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BRIDGING THE DIVIDE BETWEEN FISHERIES AND MARINE CONSERVATION SCIENCE

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ABSTRACT

Researchers from traditionally disparate disciplines and practitioners with typically incongruent mandates have begun working together to better understand and solve marine conservation and sustainable yield problems. Conservation practitioners are recognizing the need to achieve conservation goals in seascapes that are a source of livelihood and food security, while fisheries management is realizing that achieving economically and ecologically sustainable fisheries requires an understanding of the role of biodiversity and ecosystem dynamics in fishery production. Yet, tensions still exist due to the unique histories, epistemologies, cultures, values, and quantitative techniques of fisheries and marine conservation science, and the often-divergent objectives of the institutions and organizations these academic disciplines inform. While there is general agreement on what needs to be achieved (less overfishing, recovery of depleted fish stocks, reduction in bycatch and habitat impacts, jobs, food production), specific objectives and how best to achieve them remain contentious and unresolved. By analyzing three contemporary yet controversial marine policies (ecosystem-based fishery management, marine protected areas, and catch shares) and specific case studies, we demonstrate how both fisheries and marine conservation science can be used to provide clear scientific advice to practitioners and provide empirical evidence of the benefits of bridging the disciplinary divide. Finally, we discuss future prospects for collaboration in an emerging issue at the nexus of conservation and fishery management: eco-certification. Drawing on lessons learned from these empirical examples, we outline general processes necessary for clearly defining multiple conservation and fisheries objectives in working seascapes. By bridging the divide, we illuminate the process of navigating trade-offs between multiple objectives in a finite world.

A convergence between marine conservation and fisheries science has begun. Fisheries science is recognizing the need to move from conventional single-species assessments of yield towards multi-species approaches, including assessing the larger ecosystem consequences of fishing. The fishery management community is also expanding its use of policy instruments, from rights-based fisheries to cooperative structures and certification. Concurrently, marine conservation science is drawing increasingly on economics and the social sciences, and conservation practitioners are working towards achieving ecosystem protection while maintaining economically viable fisheries, fishing communities, and other activities that depend on marine resources. Collectively, there is increasing acknowledgment that marine conservation is largely about managing multiple human uses of the ocean. Though the terminology differs between disciplines, there is general agreement that science is needed to support two broadly defined objectives: (1) conserve biodiversity and (2) sustain pro-

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ductive fisheries. Achieving these two objectives, at least in the short- and medium-term, will require different policies and management actions, as current measures tend to achieve one at the expense of the other. It will also require increased communication, understanding, and integration of the sciences that underpin marine conservation and fisheries management—i.e., marine conservation biology, marine ecology, fisheries science, economics, and the social sciences.

While convergence toward common goals and perspectives has begun, the details remain problematic. Fisheries and marine conservation science have different histories, epistemologies, cultures, and priorities, leading sometimes to strikingly divergent views on the state of fisheries and marine ecosystems, and on how to achieve sustainability (Ludwig et al. 1993, Rosenberg et al. 1993, Myers and Worm 2003, Walters 2003, Hilborn 2006, Worm et al. 2006). Moreover, their separate professional societies, distinct journals, and different norms can impede communication, the sharing of scientific tools, and the acceptance of new ideas, and can lead to wildly different inferences made from the same data. Finally, the objective of maintaining or restoring marine biodiversity often conflicts with the objective of maintaining or increasing food supplies from the sea, because the level of fishing required to achieve the latter typically compromises the former (Brander 2010). These differences in objectives, tools, and inferences need to be navigated and put into practice by a variety of government agencies and nongovernmental organizations that often have conflicting mandates (Fig. 1). For example, Parks Canada is mandated to protect ecological integrity (National Parks Act 2000), while Fisheries and Oceans Canada is mandated to exploit fisheries at maximum sustainable yield (MSY, Fisheries Act 1985). Real structural incompatibilities (i.e., trade-off between extinction risk for species A and exploitation of species B) can make conflicting mandates difficult to resolve unless these underlying interactions are quantified and the trade-offs are made explicit.

We argue that the opposing views arise from a lack of clearly stated and often conflicting objectives and divergent values. The vehemence with which these contrasting views have been expressed has not helped to foster constructive dialogue aimed at making values, objectives, and differences more transparent. Although both communities are converging on a triple bottom line—ecosystem, social, and economic sustainability—there are diverging views on how best to achieve these goals (Hilborn 2007a,b), creating a gap that needs to be bridged. Furthermore, both expert and stakeholder groups often differ over the short-term policies and actions they think should receive priority. It is our opinion that opposing scientific views are healthy and dialectic[1] between disciplines should be preserved to propel scientific progress. However, conflicts over assumptions and unexpressed or misunderstood objectives are symptoms of ideological clashes rather than of scientific disputes, and do little to advance our understanding of how best to conserve marine ecosystems and the goods and services they deliver. Here, we attempt to pinpoint the problems and offer several concrete solutions. Our goal is to enhance the dialogue, bridge the divide, and spark cultural integration among fishery and marine conservation disciplines and institutions to improve the scientific basis on which the management of marine ecosystems is based.

1 A method of argument based on a dialogue between two or more people who may hold opposing views yet wish to seek truth through the exchange of their viewpoints while using reason (Plato. *The Republic,* Book X). This is in contrast to a debate, in which both sides are dedicated to their viewpoint and only wish to win the argument by proving themselves right or the other side wrong.

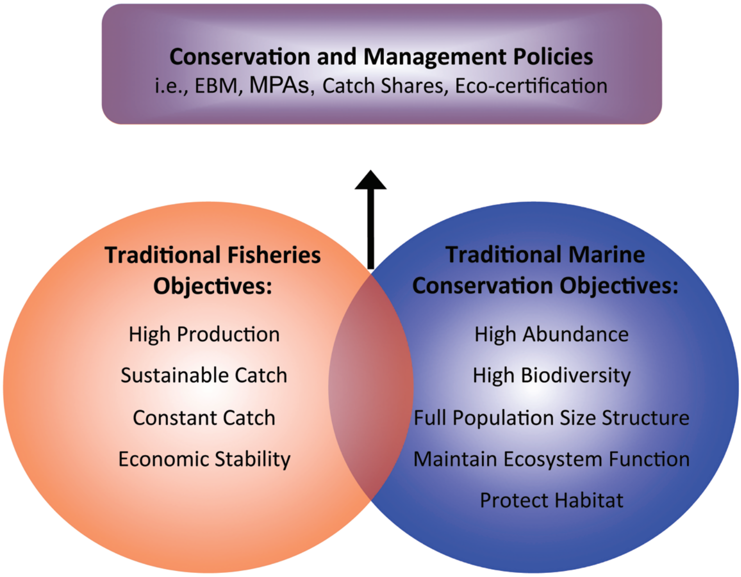

Figure 1. Fisheries and marine conservation objectives have traditionally differed. Bridging the divide between fisheries and marine conservation science will improve the effectiveness of conservation and management policy instruments. EBM = ecosystem-based management, MPA = marine protected area.

