POLICY PERSPECTIVE

Reexamining the science of marine protected areas: linking knowledge to action

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Keywords
Marine reserves; marine policy; fisheries; impact evaluation; adaptive management.

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Received
29 July 2011
Accepted
14 October 2011

Editor
Phillip Levin

doi: 10.1111/j.1755-263X.2011.00207.x

Abstract

Marine protected areas (MPAs) are often implemented to conserve or restore species, fisheries, habitats, ecosystems, and ecological functions and services; buffer against the ecological effects of climate change; and alleviate poverty in coastal communities. Scientific research provides valuable insights into the social and ecological impacts of MPAs, as well as the factors that shape these impacts, providing useful guidance or “rules of thumb” for science-based MPA policy. Both ecological and social factors foster effective MPAs, including substantial coverage of representative habitats and oceanographic conditions; diverse size and spacing; protection of habitat bottlenecks; participatory decision-making arrangements; bounded and contextually appropriate resource use rights; active and accountable monitoring and enforcement systems; and accessible conflict resolution mechanisms. For MPAs to realize their full potential as a tool for ocean governance, further advances in policy-relevant MPA science are required. These research frontiers include MPA impacts on nontarget and wide-ranging species and habitats; impacts beyond MPA boundaries, on ecosystem services, and on resource-dependent human populations, as well as potential scale mismatches of ecosystem service flows. Explicitly treating MPAs as “policy experiments” and employing the tools of impact evaluation holds particular promise as a way for policy-relevant science to inform and advance science-based MPA policy.

Introduction

The scale, intensity, and variety of human uses of the oceans have transformed marine populations and habitats, with cascading impacts on both ecosystem structure and function (e.g., Jackson *et al*. 2001; Halpern *et al*. 2008; Salomon *et al*. 2008). In response, marine protected areas (MPAs) are often implemented to conserve or restore species, fisheries, habitats, ecosystems, and ecological functions (NRC 2001). MPAs also are increasingly employed for poverty alleviation (Gjertsen 2005) and for climate change mitigation and adaptation (McLeod *et al.* 2009). In October 2010, the 193 Parties to the Convention on Biological Diversity (CBD) reaffirmed the goal of protecting and effectively managing 10% of the sea in MPAs by 2020 (CBD 2010).

Located in almost every major marine habitat, MPAs occur in diverse ecological and socio-political settings. Nearly 6,000 MPAs have been established, covering 1.17% of the ocean and 2.86% of the 200 nautical mile Exclusive Economic Zones, and ranging in size from less than a hectare (0.01 km^2) to more than 100,000 km^2 (Toropova *et al.* 2010). MPA governance arrangements are similarly diverse, ranging from "no-take" MPAs, in which all extractive uses are prohibited, to complex multiple use MPAs in which various human activities are permitted but regulated spatially, temporally, by species, mode of use, or by the characteristics of the prospective users themselves (Mascia 2004).

Although research to date provides valuable insights that can inform the development of MPA policy, meeting the ambitious 2020 CBD target of "effectively and equitably managed, ecologically representative, and well connected systems of protected areas" (CBD 2010) will require dramatic advances in the ecological and social science of MPAs, because the challenges associated with scaling up MPAs are interdisciplinary in nature. This necessitates policies grounded in both natural and social sciences; we, therefore, address this challenge and encourage science-based policy and policy-relevant science with a novel, comprehensive, and interdisciplinary review and analysis. We build upon previous (largely discipline-specific) scientific research reviewing the ecological and social impacts of MPAs and the factors that shape these impacts (e.g., Lester *et al.* 2009; Mascia *et al.* 2010), as well as manager-focused guidelines for designing and establishing MPAs and MPA networks (e.g., IUCN-WCPA 2008). We review the current state of knowledge regarding MPA ecological and social impacts (positive and negative) and the factors that explain variation in these impacts. We highlight "rules of thumb" for the establishment of effective MPAs and research frontiers that span disciplines, because the implications for MPA science and policy often entail multidisciplinary engagement, based on current insights from the natural and social sciences. We also consider some of the practical challenges to increasing the global coverage of MPAs tenfold in a decade and suggest the need to explicitly view MPAs as "policy experiments," so that decision makers can replicate successes, reform failures, and avoid future mistakes in developing more socially and ecologically sustainable MPAs.

