10–20 km diameter), spreading risk (e.g., replication of MPAs with minimum representation 20–30% of each habitat type), ensuring connectivity among MPAs, and effective management of the seascape surrounding MPAs (i.e., ecosystem-based management) (McLeod et al., 2009). However, as we have seen, many of these recommendations are unlikely to be realistic in the context of the developing nations. Furthermore, even if these recommendations are pursued, such measures will never fully climate-proof coral reefs, although they may promote faster recovery from climate change-related stresses (Carilli et al., 2009).

Several avenues for rethinking and adapting MPA design in the face of climate change are emerging (McCook et al., 2009a). Conservation objectives for regional plans, once set for static biodiversity features, need to be revisited to reflect threats from climate change (Game et al., 2008). For example, this may include explicitly targeting reefs at lower risk of bleaching (Game et al., 2008; Maina et al., 2008). Ultimately, climate change projections or scenarios should be linked to objectives to maximize the persistence of biodiversity through MPA network design with climate change. That said, the urgency of the situation means that we cannot afford to wait for perfect science; rather we should base decisions on the best available information and adapt these decisions when better information comes to hand. In addition, some MPAs may change from being static to dynamic to enhance the resilience of healthy coral reefs (Game et al., 2009b) or to track mobile features such as fronts or eddies. A caveat for dynamic MPAs is that many of the benefits of MPAs accrue over time, especially where destructive fishing practices outside MPAs prevail. Hence, frequent changes in the locations and boundaries of MPAs may undermine some of their ecological benefits, particularly in the context of open-access governance (Cinner et al., 2005; Game et al., 2009b).

Adaptive planning and management of MPAs should include consideration of social–ecological systems. The need for different types of MPAs for various social contexts is increasingly recognized (Bartlett et al., 2009; Cinner et al., 2006), and so is the potential for social contexts to change. Periodic closures based on customary norms may be an effective management tool where local socio-cultural institutions are strong and communities have the capacity to enforce resource regulations (Johannes, 2002; Muehlig-Hofmann, 2007). However, they may become unsuitable if customary governance breaks down as a result of increased market influence, population size, immigration and development (Aswani, 2002; Cinner, 2007; Cinner and Aswani, 2007; Veitayaki, 1998). Community attitudes also change, and there may be more scope to add no-take areas to customary management as success stories about no-take areas from other regions become known (e.g., Kubulau in Fiji, Clarke and Jupiter, 2010).

Institutions and governance arrangements that enable and facilitate adaptive management are essential to making adaptive MPA planning and management a reality (Christie and White, 2007). Decentralization of responsibility for marine management has provided such opportunities in Indonesia (Satria and Matsuda, 2004), Philippines (Alcala and Russ, 2006; Eisma-Osorio et al., 2009), Solomon Islands (Hviding, 1998) and East Africa (Cinner et al., 2009b). For example, the Philippines has devolved most authority for coastal resource management to local municipal governments, including the establishment of localized MPAs that now comprise the majority of MPAs in the country (Lowry et al., 2005). A key lesson is that devolution of authority to sub-national and local government has necessitated new and appropriately scaled technical assistance to build institutional capacity for MPA network design and management (TNC et al., 2008). Catalytic and capable organizations, such as local NGOs or community organizations, then become quite important where sub-national or local government does not have the capacity (or desire) to fill the gaps in capacity building.

Decentralization is not always appropriate, however, as it can also undermine existing customary institutions (Gelcich et al., 2006). For example, the Velondriake community-based MPA in Madagascar has to operate outside the government's co-management framework, Gestion Locale Sécurisée (GELOSE), because the rotational closures it employs do not comply with the rigid criteria of the GELOSE management system (Cinner et al., 2009a). The rotational closures require a flexible framework that allows users to change the timing and location of closures according to their local knowledge. Similarly, in Fiji, decentralization has meant that local MPAs are not nationally or legally recognized, leading to non-compliance locally (Clarke and Jupiter, 2010).