One of the key research challenges in sustainability science is identifying the policy instruments and actions that best promote the sustainable use of ecosystems (Essington 2010). To demonstrate the "value added" from bridging the disciplinary divide, we discuss three contemporary and increasingly common marine policies: ecosystem-based management (EBM), marine protected areas (MPAs), and catch shares, as well as the emerging application of eco-certification. All of these tools have generated debate between the marine conservation and fisheries sciences, yet their design and implementation have the potential to benefit from the strengths of both disciplines. For each policy, we describe specific case studies, with which at least one of the authors has first-hand expertise, to add to the growing number of practical examples illustrating the additional benefits from using both fisheries and marine conservation science techniques and approaches. These case studies also serve as a clear demonstration that to bridge the divide, both fisheries and marine conservation science need to broaden their interactions with other disciplines (including economists, anthropologists, sociologists, archaeologists, historians, political scientists), and intensify their interactions with policy makers, resource users, local communities, and levels of governance in working seascapes. We propose that biodiversity and food production objectives can be reconciled by using a combination of diverse management and conservation policies (including catch restrictions, gear modifications, EBM, catch shares, and marine reserves) tailored to local social-ecological contexts. Finally, we stress the critical importance of an inclusive stakeholder process to develop specific objectives for regional science and management, and the critical importance of a legislative mandate to maintain the process. Within this process, we encourage diversity in the dialogue and recognize the need to navigate trade-offs associated with any vision for the state and use of the marine environment. Agreement on common objectives, clarification of the trade-offs, and finding solutions that minimize trade-offs will help us move forward.

Multiple Objectives

Fisheries and marine conservation scientists generally operate within two different contexts as the application of their work is often linked to practitioners that need to meet different management objectives: marine ecosystem conservation vs achieving sustainable social and economic benefits from fisheries. Fisheries managers typically aim to keep stocks around a *target reference point,* typically the biomass that produces some proxy of MSY, and avoid going beyond biomass or fishing mortality *limit reference points* (Caddy and Mahon 1995). Increasingly, these management measures are applied to non-target species as well as target species (e.g., Reuter et al. 2010). Conservation practitioners tend to be more concerned with the risk of exceeding reference points and with risks to habitat and biodiversity than with maximizing yield. While the contexts are separate (fisheries management vs marine conservation), objectives can converge where there is agreement about the reference points, the appropriate buffers, the status of stocks relative to the reference points, and appropriate measures to protect habitats. There is also increasing convergence around the goal of maintaining populations of large, old spawners due to their disproportionately high contribution to the larval pool and their important ecological roles (Caddy and Seijo 2002).

The objective of most national and international fisheries legal mandates is the exploitation of populations to achieve sustainable social and economic benefits. In the US and some other countries, this is often translated as fishing to MSY (Hilborn and Stokes 2010). Achieving MSY generally means reducing target stocks to between 20% and 40% of their historical biomass—the level where net productivity or surplus production is theoretically greatest (Hilborn and Walters 1992). As fishing drives a stock down toward the biomass at which MSY is achieved, a number of its biological characteristics change. For example, a higher total mortality rate shifts the age distribution toward younger, faster growing individuals with potentially negative effects on future recruitment, and ecosystem-level processes. The aim is to make the stock as productive as possible, which necessarily means a high turnover of individuals—many recruits, and many deaths.

In contrast, marine conservation objectives are typically aimed at protecting biodiversity and minimizing extinction risk. Institutionally, this is often translated as preventing any rapid decline in populations, or changes in its biological characteristics. Consequently, whereas the reduction of a fish population to 20% or 40% of its unfished biomass with concomitant changes in age structure may be considered a necessary and acceptable outcome by fisheries scientists and managers, these may be viewed as unacceptably adverse impacts by some marine conservation scientists and practitioners. Moreover, overexploitation of stocks and severe declines beyond target reference points are rife; the median decline of 230 exploited fish populations was 83% (Hutchings and Reynolds 2004). Reductions on this scale far exceed fisheries target reference points and often breach the limit reference points that define the point beyond which reproductive output is impaired by the process known as “depensation” in the fisheries literature and “Allee effect” in the ecological literature

(Hutchings and Reynolds 2004). Until recently, such declines were of concern only to stock assessors, but now are of concern to a wide array of marine conservationists, who have in turn increased awareness of these declines among policy makers and the general public. Some of these declines are severe enough to merit concern on a wider stage. For example, until recently, 90% of assessed European stocks were fished beyond the limit reference points (Piet and Rice 2004); 17% had declined sufficiently to be classified as threatened under the World Conservation Union (IUCN) reference points based on population decline (Dulvy et al. 2005), although they would not be classified as threatened under the IUCN abundance and range extent benchmarks (Rice and Legace 2007). A more recent analysis of biomass trends for exploited marine fish stocks (Hutchings et al. 2010) offers some hope that declines may have leveled off since the 1990s.

Even when fisheries management is successful in maintaining fishing mortality and biomass at what are thought to be sustainable levels, the focus on single species often clashes with the biodiversity goals of marine conservationists. For example, even prudent and precautionary fisheries management has the potential to remove sufficient predator biomass to produce substantial shifts in ecosystem structure and function (Zabel et al. 2003, Salomon et al. 2008). Subsistence fishing, for food only, was sufficient to remove more than half of the invertivore biomass on Fijian reefs. This removal of predators unleashed outbreaks of coral-eating starfish, *Acanthaster plancii* (Linnaeus, 1758), resulting in repeated island-scale phase shifts from coral to algal dominated reefs only at the most heavily fished islands (Dulvy et al. 2004). Generally speaking, such ecological impacts of fishing receive little attention in fisheries management.