Ecological and social impacts of MPAs

Since the mid 1990s, hundreds of studies have examined the ecological impacts of MPAs. No-take protection typically results in increases (on average) in organism size (28%), density (166%), biomass (466%), and species richness (21%) within MPA boundaries (Lester *et al.* 2009). These effects vary by taxa, with species targeted by fishing showing the most dramatic effects (Lester *et al.* 2009). Direct effects (i.e., benefits to species targeted by fishing) are often detectable over a relatively short time frame (e.g., 5 years; Babcock *et al.* 2010), although this varies based upon species' population growth rates. Indirect effects, such as those resulting from trophic interactions, tend to accrue more slowly, sometimes taking decades (Edgar *et al.* 2009; Babcock *et al.* 2010). Top predators also may take longer to respond to MPA protection, because these species are often particularly slow growing and long lived (DeMartini *et al.* 2008). MPAs also have been shown to benefit habitats, for example with MPAs preventing coral loss compared to unprotected areas (Selig & Bruno 2010). An important caveat to recognize and expectation to manage when reporting averages is that whereas meta-analyses are powerful and useful in summarizing generalities, they are unable to incorporate context-dependent effects.

Scientific understanding of the ecological impacts of MPAs outside their boundaries, as well as the impacts of ecologically interconnected networks of MPAs, is limited (Lowry *et al.* 2009), but modeling research and a growing number of empirical studies indicate a net movement of fish from no-take MPAs (e.g., Abesamis & Russ 2005; Goni *et al.* 2010). MPAs and MPA networks can increase the density, size, and biomass in adjacent non-MPA areas, with these effects observable on average 0.7–1.5 km from MPA boundaries (Halpern *et al.* 2009). Research to date has not yet examined the spillover effects of MPAs on habitat in areas beyond MPA boundaries, although habitat outside MPAs can influence fish spillover (Russ *et al.* 2004; Forcada *et al.* 2009).

The ecological impacts of MPAs may enhance the flow of ecosystem services. For example, if a no-take MPA results in increased catches beyond its borders, then the fishing community experiences an increase in a provisioning service (Sanchirico 2000). MPAs that protect coastal habitat, such as mangroves or seagrass, could also protect the shoreline from erosion (Danielsen *et al.* 2005) and contribute to carbon sequestration (Nellemann *et al.* 2009), thereby providing regulating services (MEA

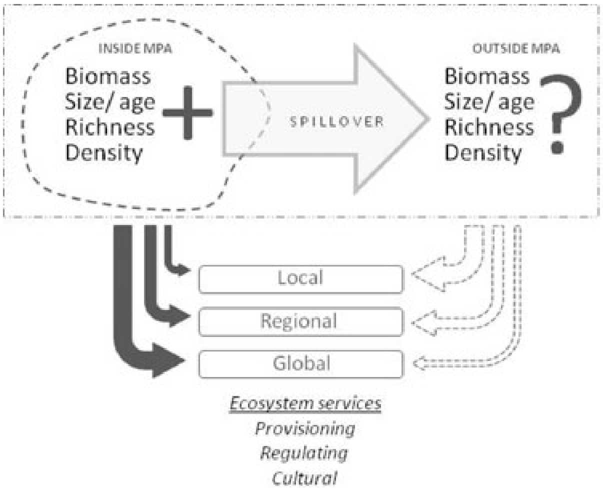

Figure 1 Mismatch in monitoring MPA impacts between scientific research and local community priorities. Ecological impacts within an MPA, including increases (+) in the biomass, density, individual size, and species richness of marine organisms, have been well established in the scientific literature. Evidence that these benefits flow outside the MPA via ecological spillover mechanisms (large arrow) is more equivocal (?). Where these ecological benefits occur, they manifest as changes to ecosystem services, including provisioning (e.g., fisheries), regulating (e.g., carbon sequestration), and cultural (e.g., recreational opportunities) services, which are important to constituents at various spatial scales. Traditional scientific research and monitoring of MPAs (solid arrows) often does not focus on documenting the types of impacts (i.e., benefits outside MPAs) at the scales of most interest to local communities and decision makers (dashed arrows), creating a scale mismatch (arrow thickness represents importance of each relationship to respective groups). Understudying the services of most interest to local communities presents a significant gap in our understanding and hinders policy-makers' attempts to address community concerns.