Adaptive management requires monitoring of key aspects of social–ecological systems to gage the effectiveness of management of single MPAs and the design of MPA networks. Given the shift in MPA design from representing static patterns of biodiversity toward adjusting to climatic changes, and from being ecologically focused to considering social objectives, a similar shift is happening in what we measure. Ecologically, there has been a change from a focus on species abundances toward overall ecosystem function and process (e.g., moving from counting individuals to evaluating demographics of species of interest by measuring size classes) to explicitly reflect and assess management objectives (McCook et al., 2010). There is also a growing emphasis on monitoring societal benefits and impacts of MPAs (e.g., Pollnac et al., 2010). With both kinds of changes, there remains the need to relate monitoring programs back to management responses (e.g., through trigger points) to enable adaptive management.

One of the challenges, albeit a surmountable one, of adaptive planning is the tension between adaptive spatial decisions that change through time and the need for spatial stability for stakeholders affected by resulting constraints on resource use. Lack of stability can affect marine users in several ways. It can reduce willingness to invest in their industry, for example if people are unwilling to invest in new boats or nets because of an uncertain regulatory environment. It can also result in lack of trust between users and managers, giving the impression that managers are incompetent if they need to adjust spatial plans frequently. Institutional inertia can also prevent adaptive planning from becoming a reality.

Adaptive management and planning provide several interrelated opportunities for advancing coral reef MPAs:

1. To assess whether individual MPAs or networks of MPAs are meeting their goals, the goals themselves need to be clearly defined. Definitions of clear, measurable goals should integrate local, community needs and aspirations with regional, biodiversity considerations, thereby involving relevant communities, stakeholders and institutions at several scales.
2. Institutions are needed to facilitate adaptive management and planning. Such institutions could be formal or informal, including community organizations, MPA management agencies, non-government organizations, or government agencies. The institutions should be responsible for tracking management and design outcomes relative to goals through monitoring, and consulting with stakeholders to implement changes. Passive or active adaptive management are both helpful, although active adaptive management may provide insights more quickly.
3. Making adaptive planning operational requires the relevant institution (see #2 above) to periodically or continually reassess the MPA design. Decision support tools can greatly facilitate such re-design. For example, as the individual MPAs that constitute a

larger regionally designed network are progressively implemented, changes to their locations and boundaries will almost certainly be needed to adjust to new data and local constraints and opportunities (Mills et al., 2010). These adjustments can be made within the decision support tool and will flow on to other parts of the design because of the requirements for complementarity and connectivity. Similarly, changing threats (e.g., climate change, changing use patterns) can be integrated into the cost layer with each review of the MPA design.

5. Synthesis and conclusion

We provide some new perspectives on MPA design, implementation and management relevant to coral reefs by highlighting three interlinked emerging trends. First, MPA design is evolving to merge community (usually local and bottom-up) and systematic conservation planning (usually regional and top-down) approaches. Second, linked social–ecological considerations are now viewed as essential in MPA design and management, especially for inshore waters with customary tenure and community management. Finally, these two trends combined with social and ecological changes, especially with climate change, necessitate an adaptive management approach to MPA planning and management.

These emerging trends highlight opportunities for increasing socially and ecologically relevant MPA planning and management in coral reef regions (Table 3). Experience in coral reef regions of developing countries has shown that recommendations derived from developed countries are usually not applicable (e.g., Weeks et al., 2010a). Instead, much progress can be made toward coral reef conservation and sustainability by merging local and regional approaches to MPA design and implementation. For planners, this means acting on local opportunities for conservation while keeping a regional perspective (Game et al., 2011). It also means providing incentives for communities to coordinate their actions within larger regions and to establish effective management more extensively, especially for some habitats, than they would otherwise consider. Iteratively and adaptively, gaps in regional representation can then be filled through local opportunities. Integrating social objectives and perspectives into MPA design and management will help to identify opportunities and appropriate management actions for local contexts. Furthermore, embodying adaptive management in MPA planning and design will facilitate both ecological and social success.

Table 3
Opportunities for designing, implementing and managing coral reef MPAs: recommendations for MPA practitioners.