Differing interpretations of the meaning and significance of declines in biomass arise from the fact that fisheries management focuses on the rate of change of growth and recruitment of single species—the higher the better because the stock is more productive. In contrast, marine conservation focuses on rates of change in mature populations or communities—with the goal of maintaining "natural" age or community structure and increasing resiliency in the system, thus hedging against collapse. These contrasts in objectives and perceptions of status correspond to present competing views on the state of the world's fisheries and appropriate policy prescriptions. If one generalizes that population declines are part and parcel of sustainable fishery management, one is likely to view the state of fisheries as a mixed bag with many successes and some failures. Conversely, one is likely to view the state of fisheries as in crisis if one generalizes that observed population declines are indicators of extinction risk and loss of ecological function (Clark 1990, Hutchings 2001). In truth, some population declines are inevitable where fishing occurs, but some are associated with failure to meet management objectives or unsustainably high harvest goals. Similarly, not all declines are indicators of extinction risk or loss of ecological function, but some are.

Another way to frame the divide is to consider the primacy of objectives: fisheries scientists often operate within a context in which managers strive to balance conservation, social, and economic objectives such as optimizing yield from fisheries (e.g., DiCosimo et al. 2010). Nevertheless, in practice, primacy is frequently given to social and economic objectives over conservation objectives in order to alleviate or prevent short-term economic and social impacts. Marine conservation scientists, however, often frame analyses assuming conservation as the primary objective on the theory that social and economic benefits flow from conservation, and eventually long-term socio-economic benefits will arise. There is increasing awareness of the need to seek win-wins where tradeoffs between objectives are minimized. The discourse becomes dysfunctional when there is a lack of appreciation for the different values and goals, and a full and nuanced understanding of each side's assumptions and accepted tools. This dysfunction is amplified when there is a lack of real human-to-human communication about these values and associated tools (e.g., when discourse occurs solely through press releases or publications). When these differences in goals, values, and tools are understood, and the tendency to generalize is avoided, the dialogue between the disciplines has been extremely fruitful (e.g., Worm et al. 2009).

Addressing Uncertainty and Variability

Fisheries management has long identified the quantification of production parameters and their uncertainty as a central goal and a key management component (Walters 1986). In fact, many fisheries models estimate both process and observation error, and in the past decades have begun to consider uncertainty about future states of nature and that associated with implementation—both important for making management decisions about next year's (or next decade's) fishery. At the same time, qualitative aspects of species interactions and variability in key mechanisms is often overlooked or averaged out by fisheries scientists [e.g., natural mortality (M) is often *still* assumed to be 0.2 or some other constant number and stock recruitment relationships are treated as stationary]. To be fair, many such assumptions are made out of necessity (i.e., lack of data), not because they are believed to be unimportant or true. Nevertheless, it is argued that more complex and realistic models are usually difficult to parameterize, do not necessarily lead to more accurate outcomes, and have less, not more, precisions in estimates (Adkison 2009). The model agnosticism and the appreciation of diversity and surprises that many marine conservationists share may be of benefit to the fisheries management culture.

Marine conservation practitioners often view the variability and uncertainty inherent in any scientific assessment of a population as cause for precaution. This reflects a value judgment: that it is better to err on the side of conserving stocks and biodiversity. Such a value judgment can affect the framing of scientific analyses conducted by marine conservation scientists. In contrast, fisheries scientists are working within the context of fishery management where the concrete short-term adverse impacts of reductions in fishing opportunity need to be balanced with uncertain and less quantifiable conservation and economic benefits in the long-term. Indeed this is the crux of the matter—policies that create jobs and revenue today are pitted against policies that would protect biodiversity and generate revenue and employment options in the future. While many fishery managers and scientists operate within a legal context of precautionary action in the face of uncertainty, which has resulted in precautionary cuts in allowable harvest and other measures, economic and social concerns make such actions difficult in many fisheries. A mutual appreciation of the different values, legal mandates, and respective operating management contexts that drive behavior and attitudes with respect to dealing with uncertainty and variability would probably reduce conflict between the disciplines and communities. Conservation measures designed to minimize adverse social and economic impacts, and/or to solve implementation problems (for example, with collaborative planning processes, financing transition costs, risk pooling, etc.) would also help.

The disciplinary divide may be further magnified by the different needs of small-scale vs industrial fisheries and the experiences of scientists and practitioners working in these vastly different environments. Indeed, the effectiveness of fisheries management and conservation tools will vary as a function of economic, social, and ecological context. For example, what may be effective for industrial fisheries in the developed world, where fisheries target few species and data necessary for stock assessments tend to be available, may be irrelevant for fisheries in the developing world that tend to be multi-species and data-deficient.

Bridging the Divide

Fortunately, traditional barriers to communication between marine conservation and fisheries scientists are beginning to break down and interdisciplinary collaborations between them, and with social scientists and economists, are emerging (Hughes et al. 2005). This trend is driven, in part, by an increasing awareness of the magnitude and accelerating rate by which humans are altering the functioning of marine ecosystems and awareness that many past efforts to halt, and where necessary reverse, these alterations are either ineffective or working too slowly. Ultimately, understanding the ecological, social, and economic performance of both fisheries and conservation initiatives requires an improved understanding of linked social-ecological systems (Fig. 2; McEvoy 1986, 1996, Francis et al. 2007). This awareness has led to increasing acceptance of novel approaches to marine conservation and management (e.g., catch shares, private buyouts, fisheries funds to finance transition costs), increasing acknowledgment of ecosystem approaches to management in the mandates of governmental and intergovernmental agencies, and the growing role of international conservation conventions like the Convention on Biodiversity (CBD) and the Convention on International Trade in Endangered Species (CITES) in solving marine conservation issues (Doukakis et al. 2009).