2005). Furthermore, MPAs can increase cultural services, such as nonconsumptive recreation (e.g., scuba and snorkeling) and "existence values" (i.e., values individuals hold for a service even though they might never experience it).

Mapping these ecosystem services onto current research on MPA impacts suggests that mismatches between areas of research emphasis and ongoing policy debates may impede MPA establishment (Figure 1, Carpenter *et al*. 2009). For example, for the most part, cultural services are valued at a global scale, whereas provisioning services are valued locally by resource-dependent fishing communities (Smith *et al*. 2010). Research to date has principally focused on cultural services, but under studying the services of most interest to local communities leaves an important gap in our understanding and hinders policymakers' attempts to address community concerns. For example, fishing has variable implications for the flow of services, depending upon whether the "provisioning" is conducted by large-scale commercial fisheries, recreational fisheries, or small-scale artisanal fisheries. Moreover, the scale at which benefits of regulating services accrue depends on the particular service in question (e.g., storm surge protection [local] vs. carbon sequestration [global]). Research into these variations would inform policy needs.

The social impacts of MPAs are a complex manifestation of MPA governance arrangements, social context, and flows of ecosystem services (Broad & Sanchirico 2008; Charles & Wilson 2009; Mascia & Claus 2009). Despite widespread interest in the social impacts of MPAs, few quantitative peer-reviewed studies exist. Findings indicate that food security generally increases following MPA establishment, though some fishing subgroups experience a relative decline in their catch per unit effort (Mascia *et al*. 2010). Similarly, MPAs may either empower or disempower local stakeholders by assigning or revoking decision making authority and resource use rights, sometimes privileging one group over another (Mascia *et al*. 2010); this can have corresponding cultural impacts on traditions of customary marine tenure (Johannes 2002). Evidence regarding impacts on community organization, employment, health, and income remain scarce (Gjertsen 2005; Mascia *et al*. 2010), although fishers may face significant upfront costs with MPA establishment from lost access to fishing grounds (Smith *et al*. 2010). Livelihoods shift and sometime diversify in MPAs associated with tourism (Broad & Sanchirico 2008). MPAs may also reduce user conflicts, enhance environmental awareness, and build social capital (Walmsley & White 2003). Negative social impacts of MPAs may include inequitable distribution of benefits, dependence on project assistance, and unmet expectations (Walmsley & White 2003; Christie 2004). Although this literature is growing, more peer-reviewed evidence is needed regarding the magnitude of social impacts and how these impacts vary over time, across spatial scales and levels of social organization, across social domains, and within and among social groups.

Explaining variation in ecological and social impacts

Scientific insights into the factors that shape the ecological and social impacts of MPAs can inform more effective MPA policies. These factors include MPA design attributes, length of reserve establishment (Edgar *et al*. 2009; Babcock *et al*. 2010); as well as the ecological, oceanographic, and social contextual factors independent of the MPA itself. MPAs that permit extractive uses also demonstrate biological benefits relative to non-MPAs, but demonstrate less pronounced effects than MPAs (or portions of MPAs) that prohibit all fishing (Lester & Halpern 2008). The ecological context of MPAs—including habitat characteristics, the level of exploitation prior to MPA establishment, and type of species assemblages and ecosystem—explains some of variation in MPA impacts. Species that have experienced the greatest declines relative to historic levels have greater scope for improvement following MPA establishment, whereas species that increase with fishing pressure (e.g., macroalgae) may decline over time inside MPAs (Hughes *et al.* 2007). Species with diverse life histories demonstrate population increases in response to MPA establishment, including species with home ranges larger than the MPA itself (Lester *et al.* 2009). Although tropical and temperate MPAs are similarly effective (Lester *et al.* 2009), few studies have examined the impacts of pelagic or open ocean MPAs or compared their effectiveness relative to MPAs on continental shelves (Game *et al.* 2009).

Social context also plays a role in MPA outcomes. The ecological integrity of MPAs is influenced by geographic location, human population density, market access, and marine resource dependence (Cinner 2007; Pollnac *et al.* 2010). Alternative livelihood programs, for example, can foster proconservation behaviors by ensuring that the financial benefits of MPA establishment exceed the costs (Pollnac *et al.* 2001). Community-based fisheries management where MPAs form a core component of the system can be effective, particularly in contexts where there are rapid feedback loops in the social-ecological system, but without linkages to higher-level authorities their effectiveness can be limited (Cudney-Bueno & Basurto 2009).