Recommendation	Description
Integrate community-based MPAs with regional perspectives through systematic conservation planning	
Modify regional plans based on community-scale information.	Local-scale information, such as conservation values, threats, opportunities and constraints for action, can be used to adjust regional plans to make them more locally relevant. It means planners should be willing to adjust their plans based on community-priorities and information.
Modify community priorities based on regional information.	As the process of planning and implementation progresses, managers need to continually re-evaluate whether community MPAs are meeting or contributing to regional goals, and take appropriate action to fill gaps (Game et al., 2010). It also means providing incentives for communities to coordinate their actions within larger regions and to establish effective management more extensively than they would otherwise consider.
When integrating community and regional goals, many iterations may be required before plans achieve both sets of goals, thereby moving between scales.	Integrating community and regional goals is facilitated by acknowledging the need to move between scales. This can be done by providing basic guidelines to local communities to consider regional goals (e.g., representation and connectivity, in conjunction with other communities) and by incorporating as much fine-scale information as possible during planning. Formal and informal governance spheres should be identified that have both the influence and capacity to coordinate management actions at different scales.
Provide simple guidelines to communities, informed by regional goals.	Examples of guidelines could include: (1) in general, bigger MPAs are more effective, (2) include multiple habitat types in MPAs where possible, and (3) try to protect good examples of each habitat type.
Incorporate more social context into conservation planning	
Make conservation goals utilitarian to reflect local resource needs	Incorporate ecosystem services as conservation features rather than considering only biodiversity. Ecosystem services better reflect local values and needs (e.g., food security) and emphasize the benefits of MPAs. Incorporating community preferences into plans will increase local buy-in and facilitate action.
Define explicit social and economic objectives and incorporate relevant data in the planning process.	Social and economic goals will need to reflect local cultural values or social opportunities (e.g., working with communities that have strong leadership). Data will need to be collected and objectives defined to directly reflect explicit social and economic objectives.
Undertake case studies in a manner that allows consistent comparisons between them.	Understanding links between characteristics of the resource (e.g., fish reproduction) to those of governance systems (e.g., lack of sanctioning) or resource users (e.g., number of fishermen) will help to identify trends in interactions between social and ecological dimensions of coral reef areas. In turn, this will provide decision-makers with a greater understanding of how complex social–ecological systems can be managed.
Adaptively manage and design MPAs	
Make adaptive management part of daily, monthly and yearly operations	An institution (e.g., community group, NGO, management body, government agency) responsible for adaptive management needs to be in place to keep records of what actions have worked/not worked for specific situations. This institution should learn from successes and failures within and beyond the region. Then MPA designs and management plans can be revisited periodically to review the relevance of goals, data and objectives.
Assess impacts seen and expected from climate change	Through local/regional knowledge and/or time-series data, climate change impacts to date can be reviewed. A question to ask is: Are some parts of the region more or less affected than others? This will help to consider appropriate management responses to these effects. Managers can then use this information to recognize that regional plans for MPAs may require modification to address climate change or other changes.
Make "no regrets" decisions; adhere to the precautionary principle	Consider whether management actions will preclude future options (e.g., if destructive fishing practices are permitted, coral reefs may be destroyed and will no longer be available for future protection). Are there other management actions that will leave open future options while still achieving short-term objectives? If so, those should be used.

We therefore conclude that MPAs remain a highly pertinent, necessary and adaptable tool for coral reef nations in the face of declining coral health and the increasing scale and severity of threats. Coral reef developing nations have adapted the MPA concept to local conditions and needs, thereby making it relevant and effective. While the mostly small MPAs in these countries may not adhere to MPA design recommendations prevalent in the literature, their success and popularity provide great opportunities to scale up and speed up their implementation while adaptively assessing and filling gaps.

Our review focused primarily on the context of developing nations where most coral reefs occur, but many of the emerging trends and recommendations may also be relevant to developed nations. The importance of involving local stakeholders in effective conservation actions is generally recognized in conservation planning (Pressey and Bottrill, 2009) and in management of coral reefs (McCook et al., 2010). Hence, some combination of scaling regional MPA plans down or scaling local opportunities up may lead to more significant conservation advances in all countries. In particular, some developed nations have social contexts similar to developing nations (e.g., high reliance on seafood for subsistence, traditional local management of resources). For example, indigenous rights and traditional ownership regimes in parts of Canada and Australia suggest that an integrated local and regional approach may be most effective (Ban et al., 2008, 2009; Smyth, 1995). Adaptive management is generally recommended, regardless of location, and both adaptive management and planning will be particularly important as the effects of climate change on ecosystems and people become more extensive, and as marine spatial planning becomes more widespread (Ehler, 2008; Lawler, 2009).