Ecosystem-Based Management

The shift toward an ecosystem approach to fishery management (Pikitch et al. 2004) has increased the applicability of ecological knowledge to the fisheries and marine resource management process. In particular, an understanding of predator-prey interactions and the transfer of energy between trophic levels has taken on new importance in fisheries science. These insights are resulting in improved accounting for variations in recruitment, e.g., by factoring in natural predation and cannibalism, and the need to reserve prey for dependent predators, e.g., managing fisheries on capelin and euphausiids to support predators like squid, fish, birds, seals, and baleen whales. Moreover, increased sensitivity to the social and economic impacts of conservation measures on fisheries and other marine resource sectors within the marine conservation community has led to efforts to minimize adverse impacts (e.g., through the use of optimization processes to design small MPAs that nevertheless meet conservation objectives, catch shares to achieve greater profitability, etc.). While many challenges remain, such as the application of management and conservation measures at appropriate scales (e.g., scaling up protections to account for

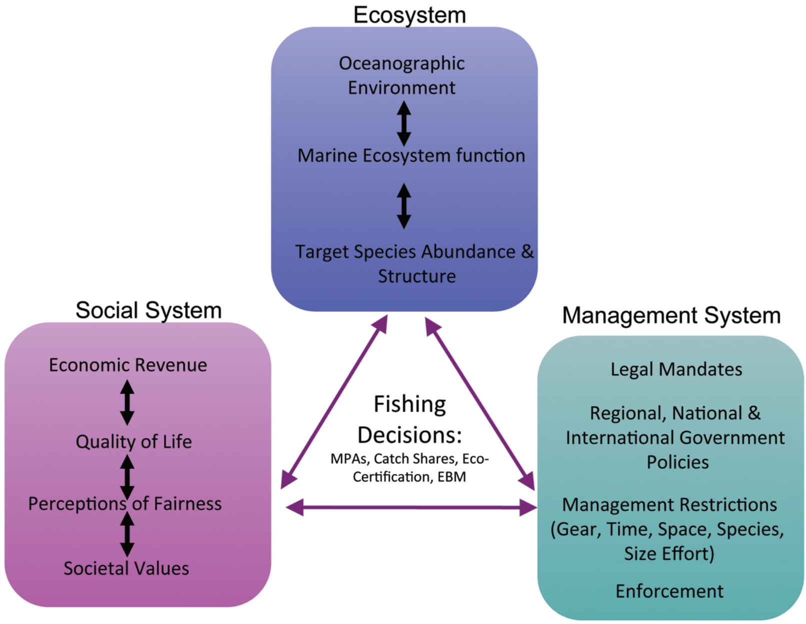

Figure 2. An improved understanding of coupled social-ecological system dynamics will yield more effective fisheries and marine conservation decisions (McEvoy 1986, 1996, Francis et al. 2007). EBM = ecosystem-based management, MPA = marine protected area.

migrations and large ecosystem processes, and scaling down fisheries management measures to account for local variations in species life history and fishing practices), progress toward bridging the divide is being made.

Case Studies

Arctic Fishery Management Plan.—The North Pacific Fishery Management Council, which develops management advice for the US National Marine Fisheries Service for US fisheries in federal waters off Alaska, recently developed an ecosystem-based fishery management plan for US Arctic waters that is seen as a win-win for conservation and fisheries (Wilson and Ormseth 2009). The plan anticipates future fisheries emerging as a result of climate change, and identifies potential target species, including Arctic cod, *Boreogadus saida* Lepechin, 1774, which is the most abundant fish in the US Arctic and commercially important in other regions. However, the plan also identified Arctic cod as critically important forage for marine mammals and seabirds in the ecosystem. Based on this finding, as well as the current expense of operating commercial fisheries in these distant waters and uncertainties regarding ecosystem productivity and dynamics, the plan effectively closes US Arctic waters to commercial fishing, but outlines conditions under which fishing would be allowed in the future. These conditions include sufficient data and analysis to ensure that fisheries will not harm the ecosystem and can be conducted sustainably. An exception is the transition of existing subsistence fisheries to commercial fisheries; the plan puts in place a process for scoping and managing such fisheries if they arise. The Council explicitly recognized ecological, economic, and social axes of sustainability:

> "This management policy recognizes the need to balance competing uses of marine resources and different social and economic goals for sustainable fishery management, including protection of the long-term health of the ecosystem and the optimization of yield from its fish resources. This policy recognizes the complex interactions among ecosystem components, and seeks to protect important species utilized by other ecosystem component species, potential target species, other organisms such as marine mammals and birds, and local residents and communities."
> (North Pacific Fishery Management Council 2009)

We note that almost no other US fishery management plans have preemptively closed potentially valuable fisheries in response to ecological considerations. This is an example of ecosystem-based fishery management which can prevent difficulties balancing the conservation of fragile ecosystems with initially unplanned and unregulated fishing.

Kenyan Coastal Community Management.—The Kenyan government had two main objectives in management of coastal resources shortly after Independence in 1963: (1) increase tourism and (2) develop fishery resources for food and export. These economic objectives lead to the establishment of a series of four fisheries closures (10–25 km^2) that covered ~7% of the nearshore and a policy of largely unrestricted access to fisheries resources in the remaining areas (Wells et al. 2007). The result was a strongly dichotomized social-ecological system where a few protected areas maintained largely undisturbed ecosystems for tourism while heavy fishing was undertaken in most of the remaining shallow ecosystems. Fishing effort ranged from 4 to 16 fishers km^{-2} and small-meshed seine nets were most frequently used, capturing the few fish species that could maintain production under the heavy exploitation (McClanahan et al. 2008). Catches in these fisheries were seldom more than 2–3 kg per person per day and incomes less than a few dollars per day. This created a strong sense of ecological and economic disparity between the fisheries and tourism-dependent communities, as well as large differences in reef ecology and biodiversity in these two systems. Government efforts to increase the areas in fisheries closures were meet with hard opposition from fishing communities who were concerned about loss of access and further economic marginalization.

Management actions to control fisheries effort were largely unsuccessful and large closures of > 5 km^2 were becoming increasingly difficult to establish (McClanahan 2007). Gear restrictions were implemented in some areas, but not others, dependent on local support for government regulations. Declining finances and ability of the government to control local fishers and their fishing behaviors led to the recognition that progress could not be made unless fishers took a larger role in their own management. This lead to legislation that created what are now commonly called Beach Management Units (BMUs). BMUs allow for local bylaws and management of local resources by BMU committees composed of fishers and other stakeholders who propose regulations to the Director of Fisheries. The implementation of this local management system is new and untested, but it is leading to greater recognition of the need for local responsibility and planning of fisheries and coastal economic development. One of the first achievements of this BMU process was the local planning and implementation of small community closures, called *Tengefu*, which means "set aside" in Swahili. Communities plan to use these Tengefu to attract tourism to their reefs and also create refuge for the key fisheries species. The concept and implementation is only partially being evaluated, but it is anticipated that the Tengefu will reduce the strong dichotomy in management and create some intermediate system that may potentially benefit the ecosystems and communities that are not being protected by the few larger fisheries closures.