Design attributes that shape variation in ecological and social impacts include MPA size, spacing or connectivity, types of uses allowed, and habitat representation (including oceanographic and hydrodynamic features). Existing knowledge of the range, variability, and diversity of key variables and processes suggest ecological "rules of thumb" for effective MPAs and MPA networks (Table 1), which can be used to guide policy and implementation, even as policy-relevant research frontiers (Table 2) are addressed. Even small reserves can have significant biological responses (Lester *et al.* 2009) and smaller and older MPAs are more frequently associated with increases in food security (Mascia *et al.* 2010), though these responses are localized. Enhanced fisheries are anticipated when significant proportions (~20–40%) of a variety of habitats are protected in MPA networks (Gaines *et al.* 2010). Size and spacing recommendations for these networks are based on scientific principles regarding spillover, mobility, and larval dispersal distance of target species. Highly mobile species like tunas and sharks require larger MPAs than species with restricted home ranges to benefit from MPA protection (Russ *et al.* 2004; Sandin *et al.* 2008). Adult spillover is positively correlated with mobility, and good order-of-magnitude estimates of how far species are likely to move exist, based on species life history and mobility characteristics (Pittman & McAlpine 2003). Although species range data exist and the "imprint" of spillover has been found in an increasing number of studies (Halpern *et al.* 2009), estimates of the amount of spillover (e.g., population numbers or biomass) are lacking from most studies. Estimates of maximum and average larval dispersal distances exist for many taxa, including vulnerable and heavily exploited species (Kinlan *et al.* 2005). In the absence of empirical estimates, a variety of inter-MPA distances are recommended (e.g., 20–30 km for coral reef MPA networks, McCook *et al.* 2009). Evidence regarding the impact of MPA connectivity is limited (Table 2), although modeling studies can be used to estimate the importance of these factors (Mumby 2006; Costello *et al.* 2010). Finally, the link between habitat quality and quantity and population responses (e.g., Chapman & Kramer 1999) suggests the need for a variety of habitats in MPAs and MPA networks, including habitat bottlenecks for critical life history stages of highly mobile species (Gell & Roberts 2003) and large-scale oceanographic features, such as major currents, upwelling zones, convergence zones and gyres, which often demarcate shifts in the dynamics and functioning of marine communities (Hyrenbach *et al.* 2000). Additional research on the influence of spatial and temporal scales and the role of life history and ecological traits in mediating impact would further explain variations in MPA performance (Table 2).

Four elements of MPA governance appear particularly important to the ecological and social impacts of MPAs: decision-making arrangements, resource use rules, monitoring and enforcement systems, and conflict resolution mechanisms (Mascia 2004; Ostrom 2005; McClanahan *et al.* 2006). Although scientific understanding of the relationship between MPA governance and effectiveness is in its early stages, and human capacity to govern these complex systems may ultimately be limited (Jentoft *et al.* 2007), research suggests several social rules of thumb for the design of effective MPAs and MPA networks (Table 1). Decision-making arrangements correlated with effective MPAs include active participation of resource users in the design and modification of rules governing marine resources (Pollnac *et al.* 2001; Christie *et al.* 2003b); self-governance rights for resource users, especially if supported by higher levels of government (Cudney-Bueno & Basurto 2009); and shared leadership of management interventions (Christie *et al.* 2003a; Gutierrez *et al.* 2011). Supportive local governments, particularly for community-managed areas, and external

Table 1 Science-based rules of thumb for the design of effective MPAs

Attribute	Principle
Ecological	Dispersal distance and larval connectivity
	Protect a significant percentage (~20–40%) of a variety of habitats.
	Have a variety of inter-MPA distances if aim is to establish MPA network.
	MPAs should ideally be at least 4–6 km in diameter/width although smaller ones have also been effective.
	Ensure MPAs encompass a range of sizes.
	Life history characteristics of target species
	Protect habitat "bottlenecks" (e.g., spawning grounds).
	Incorporate traditional fisheries management structures to address needs of highly vagile species.
	Hydrodynamics
	Ensure representation of habitats includes oceanographic conditions (e.g., eddies, upwelling).
Social	Decision-making structures
	Share responsibility and authority for MPA establishment and management.
	Foster participatory decision making and adapt management strategies.
	Foster decision-maker accountability.
	Facilitate self-governance by resource users.
	Share leadership of management interventions.
	Resource use rules
	Clearly define MPA rules and boundaries.
	Link rules-governing resource use to social and environmental conditions.
	Build upon informal or traditional use rights and formal management rules.
	Structure MPA rules so that benefits and costs are distributed proportionally.
	Monitoring and enforcement
	Share authority for enforcement.
	Monitor the environmental and social performance of the MPA.
	Make research and monitoring participatory, and share results.
	Make sanctions fit the offense.
	Conflict resolution mechanisms
	Establish accessible mechanisms for conflict resolution and information exchange.
	Create opportunities for trust building among local stakeholders.