The emerging trends highlighted here – integrating community and regional MPA efforts, linking social–ecological systems, and moving toward adaptive MPA planning and management – provide insights into the future of MPAs. They offer crucial and much-needed opportunities for improving MPAs in our rapidly changing world. Incorporating these trends in coral reef regions should enhance the ecological and social benefits of MPAs, and their viability as management approaches.

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References

Adams, V.M., Pressey, R.L., Naidoo, R., 2010a. Opportunity costs: who really pays for conservation. Biological Conservation 143, 439–448.
Adams, V.M., Mills, M., Jupiter, S.D., Pressey, R.L., 2010b. Improving social acceptability of marine protected area networks: a method for estimating opportunity costs to multiple gear types in both fished and currently unfished areas. Biological Conservation 144, 350–361.
Airamé, S., Dugan, J., Lafferty, K.D., Leslie, H., McArdle, D., Warner, R.R., 2003. Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. Ecological Applications 13 (1), S170–S184.
Alcala, A.C., Russ, G.R., 2006. No-take marine reserves and reef fisheries management in the Philippines: a new people power revolution. AMBIO: A Journal of the Human Environment 35 (5), 245–254.
Allison, G.W., Lubchenco, J., Carr, M.H., 1998. Marine reserves are necessary but not sufficient for marine conservation. Ecological Applications 8 (1), S79–S92.
Almany, G., Connolly, S., Heath, D., Hogan, J., Jones, G., McCook, L., Mills, M., Pressey, R., Williamson, D., 2009. Connectivity, biodiversity conservation and the design of marine reserve networks for coral reefs. Coral Reefs 28 (2), 339–351.
Aswani, S., 2002. Assessing the effects of changing demographic and consumption patterns on sea tenure regimes in the Roviana Lagoon, Solomon Islands. AMBIO: A Journal of the Human Environment 31 (4), 272–284.
Aswani, S., Hamilton, R., 2004. Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. Environmental Conservation 31 (01), 69–83.
Ban, N.C., Klein, C.J., 2009. Spatial socioeconomic data as a cost in systematic marine conservation planning. Conservation Letters 2 (5), 206–215.
Ban, N.C., Picard, C., Vincent, A.C.J., 2008. Moving towards spatial solutions in marine conservation, with indigenous communities. Ecology and Society 13 (1), 32 Online.
Ban, N.C., Picard, C.R., Vincent, A.C.J., 2009. Comparing and integrating community-based and science-based approaches in prioritizing marine areas for protection. Conservation Biology 23 (4), 899–910.
Ban, N.C., Adams, V., Pressey, R.L., 2011. Promise and problems for estimating management costs of marine protected areas: a case study in the Coral Sea. Conservation Letters 4 (3), 241–252.
Bartlett, C.Y., Manua, C., Cinner, J., Sutton, S., Jimmy, R., South, R., Nilsson, J., Raina, J., 2009. Comparison of outcomes of permanently closed and periodically harvested coral reef reserves. Conservation Biology 23 (6), 1475–1484.
Bellwood, D.R., Hughes, T.P., Folke, C., Nyström, M., 2004. Confronting the coral reef crisis. Nature 429, 827–833.
Berkes, F., Folke, C., 1998. Linking Social and Ecological Systems. Cambridge University Press, Cambridge, United Kingdom.
Carilli, J., Norris, R., Black, B., Walsh, S., McField, M., 2009. Local stressors reduce coral resilience to bleaching. PloS One 4 (7), e6324.
Carpenter, K.E., Abrar, M., Aeby, G., Aronson, R.B., Banks, S., Bruckner, A., Chiriboga, A., Cortes, J., Delbeek, J.C., DeVantier, L., Edgar, G.J., Edwards, A.J., Fenner, D., Guzman, H.M., Hoeksema, B.W., Hodgson, G., Johan, O., Licuanan, W.Y., Livingstone, S.R., Lovell, E.R., Moore, J.A., Obura, D.O., Ochavillo, D., Polidoro, B.A., Precht, W.F., Quibilan, M.C., Reboton, C., Richards, Z.T., Rogers, A.D., Sanciangco, J., Sheppard, A., Sheppard, C., Smith, J., Stuart, S., Turak, E., Veron, J.E.N., Wallace, C., Weil, E., Wood, E., 2008. One-third of reef-building corals face elevated extinction risk from climate change and local impacts. Science 321 (5888), 560–563.