European Union's Ecosystem Approach to Fisheries Policy.—The declining productivity of European waters coupled with fleet building in the early 1970s set the stage for widespread overexploitation of many species, including the near regional extinction of formerly abundant elasmobranchs, such as the common skate and the angel shark (Brander 1981, Walker 1998, Dulvy 2000). The hopelessness of managing fish stocks around the knife edge of limit reference points, increasing concerns for weaker, less productive species such as skates and other elasmobranchs, and a decline in the influence of stock assessments led to radical change in European fisheries science and management. Stock assessors, even into the new millennium, were increasingly despondent at the challenges from industry regarding the quality of stock assessments. The challenges were frustratingly valid, because it was widely known that stock assessments weakened year-on-year as they overlooked an ever increasing proportion of illegal and unreported landings—up to 40% of the landings of cod and saithe were illegal in the late 1990s (Clover 2006). Stock assessors and fisheries managers, instead of being afraid of conservationists, were desperate for a new paradigm that has subsequently been filled by the development of an ecosystem approach to fisheries management.

At that time, the upcoming cadre of senior European fisheries scientists had come from more ecological or conservation related disciplines than their predecessors, ranging from plant ecology to bird community ecology to coral reef ecology. Many more had lived through attempts to bring food-web realism to fisheries through the development of multispecies stock assessment models—an EU-wide scientific endeavor that reached a pinnacle with the 1991 "Year of the stomach" survey of fish diets (Rice et al. 1991, Hollowed et al. 2000). Notably, an influential number of senior scientists have now moved from a niche-based view of shelfseas ecosystems to a size-based perspective (Bianchi et al. 2000, Jennings and Blanchard 2004, Pope et al. 2006)

Although the modern era of EU fisheries management could be considered to be dominated by indicators after a decade of effort and the discovery of several thousand potential metrics (Rice 2003), there has been a stark realization that indicators alone do not constitute an ecosystem approach. Indicators have to be "fit-for-purpose" and need to be selected to report on ecological objectives (Rice and Rochet 2005). The more recent focus has been on determining what fit-for-purpose means, and understanding of what objectives are reasonable (Rogers et al. 2007). This has lead to the articulation of vision statements (what society actually desires of our oceans), leading to clear policy statements such as the UK vision for "safe, clean, healthy, productive, biologically diverse oceans," for example. This vision encompasses water quality, harmful algal blooms, shellfish diseases, food security, biodiversity, and climate change. In reductionist scientific terms, this vision might seem vague and contradictory, but such vision statements provide valuable guidance for the formulation of specific objectives, appropriate indicators, and reference points given the constraints of available monitoring data. Critically, such visions explicitly recognize the inevitable trade-offs that need to be made.

The ongoing challenge is to develop spatial management and complementary measures to realize all elements of the vision, while recognizing and attempting to minimize trade-offs among them. With respect to spatial management, this might mean that in some areas an active decision is made to forgo the "biologically diverse" aspiration and allow high fishing pressures to meet the "productive" element of such a vision; and in others to forego "production" and eliminate benthic trawling on biologically diverse areas such as coldwater coral reefs or other biogenic habitats. It is unlikely that we can achieve all ecological quality elements in each spatial management unit, but conceivably, a spatial management portfolio exists that allows us to maximize parts of the societal vision across the full portfolio of spatial units. With respect to other measures, addressing tradeoffs may mean creating new kinds of fishing privileges (e.g., catch shares) and institutions (e.g., common pool resource co-management entities). Meeting these challenges in order to operationalize the ecosystem approach to fisheries management will require many different disciplines.

Marine Protected Areas

Marine conservation scientists and practitioners have often supported the notion of permanent spatial closures, i.e., marine reserves to protect population and community dynamics and biodiversity. Those advocating the use of marine reserves have also explicitly recognized the need to manage fisheries sustainably in the rest of the ocean, recommending spatial protection as only part of an overall fisheries management scheme (i.e., as an insurance mechanism against inevitable management uncertainties or natural catastrophes; i.e., Allison et al. 1998, Pauly et al. 2002). The risk aversion characteristic of this community results in a preference for management tools and science that fully supports a precautionary approach and facilitates the preservation of at least some part of an area's habitat and associated communities.

Marine protected areas offer an avenue to bridge the quantitative and methodological differences between disciplines. Marine ecology, an essential element of marine conservation science, has traditionally emphasized a mechanistic understanding of marine community dynamics (key ecological processes such as competition and predation) via experimental manipulations. This approach was limited to small spatial and temporal scales owing primarily to the logistical constraints of experimentation and replication. Information gathered at small scales can result in relatively strong inference due to the use of controls, but is difficult to scale up to the much larger scales at which many fisheries operate. Fisheries science depends heavily on long time series of data and parameterization of population models designed to describe phenomena over very large spatial and temporal scales while experimental manipulations are rare. Furthermore, fisheries stock assessments are not usually spatially explicit, and hence have a hard time incorporating closed areas or MPAs (except by adjusting fishing mortality or abundance estimates for the whole stock assessment region). Nonetheless, examples of convergence exist; marine reserves can be treated as large-scale management and policy experiments (depending on how the reserves have been selected, established, and managed) and can be evaluated based on their ability to achieve both biodiversity and fisheries objectives via adult and larval spill over. They are also potential controls for fishing experiments and can therefore satisfy the technical needs of adaptive fisheries management programs, as well as provide data for harvest control rules (Babcock and MacCall 2011, McGilliard et al. 2011). Moreover, fisheries management measures are now being assessed using Management Strategy Evaluation (e.g., Mapstone et al. 2008) and Before-After Control Impact (BACI)–like approaches (e.g., Essington 2010) in order to draw stronger inferences about their performance.

Historically, rigorous consideration of social science concepts or tools (e.g., governance, institutional analysis, the nature of fishing rights, occupational multiplicity, economic valuation of ecosystem services, social capital, and profitability) by either discipline was rare (but see Fujita et al. 1997). However, this is rapidly changing (McClanahan et al. 2009a,b, Fujita et al. 2010). Marine conservation and fisheries management could benefit from insights from social science related to the design of management measures that are aligned with social and economic incentives, and that minimize adverse social and economic impacts or even produce net increases in welfare. Arguably, understanding the effects of policies on human behavior is just as important as understanding the distribution and abundance of fish populations, as it is one of the only variables that management can affect.