Sources: See text for references.

institutions may be able to provide financial and/or technical assistance to augment capacity (Cudney-Bueno & Basurto 2009). Taken together, these types of participatory governance arrangements can enhance the legitimacy and management capacity of decision-making bodies, as well as their responsiveness to shifting social and ecological conditions (Abel *et al*. 2011).

Resource use rules include laws, regulations, formal and informal policies, codes of conduct, and social norms that specify the rights (i.e., privileges) of individuals to access and appropriate marine resources. Clearly defined resource and MPA boundaries, as well as clearly defined individual resource use rights, generally improve the social and environmental performance of MPAs (Mascia 2004) and other natural resource governance regimes (Ostrom 2005). MPA effectiveness increases when resource use rights are consistent with, and build upon, existing informal or culturally based resource use rights (Fiske 1992). Rules governing resource use that are tailored to specific local, social, and environmental conditions and arrangements in which costs and benefits are internalized by stakeholders tend to increase the likelihood of positive outcomes (Ostrom 2005).

Monitors who actively assess both resource conditions and resource use behavior, and are accountable to resource users (or who are themselves resource users) tend to improve the performance of MPAs (Ostrom 1990; Buhat 1994). Compliance with rules governing resource use increases when monitoring of individual behavior and sanctioning of noncompliance is viewed as accountable, legitimate, and equitable for most or all involved (Ostrom 1990; Mascia 2004); a recent review found increased compliance with MPA rules was related to higher fish biomass (Pollnac *et al*. 2010).

Finally, processes for resolving disputes—both formal and informal—permit information exchange, clarification of rules, and adjudication of disputes related to decision making, resource use, monitoring, and enforcement (Mascia 2004). Available data suggest that low cost, local, and readily accessible conflict resolution mechanisms tend to enhance the performance of natural resource governance regimes (Ostrom 1990), such as MPAs. Building

Table 2 Research frontiers in policy-relevant MPA science

Ecological
Impacts of MPAs on widely-ranging, migratory, and pelagic taxa.
Temporal variation in impact (e.g., detection time, time for recovery to reach an asymptote).
Spatial variation in impact (e.g., differences inside and outside of MPA boundaries, variation with distance from MPA).
Magnitude of MPA impact (i.e., what effect size should we expect in effective MPAs?).
Impacts of MPAs on habitat, particularly outside of MPA boundaries.
Magnitude of ecosystem level impacts (i.e., what effect size is it reasonable to expect?).
Role of MPAs in restoring and maintaining ecological resilience, particularly to global processes (e.g., oceanic climate change and acidification).
Ecosystem services
Impacts of MPAs and MPA networks on provisioning, regulating, and cultural ecosystem services (e.g., on the magnitude, and spatial and temporal distribution of ecosystem service flows).
Scale at which the benefits or costs of altering ecosystem service flows occur (e.g., relative impacts at local, regional, and global scales).
Social
Impacts at different levels of social organization (e.g., individuals, households).
Distributive impacts within and among social groups (e.g., groups based on wealth, ethnicity, political power, livelihood, location), and the social consequences of disparities between groups (e.g., conflict, gender equity).
Impacts across multiple social domains (e.g., economic well-being, health, education, political empowerment, culture) and the potential for synergies and trade offs in impacts (e.g., between food security and income).
Variation (spatial, temporal, and across MPAs) in the magnitude and extent of social impacts.
Explaining variation in MPA impacts
Synergies and trade offs between the social and ecological impacts of MPAs.
Relative importance of ecological and social design principles/rules of thumb.
Role of ecological context (e.g., biophysical attributes) in mediating ecological and social MPA impacts.
Role of social context (e.g., political, cultural, and economic attributes) in mediating ecological and social impacts of MPAs.
Role of social capital and social networks in the establishment and performance of MPAs.
Role of MPA governance on the magnitude, distribution, and sustainability of MPA impacts.
Emergent properties of MPA networks compared to individual MPAs: Is a network of MPAs greater than, equal to, or less than the sum of its parts?
Interactive effects and efficacy of marrying MPAs with other marine resource management tools.