Christie, P., White, A.T., 2007. Best practices for improved governance of coral reef marine protected areas. Coral Reefs 26 (4), 1047–1056.
Christie, P., White, A.T., Deguit, E., 2002. Starting point or solution? Community-based marine protected areas in the Philippines. Journal of Environmental Management 68, 441–454.
Cinner, J., 2005. Socioeconomic factors influencing customary marine tenure in the Indo-Pacific. Ecology and Society 10 (1), 36.
Cinner, J., 2007. Designing marine reserves to reflect local socioeconomic conditions: lessons from long-enduring customary management systems. Coral Reefs 26 (4), 1035–1045.
Cinner, J.E., Aswani, S., 2007. Integrating customary management into marine conservation. Biological Conservation 140 (3–4), 201–216.
Cinner, J.E., Marnane, M.J., McClanahan, T.R., 2005. Conservation and community benefits from traditional coral reef management at Ahus Island, Papua New Guinea. Conservation Biology 19 (6), 1714–1723.
Cinner, J., Marnane, M.J., McClanahan, T.R., Almany, G.R., 2006. Periodic closures as adaptive coral reef management in the Indo-Pacific. Ecology and Society 11, 31.
Cinner, J., Fuentes, M., Randriamahazo, H., 2009a. Exploring social resilience in Madagascar's marine protected areas. Ecology and Society 14 (1).
Cinner, J.E., Wamukota, A., Randriamahazo, H., Rabearisoa, A., 2009b. Toward institutions for community-based management of inshore marine resources in the Western Indian Ocean. Marine Policy 33 (3), 489–496.
Clarke, P., Jupiter, S.D., 2010. Law, custom and community-based natural resource management in Kubulau District, Republic of Fiji Islands. Environmental Conservation 37, 98–106.
Cowling, R., Egoh, B., Knight, A., O'Farrell, P., Reyers, B., Rouget, M., Roux, D., Welz, A., Wilhelm-Rechman, A., 2008. An operational model for mainstreaming ecosystem services for implementation. Proceedings of the National Academy of Sciences 105 (28), 9483.
Ditton, R.B., Sutton, S.G., 2004. Substitutability in recreational fishing. Human Dimensions of Wildlife: An International Journal 9 (2), 87–102.
Donner, S.D., Potere, D., 2007. The Inequity of the global threat to coral reefs. Bioscience 57 (3), 214–215.
Ehler, C., 2008. Conclusions: benefits, lessons learned, and future challenges of marine spatial planning. Marine Policy 32 (5), 840–843.
Eisma-Osorio, R., Amolo, R., Maypa, A., White, A., Christie, P., 2009. Scaling up local government initiatives toward ecosystem-based fisheries management in Southeast Cebu Island, Philippines. Coastal Management 37 (3), 291–307.
Fernandes, L., Day, J., Lewis, A., Slegers, S., Kerrigan, B., Breen, D., Cameron, D., Jago, B., Hall, J., Lowe, D., Innes, J., Tanzer, J., Chadwick, V., Thompson, L., Gorman, K., Simmons, M., Barnett, B., Sampson, K., De'ath, G., Mapstone, B., Marsh, H., Possingham, H., Ball, I., Ward, T., Dobbs, K., Aumend, J., Slater, D., Stapleton, K., 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. Conservation Biology 19 (6), 1733–1744.
Foale, S., Manele, B., 2004. Social and political barriers to the use of marine protected areas for conservation and fishery management in Melanesia. Asia Pacific Viewpoint 45 (3), 373–386.
Game, E.T., McDonald-Madden, E.V.E., Puotinen, M.L., Possingham, H.P., 2008. Should we protect the strong or the weak? Risk, resilience, and the selection of marine protected areas. Conservation Biology 22 (6), 1619–1629.
Game, E., Grantham, H., Hobday, A., Pressey, R., Lombard, A., Beckley, L., Gjerde, K., Bustamante, R., Possingham, H., Richardson, A., 2009a. Pelagic protected areas: the missing dimension in ocean conservation. Trends in Ecology & Evolution 24 (7), 360–369.
Game, E.T., Bode, M., McDonald-Madden, E., Grantham, H.S., Possingham, H.P., 2009b. Dynamic marine protected areas can improve the resilience of coral reef systems. Ecology Letters 12 (12), 1336–1346.