Many efforts are underway to bridge the quantitative divide between fisheries management and marine conservation. Convergence can be seen in the increasing use of meta-analysis by conservation scientists to overcome scale issues (Mosquera et al. 2000, Lester et al. 2009), and in the increasing interest among fisheries scientists in regional and local scale assessments and management (Prince 2005). Meta-analyses of low- or no-replication management measures, such as marine reserves, have been used by conservation biologists to derive general principles and to investigate the performance of these management measures. Meta-analysis will provide a powerful way to increase the scale and relevance of management for both conservation and resource use and is a useful tool for both disciplines where space and research effort are often constraining the development of robust general principles. Stock assessment models can now incorporate sub-regional information about growth rates, mixing, and fishing effort.

Case Studies

Ecosystem Approach to MPAs in Indonesia.—Located off the coast of West Papua in Eastern Indonesia, the Birds Head Seascape (BHS) is the center of the Coral Triangle, the most biodiverse marine region in the world (Veron et al. 2009). A system of MPAs has been established to protect this incredible biodiversity. A wide range of monitoring, education, and outreach activities has made the MPA network an accepted tool on the ground to achieve conservation in BHS while maintaining the livelihoods of local people. Participatory processes were key, as were insights into social structure (e.g., the existence of traditional marine tenure systems and the avoidance of areas of active conflict for MPA implementation). MPAs in this area are tools for both ecosystem conservation and sustainable fisheries. The area is also increasingly becoming the target for development of a wide variety of economic sectors (e.g., fisheries, energy extraction, and tourism). As a result, local governments in this region are facing difficult decisions in their attempt to balance sustainable development of an incredibly rich array of marine resources with conservation of globally significant marine diversity. The growing range of diverse objectives within the seascape, as well as the obvious existing ecological, governance, and human connections, have made the adoption of an ecosystem-based approach to management an increasing priority and focus for the BHS. As a result, conservation and fisheries objectives are addressed side by side by the practitioners working in this area.

The Nature Conservancy (TNC), Conservation International (CI), and World Wide Fund for Nature (WWF) have been working in partnership with local stakeholders to explore and describe the ecological, socioeconomic, and governmental processes that are most important to understand and include in management decisions in the BHS. Based on the results of these studies, TNC, CI, and WWF are in the process of assisting local and provincial governments to develop environmentally sound development policies able to address multiple objectives (including conservation). Effectively demonstrating the links between EBM and MPAs, and leveraging existing buy-in on the ground for MPAs to address use issues both within, as well as outside of the MPAs, will clearly be a powerful avenue for the adoption of EBM in the BHS (Agostini 2009).

Density Ratio Approach Based on Marine Reserves.—Many small-scale, nearshore fisheries lack historical abundance and catch data, which are needed to parameterize conventional fisheries stock assessment models. However, ecological monitoring from in and around marine reserves can also inform the historical impact of fishing on fish populations. McGilliard et al. (2011) and Babcock and MacCall (2011) have proposed using the ratio of the measured density of fish outside a no-take marine reserve to that inside a reserve each year (the density ratio) as the input to a control rule which managers could use to specify the appropriate direction and magnitude of change in fishing effort or catches in the next year. A lower density ratio would trigger a reduction in the allowable fishing effort or mortality, which would allow biomass to recover in the fished area, thus increasing the density ratio. The density ratio can be calculated from marine reserve monitoring data, and the allowable change in fishing effort (or catch) is calculated relative to the current effort (or catch) so that no historical data are required. Wilson et al. (2010) apply a similar approach within a decision tree framework to facilitate the use of additional data on size structure to refine allowable yield estimates.

According to simulation studies based on California rockfish species (McGilliard et al. 2011, Babcock and MacCall 2011), in the long term, the density ratio control rules performed well by increasing total biomass and maintaining yield for all species and several scenarios about fleet distribution and fish biology, provided that migration of adult fishes across the reserve boundary was minimal. Advantages of using density ratio control rules are that no historical catches or stock assessments are required, the control rules are driven by monitoring data (requiring fewer assumptions and parameters), and they allow the management system to respond appropriately to environmental fluctuation. In addition, density ratio control rules can be applied at more local spatial scales than is common for stock assessment-based control rules. Density ratio control rules are only effective for species that tend to accumulate density in marine reserves, and the method would be most effective for reserves that have been established long enough for fish density to build up in reserves.

The density ratio control rule was developed through a collaborative process that included marine ecologists, fisheries scientists, social scientists, and fishermen. It remains to be seen whether this methodology will work well in practice, but the larger point is that there is a need for "outside the box" ideas for how to achieve fishery management and conservation objectives given the data that are available or can be acquired.

Catch Shares

Fisheries management and marine conservation both face the challenge of managing common property resources. The primary goals of fishery management are to provide fishing opportunities, generate revenue and livelihoods, and maintain sustainable levels of fishing mortality and spawning stock biomass. The marine conservation community has tended to focus on the goals of conserving fish biomass, diversity, and ecosystem integrity over relatively long time horizons. Conventional approaches to fisheries management and conservation tend to create conflict among these goals, due to the incentives created by common measures, such as input or effort controls (e.g., gear restrictions, restrictions on vessel length and horsepower, seasons, etc.) and output controls (e.g., total allowable catch limits).

In the absence of strong collective action institutions, such as fishery cooperatives or fishing rights regimes (also termed catch shares where individuals or groups of individuals are allocated a percentage of the total allowable catch), individual fishermen face incentives to overexploit fish populations. Individuals who are not embedded within a well designed and functional collective resource management system, whether based on cooperation or on market forces, tend to compete with others to maximize share of the catch since individuals do not have secure shares or incentives to cooperate with the goals of maximizing values, minimizing fishing costs, and minimizing incidental catch and habitat damage. Under these incentives, overcapitalization, destructive fishing, and the use of gear that can catch very large volumes of fishes (often indiscriminantly, leading to enormous amounts of waste) become rational, even though these behaviors result in unsustainable fishing.

Imposition of input/effort controls aimed at controlling fishing mortality by limiting fishing power in the context of this common pool resource problem (i.e., in the absence of collective action institutions or catch shares) tends to increase fishing costs and create a "cat-and-mouse" game between regulators and fishermen, in which fishermen face strong incentives to innovate solutions that get around regulations in order to maximize catch. Imposition of output controls like total allowable fishing levels tends to exacerbate this race for fishes (more vessels, larger gear, more rapid fishing), increase fishing costs, and reduce value (by glutting markets). Thus, these types of conservation and management measures create economic distress and are not aligned with strong social and economic incentives. Discount rates are very high, since fishes only have value when caught and individual fishermen can never be sure what their share of the catch will be. It is not surprising, then, that in this context additional conservation measures such as MPAs intended to protect whole ecosystems and biodiversity, perceived as investments in long-term sustainability by marine conservation community, are perceived as threats to livelihoods by many fishermen and fishery managers.

