PERSPECTIVE: FISHERIES MANAGEMENT

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Marine protected area guardhouse, Bohol, Philippines

The Value of Information in Fishery Management

ABSTRACT: Fishery management is often characterized by trade-offs among conflicting objectives. One important trade-off exists between investments in assessment (reducing uncertainty) and in implementation of management actions in a system. Resource-intensive assessment programs are often used to inform decision makers, and we argue that the value of these assessments should be measured not only in terms of the information they provide, but also relative to other management actions that could be funded in their place. In this article, we illustrate the importance of accounting for all aspects of the value of information using examples drawn from three critical areas of fishery management: invasive species control, commercial fisheries stock assessments, and marine protected area design. We discuss how experts have judged the value of assessment programs in the past, and provide suggestions as to how these methods could be expanded to examine the value of information in a more holistic manner.

El valor de la información en el manejo de pesquerías

RESUMEN: El manejo de pesquerías a veces se caracteriza por el balance entre objetivos antagónicos. Un ejemplo relevante es el balance que existe entre las inversiones aplicadas a la evaluación (para reducir la incertidumbre) y aquellas aplicadas a la implementación de acciones de manejo. Los programas de evaluación que implican inversiones importantes son utilizados para informar a quienes toman las decisiones, y aquí se argumenta que el valor de dichas evaluaciones debiera ser medido no solo de acuerdo a la información que producen sino también en lo relativo a otras medidas de manejo que pudieran ser financiadas en lugar de aquellas. En este artículo se ilustra la importancia de considerar todos los aspectos concernientes al valor de la información utilizando ejemplos extraídos de las tres áreas críticas del manejo de pesquerías: control de especies invasivas, evaluación de pesquerías comerciales y diseño de áreas marinas protegidas. Se discute cómo en el pasado los expertos han juzgado el valor de los programas de evaluación y ofrecido sugerencias de cómo estos métodos pueden expandirse para examinar el valor de la información de una manera más holística.

INTRODUCTION

Uncertainty is pervasive in natural systems, and manifests itself in many forms (Morgan and Henrion 1990; Regan et al. 2002). The role of science in conservation and management of natural resources is generally to reduce uncertainty (Halpern et al. 2006), and to a lesser extent to allow managers to make decisions in the face of uncertainty. Belief is growing that traditional modes of research may not be able to resolve critical uncertainties at a reasonable cost, or perhaps not at all (Ludwig et al. 1993; Johannes 1998; Salafsky et al. 2002). However, experts in resource management continue to advocate for more resources for information gathering to support science-based decision-making (e.g., NRC 1998; NOAA 2001). We question this view, and suggest that an investment in information gathering should be valued based on its potential to improve management relative to other uses for that investment. Our purpose in writing this article is to urge a more holistic view of management in which assessment is seen as a part of an overall system. This view should facilitate consideration of trade-offs that exist between resources allocated to information gathering and those allocated to other management activities. We suggest that this trade-off has been largely ignored in the past, which can lead to inefficient use of available resources and a failure to meet management objectives.

Information gathering in natural resource management can include fundamental research, monitoring, and the analytical processing of data gathered from these tasks. Clearly, information gathering can help to reduce critical uncertainties and consequently ought to lead to better decisions about conservation and exploitation. However, the information gained through research and assessment comes at a cost, and it is reasonable to assume that a situation of diminishing returns exists, such that at some point further investments in information gathering become difficult to justify. At this point, the cost savings from reduced information gathering may outweigh the small potential loss in decision accuracy that results (Walters and Pearse 1996; deBruin and Hunter 2003; Ling et al. 2006). The challenge is thus to prioritize information needs, and to correctly identify and collect the optimal amount of information required to make good decisions. Additionally, when operating under a finite budget, resources allocated to one activity necessarily detract from those allocated to another. The costs of information gathering thus include not only direct assessment costs, but also opportunity costs: resources used to gather information could be used in some other way to improve the management of a system. Allocating resources to assessment and information gathering may increase certainty and provide economic and ecological benefits, but these benefits come at the expense of other actions that could help to achieve management objectives (Figure 1). Assessment decisions are therefore also resource allocation questions, and should be treated as such.

The consequences of more or less information on various management and policy decisions have been evaluated in numerous natural systems in the past; however, we believe that an explicit accounting for the opportunity costs of gathering information has been conspicuously absent from the published literature. Ignoring the opportunity costs of information gathering can lead to overly optimistic predictions of the value of increased assessment effort, which occur at the expense of other management activities. Funding activities other than assessment may sometimes improve the overall effectiveness of management more than increasing funding for information gathering. Thus the value of an assessment program should be measured not by the precision of the estimates it generates, but rather in how well fishery management objectives are met in a broader sense.