Game, E.T., Lipsett-Moore, G., Hamilton, R., Peterson, N., Kereseka, J., Atu, W., Watts, M., Possingham, H., 2011. Informed opportunism for conservation planning in the Solomon Islands. Conservation Letters 4 (1), 38–46.
Gelcich, S., Edwards-Jones, G., Kaiser, M., Castilla, J., 2006. Co-management policy can reduce resilience in traditionally managed marine ecosystems. Ecosystems 9 (6), 951–966.
Gerber, L.R., Wielgus, J., Sala, E., 2007. A decision framework for the adaptive management of an exploited species with implications for marine reserves. Conservation Biology 21 (6), 1594–1602.
Gjertsen, H., 2005. Can habitat protection lead to improvements in human well-being? Evidence from marine protected areas in the Philippines. World Development 33 (2), 199–217.
Govan, H., 2009. Achieving the potential of locally managed marine areas in the South Pacific. SPC Traditional Marine Resource Management and Knowledge Information Bulletin 25.
Grafton, R.Q., Kompas, T., 2005. Uncertainty and the active adaptive management of marine reserves. Marine Policy 29 (5), 471–479.
Green, A., Smith, S., Lipsett-Moore, G., Groves, C., Peterson, N., Sheppard, S., Lokani, P., Hamilton, R., Almany, J., Aitsi, J., Bualia, L., 2009. Designing a resilient network of marine protected areas for Kimbe Bay, Papua New Guinea. Oryx 43, 488–498.
Halpern, B.S., Warner, R.R., 2002. Marine reserves have rapid and lasting effects. Ecology Letters 5 (3), 361–366.
Halpern, B., Lester, S., McLeod, K., 2010. Placing Marine Protected Areas onto the Ecosystem-Based Management Seascape. Proceedings of the National Academy of Sciences.
Hobday, A., Hartmann, K., 2006. Near real-time spatial management based on habitat predictions for a longline bycatch species. Fisheries Management and Ecology 13 (6), 365–380.
Hoegh-Guldberg, O., Mumby, P.J., Hooten, A.J., Steneck, R.S., Greenfield, P., Gomez, E., Harvell, C.D., Sale, P.F., Edwards, A.J., Caldeira, K., Knowlton, N., Eakin, C.M., Iglesias-Prieto, R., Muthiga, N., Bradbury, R.H., Dubi, A., Hatziolos, M.E., 2007. Coral reefs under rapid climate change and ocean acidification. Science 318 (5857), 1737–1742. doi:10.1126/science.1152509.
Hviding, E., 1998. Contextual flexibility: present status and future of customary marine tenure in Solomon Islands. Ocean & Coastal Management 40 (2–3), 253–269.
Johannes, R.E., 2002. The renaissance of community-based marine resource management in Oceania. Annual Review of Ecology and Systematics 33 (1), 317–340.
Klein, C.J., Steinback, C., Watts, M., Scholz, A.J., Possingham, H.P., 2010. Spatial marine zoning for fisheries and conservation Frontiers in Ecology and the Environment 8 (7), 349–353.
Knight, A.T., Cowling, R.M., Difford, M., Campbell, B.M., 2010. Mapping human and social dimensions of conservation opportunity for the scheduling of conservation action on private land. Conservation Biology 24 (5), 1348–1358.
Lawler, J., 2009. Climate change adaptation strategies for resource management and conservation planning. Ann N Y Acad Sci 1162(1 The Year in Ecology and, Conservation Biology 2009), 79–98.
Lester, S.E., Halpern, B.S., Grorud-Colvert, K., Lubchenco, J., Ruttenberg, B.I., Gaines, S.D., Airame, S., Warner, R.R., 2009. Biological effects within no-take marine reserves: a global synthesis. Marine Ecology Progress Series 384, 33–46.
Lombard, A., Reyers, B., Schonegevel, L., Cooper, J., Smith-Adao, L., Nel, D., Froneman, P., Ansorge, I., Bester, M., Tosh, C., 2007. Conserving pattern and process in the Southern Ocean: designing a marine protected area for the Prince Edward Islands. Antarctic Science 19 (01), 39–54.
Lowry, K., White, A., Courtney, C., 2005. National and local agency roles in integrated coastal management in the Philippines. Ocean & Coastal Management 48 (3–6), 314–335.
Lowry, G., White, A., Christie, P., 2009. Scaling up to networks of marine protected areas in the Philippines: biophysical, legal, institutional, and social considerations. Coastal Management 37 (3–4), 274–290.