Management approaches based on dedicated access privileges (or catch shares), such as Individual Transferable Quotas (ITQs), Territorial Use Rights for Fishing (TURFs), or community development quotas (CDQs) are designed to help solve the common pool resource problem by creating incentives that encourage behavior consistent with conservation. Consequently, they offer a way to align fisheries management and marine conservation, that can minimize the tradeoff between strong conservation and good economic and social performance in fisheries. The transformation in the governance of Chile's coastal marine resources via fisher collectives that co-manage TURFs, locally known as "caletas" (Gelcich et al. 2010), provides compelling evidence of the benefits of these approaches. Furthermore, experience with collective action institutions (Ostrom 1990, 1999), a meta-analysis of over 200 catch shares systems (Costello et al. 2008), and a recent synthesis of literature and expert opinion on catch share design (Bonzon et al. 2010) suggest that good institutional design, strong governance, the re-alignment of incentives, and increased accountability can enable fisheries to overcome the problems that plague many fisheries (overfishing, high bycatch rates, and habitat impacts). Yet, catch shares have their ecological and social limitations (Pinkerton and Edwards 2009, Essington 2010, Gelcich et al. 2010, Pinkerton and Edwards 2010, Sumaila 2010, Turris 2010) and thus remain controversial.

Although designed to promote economically efficient exploitation and ecological stewardship among fishers over the long-term, catch shares do not always address the negative impacts of fishing on marine ecosystems (Branch 2008, Essington 2010) and can impede equity and social justice in resource use (Pinkerton and Edwards 2009). Thus, to meet ecological, economic, and social sustainability, the trifecta of modern fisheries management, some observers maintain that catch shares need to be designed as part of an integrated ecosystem-based management plan (Sumaila 2010), one that addresses the dynamics of linked social-ecological systems (Fig. 2). Others argue that catch share systems can be designed to achieve this trifecta better than other management policies alone, if appropriate measures (e.g., robust catch limits, MPAs, transition financing, equitable allocation formulae, community quotas, etc.) are included and implemented well (Bonzon et al. 2010). Consequently, we see the improved design and implementation of catch shares as an area that is ripe for bridging the divide between conservation, fisheries and social scientists, economists, resource managers, and resource users.

Case Study

Private Trawl Permit Buyback in California.—A 2001 lawsuit by conservation groups provided impetus for the Pacific Fishery Management Council and NOAA to implement the Essential Fish Habitat mandate of the US Sustainable Fisheries Act of 1996. The marine conservation community was calling for the creation of large no-trawl zones; fishermen were generally opposed. In 2005, The Nature Conservancy (TNC) and the Environmental Defense Fund (EDF) initiated a private buyout of trawl vessels and permits conditioned on the establishment of no-trawl zones collaboratively designed with fishermen to optimize conservation gains and minimize impacts on fishermen and fishing communities. As a result, trawl effort based in Morro Bay, California, was reduced from six vessels to one, the F/V South Bay, and three no-trawl zones totaling 3.8 million acres of diverse habitat were established by NOAA.

Subsequently, a community-based fishing association (CBFA) was created, consisting of these two NGOs, two commercial fisherman's associations, two harbormasters, and the California Department of Fish and Game. This CBFA successfully applied for an Exempted Fishing Permit (EFP) to allow TNC to lease the trawl permits it had acquired to fishermen willing to use hook and line or trap gear only. TNC also completed an innovative Conservation Fishing Agreement with a trawl fishermen who agreed to comply with stringent spatial and gear restrictions in order to target groundfish (e.g., flatfish) that could not be captured with hook and line or trap gear. These arrangements amounted to a hybrid catch share–collective action fishery; the EFP includes caps on multiple species aimed at ensuring sustainable harvest and bycatch rates (essentially, a catch share allocation to a community). A collective action institution (the CBFA) was developed to implement the EFP fishery by sharing information and creating economic and social incentives aimed at maximizing the value of the entire portfolio of fisheries included within the EFP.

Nested within a fishery with high bycatch and discard rates that constrained fishing opportunity, the CBFA's fishery resulted in 100% compliance with hard catch limits and near-zero bycatch in the past two fishing seasons. Data from fishermen and observers flow into an electronic database, know as "eCatch", which is used to inform in-season adjustments in order to avoid bycatch and extend fishing opportunity by reducing mortality rates on species for which landings are approaching hard caps. TNC is testing the use of a video-based electronic monitoring recording system developed by Archipelago Marine Research Ltd. to determine whether it is a feasible alternative to 100% human based observer coverage for fixed gear vessels fishing in the EFP.

Project partners are developing niche markets and new distribution channels for local, fresh fish to generate higher values in order to offset economic losses resulting from the trawl buyout. Business planning support and low-interest loans from the California Fisheries Fund (developed by EDF, California's Ocean Protection Council, and private funders) are being employed to support these activities. This project has resulted in significant conservation gains and shows promise for the creation of a new, higher value, lower impact fishery to replace a trawl fishery. However, the project also resulted in substantial economic and social impacts. Information on these impacts is still preliminary, but early results suggest that the project is on a trajectory toward ameliorating them. Initial transition payments from TNC helped to alleviate the immediate economic distress associated with the reduction of trawling. Value per pound increased from $0.81 in 1990 to $1.69 in 2009 (Wise 2010). Since the Central Coast Groundfish Project fishery, which includes both the trawl Conservation Fishing Agreement and the EFP, started in late 2007, 1.51 million pounds of fish have been landed, resulting in ex-vessel revenues of $2.34 million.

Eco-Certification

Eco-certification of fisheries products as coming from sustainable fisheries offers another opportunity for bridging the gap between the fisheries management and marine conservation communities. Eco-certification is well established for some resource-based industries, such as forestry, agriculture (Hatanaka et al. 2005), and biofuels (Lewandowski and Faaij 2006). There are many controversial issues associated with using economic instruments in fisheries management (Rice 2007), but a thorough review of the potential strengths, weaknesses, and complicating factors with regard to certification (FAO 2001, 2005) concluded that use of market tools including eco-certification may be a constructive factor in increasing the sustainability of fisheries, if they are properly designed and implemented. This means that there have to be clear and explicit standards for certification assessments that must be sound and objective, use best available information, take full account of uncertainties, and be conducted by credible assessors that are held accountable.