trust helps create social networks that can ameliorate day-to-day resource conflict (Ostrom 2005) and that can be drawn upon in times of social and environmental upheaval (Paulson 1993). Additional research is needed to understand better the role of conflict resolution mechanisms in MPA performance (Table 2).

From policy-relevant science to science-based policy: opportunities and challenges

Meeting CBD targets for MPAs will require a tenfold increase in global coverage of MPAs (Toropova *et al*. 2010). Scaling up MPAs has proven difficult, however, due to both biophysical and sociopolitical factors. Although guidelines on scaling up exist (e.g., IUCN-WCPA 2008), complexities include divergent interests of stakeholders in marine resource governance; the types, magnitude, and distribution of MPA social impacts (positive and negative); organizational and financial capacity limitations; boundary delineation; monitoring compliance; and conflict resolution (NRC 2001; Lowry *et al*. 2009; Mascia & Claus 2009). Although we recognize the need for political will and marine resource management reform, the 2020 target is a top-down declaration, yet research findings point to the need for a strong bottom-up approach. Nonetheless, the severe costs of delayed conservation action or inaction (Fuller *et al*. 2007; Grantham *et al*. 2009) highlight the need to move forward in developing MPA policies despite these challenging complexities.

Though no one-size-fits-all blueprint exists for establishing effective MPAs, research over the last 20 years has provided greater understanding of the potentials and the limitations of MPAs, as well as the factors that foster socially and ecologically effective MPAs. These scientific insights provide decision makers with the evidence base to tailor MPA design and management to local social and ecological contexts, which vary widely (e.g., developing vs. developed economies). Further advances in science-based MPA policy will require policy-relevant science that addresses key questions across social, ecological, and interdisciplinary domains (Table 2).

Innovative policies and programs are needed to increase the spatial extent and effectiveness of MPAs. A flexible and more entrepreneurial approach to "prototyping" different MPA arrangements and MPA policy, rather then implementing long-running and involved pilot projects within a rigid policy framework, may help. With flexibility, implementors may be more willing to act in case of failure to significantly enhance the success of MPA management. In the Coral Triangle, for example, engaging communities to reduce waste in their fishing operations, in conjunction with MPAs, has led to more profitable and sustainable livelihoods (L. Pet-Soede, unpublished data).

Though current science and practical experience demonstrate that MPAs can be implemented successfully despite imperfect knowledge, impact evaluation is a particularly promising approach to improving MPA science behind policy making. Growing calls for rigorous evaluation of MPAs (Sutherland *et al.* 2009; Rudd *et al.* 2011) have been accompanied by a few novel evaluative studies (e.g., McClanahan *et al.* 2006). MPAs are de facto "policy experiments;" by explicitly treating them as such, and employing rigorous research designs, impact evaluation can document and explain MPA impacts on ecosystems and society. Central to impact evaluation are two elements: a focus on long-term impacts (intended and unintended), and attempts to better control for alternative explanations of observed impacts—particularly the possibility that observed changes might have occurred even without the policy intervention (i.e., counterfactual argument; Ferraro & Pattanayak 2006).

At the same time, not all policy-relevant priorities for MPA science are appropriate for impact evaluation. Many important research questions do not lend themselves to quasi-experimental (ex post) designs (e.g., modeling the likely effects of MPAs on long-range larval transport) or are not focused on documenting or explaining impact (e.g., ethnographic investigations of historic patterns of marine resource use). Efforts to explain variation in ecological and social MPA impacts will also require methodological advances that enable scientists to readily describe formal and informal aspects of MPA governance; explore effects within and among elements of governance, human behavior, ecological impacts, and social impacts; and demonstrate causal relationships among these factors. Beyond further exploration of MPA governance, promising avenues for future policy-relevant MPA social science research include the roles of social networks and social capital, organizational structure, and legal frameworks in the emergence, evolution, and performance of MPA networks (Table 2, Lowry *et al.* 2009).