Maina, J., Venus, V., McClanahan, T., Ateweberhan, M., 2008. Modelling susceptibility of coral reefs to environmental stress using remote sensing data and GIS models. Ecological Modelling 212 (3–4), 180–199.
Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405 (6783), 243–253.
Mascia, M.B., Claus, C.A., 2009. A property rights approach to understanding human displacement from protected areas: the case of marine protected areas. Conservation Biology 23 (1), 16–23.
McCarthy, M.A., Possingham, H.P., 2007. Active adaptive management for conservation. Conservation Biology 21 (4), 956–963. doi:10.1111/j.1523-1739.2007.00677.x.
McClanahan, T.R., 2010. Effects of fisheries closures and gear restrictions on fishing income in a Kenyan coral reef. Conservation Biology 24 (6), 1519–1528.
McClanahan, T.R., Marnane, M.J., Cinner, J.E., Kiene, W.E., 2006. A comparison of marine protected areas and alternative approaches to coral-reef management. Current Biology 16 (14), 1408–1413.
McCook, L., Folke, C., Hughes, T., Nyström, M., Obura, D.O., Salm, R., 2009a. Ecological resilience, climate change and the Great Barrier Reef. In: Johnson, J., Marshall, P. (Eds.), Climate Change and the Great Barrier Reef. Great Barrier Reef Marine Park Authority, Townsville, pp. 75–96.
McCook, L., Almany, G., Berumen, M., Day, J., Green, A., Jones, G., Leis, J., Planes, S., Russ, G., Sale, P., Thorrold, S., 2009b. Management under uncertainty: guide-lines for incorporating connectivity into the protection of coral reefs. Coral Reefs 28 (2), 353–366.
McCook, L.J., Ayling, T., Cappo, M., Choat, J.H., Evans, R.D., De Freitas, D.M., Heupel, M., Hughes, T.P., Jones, G.P., Mapstone, B., Marsh, H., Mills, M., Molloy, F.J., Pitcher, C.R., Pressey, R.L., Russ, G.R., Sutton, S., Sweatman, H., Tobin, R., Wachenfeld, D.R., Williamson, D.H., 2010. Adaptive management of the Great Barrier Reef: a globally significant demonstration of the benefits of networks of marine reserves. Proceedings of the National Academy of Sciences 107 (43), 18278–18285.
McLeod, E., Salm, R., Green, A., Almany, J., 2009. Designing marine protected area networks to address the impacts of climate change. Frontiers in Ecology and the Environment 7 (7), 362–370.
Mills, M., Weeks, R., Pressey, R.L., Foale, S., Ban, N.C., 2010. A mismatch of scales: challenges in planning for implementation of marine protected areas in the Coral Triangle. Conservation Letters 3, 291–303.
Mills, M., Jupiter, S.D., Pressey, R.L., Ban, N.C., Comley, J., in press. Assessing effectiveness of community-based management strategies towards achieving national conservation objectives: A new approach and gap analysis for marine conservation in Fiji. Conservation Biology.
Muehlig-Hofmann, A., 2007. Traditional authority and community leadership: key factors in community-based marine resource management and conservation. SPC Traditional Marine Resource Management and Knowledge Information Bulletin 21, 31–44.
Noss, R., Carroll, C., Vance-Borland, K., Wuerthner, G., 2002. A multicriteria assessment of the irreplaceability and vulnerability of sites in the Greater Yellowstone ecosystem. Conservation Biology 16 (4), 895.
Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences 104 (39), 15181.
Ostrom, E., 2009. A general framework for analyzing sustainability of social–ecological systems. Science 325 (5939), 419.
Pollnac, R., Pomeroy, R., 2005. Factors influencing the sustainability of integrated coastal management projects in the Philippines and Indonesia. Ocean & Coastal Management 48 (3–6), 233–251.
Pollnac, R., Christie, P., Cinner, J.E., Dalton, T., Daw, T.M., Forrester, G.E., Graham, N.A.J., McClanahan, T.R., 2010. Marine reserves as linked social–ecological systems. Proceedings of the National Academy of Sciences PNAS published ahead of print February 22, 2010, doi:10.1073/pnas.0908266107.