In this article we illustrate the importance of accounting for all aspects of the value of information using examples drawn from three critical areas of fishery management: invasive species control, commercial fisheries stock assessments, and marine protected area design. We first discuss our own experience in sea lamprey (*Petromyzon marinus*) control in the Great Lakes, a situation in which the trade-offs are readily apparent. We believe that the lessons learned from this system regarding the value of information can be applied to other managed ecosystems where the trade-offs are less clear, such as commercial fisheries stock assessments and the designation of marine protected areas. We discuss how experts have judged the value of information in the past, and provide suggestions as to how these methods could be expanded to examine the value of information in a more holistic manner.

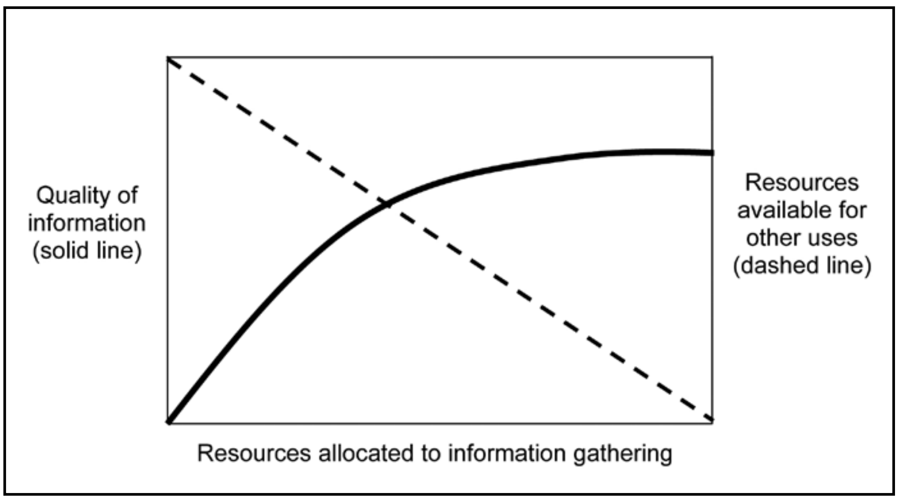
SEA LAMPREY CONTROL IN THE NORTH AMERICAN GREAT LAKES

The sea lamprey is an invasive, parasitic fish species in the Great Lakes that is the focus of an intensive pest control program with an annual budget of over $15 million US. Control of sea lampreys is achieved mainly through the chemical treatment of Great Lakes tributaries, which targets stream-dwelling larval sea lampreys prior to their metamorphosis into parasitic juveniles. Because larval sea lampreys remain in their natal streams for several years before becoming parasitic, it is neither necessary nor cost-effective to treat every stream each year. However, natural variation in demographic rates of larval sea lampreys makes it impossible to predict with certainty when each stream will require treatment to prevent the downstream migration of parasitic juveniles. Therefore, each year a group of candidate streams is assessed to determine which streams should be prioritized for treatment (Christie et al. 2003; Slade et al. 2003). The current larval assessment methods are costly, using roughly one-third of the total chemical control budget, yet uncertainty remains in the population estimates produced by assessment and hence in the set of streams that should be treated each year (Hansen et al. 2003; Slade et al. 2003; Steeves et al. 2003). Resources allocated to assessment diminish those available to implement control strategies; therefore, any increase in assessment costs in an attempt to increase certainty about which streams to treat will result in a corresponding decrease in the resources available to actually treat streams. Here, the opportunity cost of assessment is very straightforward.

The optimal balance between assessment and control expenditures that will maximize the number of sea lampreys killed is unknown. Recently, we evaluated the effectiveness of an alternative assessment method that is less costly than the current method, under the assumption that resources saved on assessment would be used to fund the chemical treatment of additional streams (Hansen and Jones in press). We used an adaptive management approach, implementing both the experimental and the currently used assessment methods over a three-year period, and independently estimated the total population of sea lampreys that would be targeted by chemical treatments as a result of each method. Our results show that more sea lampreys are killed using the less resource-intensive assessment method than using the current assessment method. A reduction in assessment expenditures resulted in less precise, and possibly less accurate, population estimates, but the corresponding increase in resources available for stream treatments appeared to make up for the decrease in assessment accuracy, resulting in more sea lampreys killed overall.