It is in these evidence-based assessments and their review that the two communities must come together. The language of the Marine Stewardship Council (MSC, probably the most widely recognized fisheries certification body) Scoring Criteria and Assessment Guidelines is the language of fisheries science: limit reference points, target reference points, harvest control rules, etc. However, the concepts to which those standards are applied include not just seven criteria about the status and exploitation of the target species assessed under Principle 1, but also 15 criteria regarding the ecosystem effects of the fishery (Principle 2), and nine criteria related to the governance of the fishery (Principle 3). Under Principle 2, a fishery must have demonstrated to be sustainable with regard to its impact on all bycatch species, all habitat impacts, trophodynamic consequences, and species given special protection under, for example, endangered species legislation. Language in the scoring guidelines for passing scores on sustainability closely reflects the language of sustainability and precaution in Agenda 21 of the Rio Declaration, the basis for much of the progress in conservation science during the last 20 yrs. A fishery cannot receive a score below 60% on any single criterion under any of the Principles, and must have at least an average of 80% for all the criteria under each of the three principles. Existing fish stock assessments are often the basis for scoring against the P1 criteria, but for P2 and P3, the certification assessment process requires analyses rarely done for fisheries managers (Rice 2010). In the work to prepare analyses and reviews for evaluations of P2 and some aspects of P3, and in the sequence of opportunities for review and engagement of experts and stakeholders throughout the MSC assessment process, there are many opportunities for collaborative work of experts from the two disciplines, and a meeting of minds over evaluating ecosystem factors familiar to conservation scientists in a framework familiar to fisheries scientists.

Certainly, when research used to certify seafood comes from the industry itself, conflicts of interest (i.e., industry-funded labels) can arise quickly. Thus, a key challenge for eco-certification is to ensure that it has high integrity and is a force for sustainability and thus free from the conflicts of interest that plague it now (Jacquet et al. 2010). Eco-labeling can help break the tyranny of the market chain that constrains prices and drives a race to fish, or it can become another method of brand differentiation to sustain further supermarket sales. This latter process may well aid security of supply over larger spatial scales, but it remains an open question as to its net benefit for the viability of fishing communities and exploited ecosystems. Of course the costs of acquiring eco-labeling sets small developed and developing world fisheries at a distinct disadvantage compared to industrialized capital-intensive fisheries (Jacquet et al. 2010) unless grants or loans are made available to address this inequity.

General Recommendations to Bridge the Disciplinary Divide

In order to bridge the fisheries-conservation science disciplinary divide, improve the scientific basis of marine resource management, and ultimately facilitate sustainable use of marine resources and the protection of marine ecosystems, we make the following recommendations:

Objectives

1. Clarify values and objectives of agencies, NGOs, stakeholder groups, and indigenous peoples at the outset of decision-making processes so that scientific analyses are framed and interpreted appropriately.
2. Tailor the quantitative, qualitative, and policy tools that address both fisheries and conservation objectives to the ecological, economic, and governance structure where they are applied.
3. Implement measurable performance standards that reflect specific social values; such standards are necessary for meeting biodiversity and conservation objectives. Prescriptions without clear performance indicators often introduce incentives to game the regulatory system. Shifting the discourse to objective measures of progress and their stated values can help defuse polarized ideological arguments by focusing on the pragmatic and objective measures.
4. The best available science and data need to be available to managers and practitioners to define objectives and measure progress in the future. This requires open access to data to facilitate transparency. The availability of fisheries data and accessibility of the stock assessment process must increase outside of the fisheries science community.

Tools

1. Apply tools that measure trade-offs among the full suite of objectives and make these trade-offs clear in the analyses and methodology.
2. Apply tools and policy measures that minimize or eliminate trade-offs. For example, align institutional and economic incentives with indicators of performance and sustainability for economic, ecological, and social objectives.
3. Develop tools that allow inclusion or explicit consideration of the multiple and differing scales over which dynamics of fisheries, ecology, and human dimensions occur (Fujita et al. 2010) .
4. When evaluating biodiversity and conservation objectives, determine the outcome of a variety of social and economic objectives that are achievable over short and medium time frames. Design tools that convert future value of conservation into net present value for fishermen and fishery managers (e.g., catch shares, loans, new markets for ecosystem services).

Practice

1. Converge on “one window” for science advice for all agencies with overlapping mandates so the fisheries agencies, species-at-risk agencies, the ecosystem integrated planners, and the MPA managers all get the same advice from the same group of experts. That group of experts should include the full spectrum of types of expertise and perspectives, and may be producing a variety of products tailored for management and policy bodies with different duties.

2. Both fisheries and marine conservation scientists need to interface more regularly with social scientists, fisheries managers, conservation practitioners, policy makers, and fishermen to recognize the profound importance of understanding fishermen/fleet/institution behavior. For example, experienced fishers can be helpful in identifying important research questions and designing alternative exploitation practices.
3. Develop governance and financial systems that create incentives for fishermen to engage in conservation and stewardship. These tools include dedicated access privileges (catch shares), loans, permit and quota banks, and cooperative structures (Ostrom 1990).
4. Employ trade-off analysis and stakeholder processes to explicitly identify and assess ecosystem service and biodiversity trade-offs in order to find optimal solutions outside of the "normal" solution space that is constrained by unclear values, goals, and relationships among ecosystem services.

Communication

1. Identify, evaluate, and communicate shared values. Communication focused on understanding people's interests and points of view rather than focusing discourse on their positions.
2. Increase the variety of technical input represented in formal fisheries management decision-making. Increase power sharing in the fishery management process to include diverse stakeholder groups and conservation non-governmental orginizations that fully engage within the decision making process.
3. Clearly articulate the social, environmental, and fisheries consequences of policy options for all sectors affected by potential management actions (fisheries, conservation, marine transportation, energy, coastal zone development, etc.). Quantify societal preferences for the delivery of different combinations of ecosystem services, and provide decision makers with information about how various stakeholders might weigh trade-offs based on their preferences and values.

Conclusion

With the growing awareness that marine conservation and resource use problems are by nature interdisciplinary (Fig. 2), researchers from traditionally disparate disciplines have begun working together to better understand and solve them. Bridging the disciplinary divide between fisheries and marine conservation science and achieving multiple objectives will require lively dialogue and a diversity of expertise. To that end, we have attempted to illustrate the major features of the disciplinary divide and to provide guidance and examples of how fisheries and marine conservation science can come together to create a better scientific basis for decision making and generate solutions that can improve human welfare while protecting and restoring marine biodiversity and marine ecosystems.

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