Well-designed social and ecological monitoring can inform MPA policy decisions, such as changes to MPA boundaries or regulations, and assessments of policy success or failure. In California, USA, for example, a statewide MPA network is being established to protect biodiversity and ecosystem structure, function, and integrity. Science-based guidelines for MPA placement and network design have guided MPA implementation the California legislation also expressly requires adaptive management and monitoring to ensure the MPAs are meeting defined policy goals. The efficacy of these guidelines for specific design and management decisions, including MPA size and spacing, will be evaluated as part of California's routine monitoring system. Around the world, similar monitoring efforts—although sometimes uninspiring to researchers and the public alike—have proven essential for assessing MPA performance and informing policy (Uychiaoco *et al.* 2005; Govan 2009).

Participatory monitoring, where resource users help to define monitoring metrics and methods as well as collect, analyze, and interpret data, holds particular promise as a mechanism for evaluating MPAs and catalyzing policy reforms. It can effectively integrate the perspectives of resource users and scientists, generate necessary data, leverage management capacity, and build collective understanding (Danielsen *et al.* 2009). Participatory monitoring can also increase human capacities for MPA monitoring and management, enhance the legitimacy of MPA monitoring results in the eyes of affected individuals, inform (and possibly accelerate) adaptive management, and spur further voluntary, community-based conservation activities (Aswani & Weiant 2004). Participatory monitoring is most effective when users have access to decision-making processes, and where western science and local forms of knowledge can form productive partnerships. In Mozambique, for example, participatory monitoring of fish abundance at the Quirimbas National Park has led to the establishment of numerous temporary no-take MPAs, women-led community-managed no-take MPAs to rebuild spawning stock biomass and bivalve populations, and, in an adjacent province, no-take mangrove MPAs to conserve juvenile shrimp (A. Costa, unpublished data).

Although policy-relevant monitoring can enhance the development of effective MPAs, science is only one of many considerations in MPA management and policy processes (IUCN-WCPA 2008). Science can provide decision makers with a better understanding of how the world works and the implications of various management and policy decisions, but it is often not the limiting factor in policy deliberations. What to do with scientific information, and how to act upon it, rests in the hands of decision makers and society more generally. Indeed, natural and social scientists must recognize and address real world societal and ecological constraints: in many contexts, MPAs often represent a viable conservation strategy only to the extent that they contribute to human well being. Strategies that mitigate negative social impacts and help communities adapt to MPA establishment may play a critical role in addressing social concerns. Balancing trade offs and deciding among policy alternatives are often at the crux of debates over MPAs and other environmental policies (Agrawal & Chhatre 2011; McShane *et al*. 2011).

Conclusion

Growing evidence demonstrates the potential of MPAs to conserve and restore localized populations and habitats. When designed well and effectively implemented, MPAs can restore fisheries and ecosystems both within and beyond MPA boundaries, as well as alleviate poverty among coastal communities. MPAs may be particularly useful as a conservation intervention in data poor contexts (the norm rather than the exception) in which the MPA can provide insurance against over harvest (Johannes 1998; Botsford 2005) and provide valuable ecological data on which to base future management decisions (Botsford 2005). Because policy goals vary, and there is no one-size-fits-all MPA approach, we must think more subtly about MPAs as policy interventions, recognizing that different forms of MPAs are appropriate for different contexts (Agardy *et al*. 2011). By increasing the use of impact evaluation and adopting an explicitly adaptive approach that simultaneously encourages science-based policy and policy-relevant science, immediate steps can be taken to address current marine conservation challenges and to lay the foundation for more effective marine management in the future.

Acknowledgments

We gratefully acknowledge the Gordon and Betty Moore Foundation, the Walton Family Foundation, and the David and Lucile Packard Foundation for supporting this work, portions of which were presented at the 2010 WWF Kathryn S Fuller Science for Nature Symposium, "New Perspectives on MPA Performance: Linking Knowledge to Action." We thank C.A. Claus, S. Gaines, B. Halpern, K. Selkoe, and R. Steneck for previous discussions on this topic, which benefited our thinking; R. Robison, P. Levin, and two anonymous reviewers for helpful comments on the manuscript; and K. Haisfield for assistance with formatting and references. This article is contribution #4 of the WWF research initiative "Solving the mystery of MPA performance."

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