This study provides a clear illustration of the importance of accounting for opportunity costs when evaluating any information gathering program. In sea lamprey management, our results suggest that the benefits of increased assessment accuracy are outweighed by the costs of forgoing additional lampricide treatments that could be paid for using assessment dollars. This case study provides a relatively simple, but important real-world example of the tradeoff illustrated in Figure 1. We

Figure 1. The relationship between resources allocated to information gathering, the resulting quality of information (solid line), and the resources consequently available for other uses (dashed line). The details of this trade-off vary depending on the context, and are explained for each example described in the text. For example, in sea lamprey management the x-axis represents resources allocated to larval assessment, and the solid line represents the increase in assessment accuracy and thus the ability to identify the most suitable set of streams to treat with lampricide in a given year. The dashed line represents resources available for the chemical treatment of streams, and thus the number of streams that can be treated in a single year.



contend that the principles illustrated by this case study are of general relevance to natural resource management, and discuss below how they might apply to two more broadly relevant examples.

COMMERCIAL FISHERY HARVEST MANAGEMENT

Worldwide declines in exploited fish populations have generated a great deal of concern among scientists, managers, and the public in recent years (e.g., Cochrane 2000; Jackson et al. 2001; Myers and Worm 2003). The concerns are multi-faceted, but in the end the major questions in fisheries management concern how to determine and implement sustainable harvest rates for economically valuable stocks. The traditional approach to management of large commercial fisheries has been characterized as an "absolutist approach," in which large quantities of assessment data are collected and used to estimate population status and forecast the expected performance of alternative harvest strategies (Walters 1998; Parma 2002; Kelly and Codling 2006). Even when these assessments are well-funded and include fishery-independent data, the estimates of population parameters that are derived from the data are frequently imprecise and subject to a variety of biases (Hilborn and Walters 1992; NRC 1998; Quinn and Deriso 1999).

Experience with commercial fisheries worldwide during recent decades suggests that allocating considerable resources to data collection and stock assessments has not prevented overexploitation and collapse (Walters and Maguire 1996; Pauly et al. 2002; Myers and Worm 2003). This failure of management has occurred in part because of high levels of uncertainty, which are for all practical purposes irreducible, that plague complex, exploited systems, and the inappropriate treatment of such uncertainty in population models (Sainsbury 1998; Schnute and Richards 2001; Kelly and Codling 2006). The failures of fisheries management in the past despite high levels of funding for stock assessments raise questions regarding the role that better-funded stock assessments might play in improving the management of commercial fisheries in the future, and the value of such costly stock assessments should be examined explicitly. This is not to suggest that the current fisheries management crisis is largely due to over-investment in stock assessments, but rather that these assessments should be viewed as components of the entire managed system.

Uncertainty in managed systems can be partitioned into many types (see Williams 1997; Regan et al. 2002 for discussions of types of uncertainty in natural resource management). Some types of uncertainty (e.g., observation error) can be reduced by allocating more resources to assessment, but others (e.g., environmental variation) cannot. We would therefore expect the relationship depicted in Figure 1 to apply to stock assessments for commercial fisheries in that more resources allocated to stock assessments (the x-axis) would result in better estimates of stock abundance and more certainty about management decisions (the solid line). At the same time, as assessment accuracy increases, an increasing proportion of the remaining uncertainty will be irreducible, resulting in diminishing returns from information gathering and the asymptote shown in Figure 1. In some cases, increased data collection to reduce uncertainty may be justified by the increased benefits in harvest or reduced risk of over-exploitation (Charles 1998). However, assessment, statistical analyses, and modeling are cost and labor intensive, and an excessive focus on these activities can detract from other important management procedures (Walters 1998; Schnute and Richards 2001; Kelly and Codling 2006).

The opportunity costs of allocating management resources to assessment of commercial fisheries (the dashed line in Figure 1) could take many forms, as resources currently used to fund intensive stock assessments could be used in a number of different ways. At a very broad level, the dashed line could represent the number of separate stocks assessed worldwide or within a nation's waters: devoting more resources to individual assessments reduces the number of stocks for which assessments can be conducted (Kelly and Codling 2006), many of which are lacking data (Johannes 1998). Alternatively, the dashed line could represent funding available for research on fundamental uncertainties in biological processes and relationships that would serve to reduce process uncertainty about the exploited stock (Pereiro 1995; Charles 1998; Kelly and Codling 2006). The dashed line could also represent monitoring of the consequences of management actions, a key step of adaptive management which is often lacking (Walters 1997; Walters 2007). Such monitoring would improve future management as the consequences of various management actions became better understood. Finally, the dashed line could represent funds for the enforcement of regulations. Enforcement can reduce so-called "implementation uncertainty": uncertainty in how regulations will play out in the real world due to illegal landings, bycatch and discards, unreported or underreported catches, and other factors (Rosenberg and Brault 1993).