Pressey, R.L., 1994. Ad hoc reservations: forward or backward steps in developing representative reserve systems? Conservation Biology 8 (3), 662–668.
Pressey, R.L., Bottrill, M.C., 2008. Opportunism, threats, and the evolution of systematic conservation planning. Conservation Biology 22 (5), 1340–1345.
Pressey, R.L., Bottrill, M.C., 2009. Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. Oryx 43 (04), 464–475.
Roberts, C.M., 2000. Selecting marine reserve locations: optimality versus opportunism. Bulletin of Marine Science 66, 581–592.
Roberts, C.M., Andelman, S., Branch, G., Bustamente, R.H., Castilla, J.c., Dugan, J., Halpern, B.S., Lafferty, K.D., Leslie, H., Lubchenco, J., McArdle, D., Possingham, H.P., Ruckelshaus, M., Warner, R.R., 2003. Ecological criteria for evaluating candidate sites for marine reserves. Ecological Applications 13 (1), S199–S214.
Russ, G.R., Alcala, A.C., Maypa, A.P., Calumpong, H.P., White, A.T., 2004. Marine reserve benefits local fisheries. Ecological Applications 14 (2), 597–606.
Samonte-Tan, G., White, A., Tercero, M., Diviva, J., Tabara, E., Caballes, C., 2007. Economic valuation of coastal and marine resources: Bohol Marine Triangle, Philippines. Coastal Management 35 (2), 319–338.
Satria, A., Matsuda, Y., 2004. Decentralization of fisheries management in Indonesia. Marine Policy 28 (5), 437–450.
Smyth, D., 1995. Caring For Sea Country-accommodating indigenous peoples' interests in marine protected areas. In: Gubbay, S. (Ed.), Marine Protected Areas: Principles and Techniques for Management. Chapman & Hall, London, pp. 149–173.
Spalding, M.D., Ravilious, C., Green, E.P., 2001. World Atlas of Coral Reefs. University of California Press, Berkeley, USA.
TNC, WWF, CI, WCS, 2008. Marine Protected Area Networks in the Coral Triangle: Development and Lessons. TNC, WWF, CI, WCS and the United States Agency for International Development, Cebu City, Philippines. 106 pp.
Veitayaki, J., 1998. Traditional and community-based marine resource management system in Fiji: an evolving integrated process. Coastal Management 26 (1), 47–60.
Walters, C.J., 2007. Is adaptive management helping to solve fisheries problems? AMBIO: A Journal of the Human Environment 36 (4), 304–307.
Walters, C., Hilborn, R., 1978. Ecological optimization and adaptive management. Annual Review of Ecology and Systematics 9 (1), 157–188.
Watts, M.E., Ball, I., Stewart, R.S., Klein, C.J., Wilson, K., Steinback, C., Lourival, R., Kircher, L., Possingham, H.P., 2009. Marxan with Zones — software for optimal conservation-based land- and sea-use zoning. Environmental Modelling and Software 1–9.
Weeks, R., Russ, G.R., Alcala, A.C., White, A.T., 2010a. Effectiveness of marine protected areas in the Philippines for biodiversity conservation. Conservation Biology 24 (2), 531–540.
Weeks, R., Russ, G.R., Bucol, A.A., Alcala, A.C., 2010b. Incorporating local tenure in the systematic design of marine protected area networks. Conservation Letters. doi:10.1111/j.1755-263X.2010.00131.x.
White, A.T., Hale, L.Z., Renard, Y., Cortesi, L., 1994. Collaborative and Community-Based Management of Coral Reefs, Lessons from Experience. Kumarian Press, West Hartford, CT.
White, A., Alino, P., Meneses, A., 2006a. Creating and Managing Marine Protected Areas in the Philippines. Fisheries Improved for Sustainable Harvest Project, Coastal Conservation and Education Foundation, Inc. and University of the Philippines Marine Science Institute, Cebu City, Philippines. 83, 00–03.
White, A., Meneses, A., Ovenden, M., Tesch, S., 2006b. Sustaining marine protected areas through continued monitoring and evaluation: the MPA report guide and management rating system. Proceedings of the 10th International Coral Reef Symposium, pp. 1466–1470.
Wood, L.J., Fish, L., Laughren, J., Pauly, D., 2008. Assessing progress towards global marine protection targets: shortfalls in information and action. Oryx 42 (03), 340–351.