Many authors have examined the value of reducing uncertainty or the value of increased surveys in commercial fisheries using operating models designed to maximize given objectives (e.g., McAllister et al. 1999; Punt and Smith 1999; Moxnes 2003) by using techniques including Monte Carlo simulations (e.g., Bergh and Butterworth 1987; Powers and Restrepo 1993; Punt et al. 2002) and Bayesian approaches (McAllister and Pikitch 1997; McDonald and Smith 1997). However, these studies did not include any analysis of the value of other management activities that could be funded in place of detailed assessments. Including such an analysis may change the value of increased survey intensity.

An explicit examination of the trade-off we describe may point towards a need to fundamentally restructure the assessment process of a given system. The initial costs of such a change in assessment will perhaps be high, as the new approach is implemented and debugged (e.g., Martell and Walters 2002; Walters and Martell 2002). However, if the long-term trade-offs between assessment costs and other uses for resources that will further management goals are accounted for, high initial investment in the development and implementation of alternative assessment methods may be justifiable. Alternatives exist to complex stock assessments. Rapid assessment techniques have been shown to be effective alternatives to detailed, resource-intensive surveys for a variety of natural systems (e.g., Oliver and Beattie 1993; Jones and Stockwell 1995; Metzeling et al. 2003), although these types of methods have enjoyed limited use in marine fisheries management. Fisheries population estimation techniques and harvest regulations that are effective in the absence of detailed stock data have also been developed (e.g., Walters and Pearse 1996; Hilborn 2002; Shotwell and Adkison 2004). In the end, the appropriate assessment procedure and the activities that could be funded in place of detailed assessments will vary depending on the specific characteristics of the fishery, and on the trade-offs involved.

MARINE PROTECTED AREAS

Marine protected areas (MPAs) are regions of marine habitat protected to varying degrees from exploitative uses. MPAs have received much attention in recent years as a means of preserving biodiversity and ecosystem processes, protecting vulnerable populations and habitats, and ensuring the sustainability of fisheries resources (e.g., Botsford et al. 1997; Roberts 1997; Halpern 2003). While some controversy exists regarding the efficacy of MPAs for enhancing populations of exploited fish species to support use outside of the reserve (Hilborn et al. 2004; Sale et al. 2005), they are generally believed to be effective conservation tools, and many countries and regions have established programs to create additional reserves in the future (Day and Roff 2000; Gladstone 2000; NRC 2001). Experts have suggested that if MPAs are to be successful at supporting fishery production and preserving biodiversity, protection of 20% or more of each type of marine habitat will be necessary (Roberts and Hawkins 2000; NRC 2001). Even if the long-term benefits of MPAs are sufficient to justify their establishment, the short-term costs associated with protecting this amount of ocean habitat are likely to be enormous. The cost of a global network of MPAs sufficient for biodiversity protection and fisheries sustainability has been estimated at \$5–19 billion US, not including start-up or assessment costs (Balmford et al. 2004). With costs of this magnitude, evaluating the cost effectiveness of alternative marine reserve design is critical.

If costs of information were not an obstacle, MPA networks should be designed using detailed, spatially explicit data on species distributions and abundances throughout their range, ecological processes such as dispersal rates, and socioeconomic factors. However, such information is rarely available on the scale necessary to design MPA networks, especially in impoverished areas where reserves are most needed (Gaston and Rodrigues 2003), and the cost of gathering this information is very large relative to the resources typically available for assessment (Halpern et al. 2006). Furthermore, attempts to assemble a comprehensive database will inevitably divert resources from other important conservation goals (Roberts 2000; Halpern et al. 2006).

Protected areas are generally believed to be more effective when they are created with careful planning, following a systematic process (Pressey et al. 1993; Botsford et al. 2003; Roberts et al. 2003). Numerous criteria have been suggested as data inputs needed to guide the creation of MPAs (Table 1), and spatially-explicit algorithms have been created to assist in the delineation of MPAs which use selected criteria from Table 1 to maximize stated objectives (i.e., Worldmap, Williams 1999; BioSelect, Nichols and Margules 1993; MARXAN, Ball and Possingham 2000). However, there is no consensus on how to trade-off different criteria whose use might lead to different "optimal" configurations. Furthermore, there is good evidence that

Table 1. Criteria identified as important for consideration in the design of marine reserves.

Criterion	**Selected References**
Species diversity and abundance	Pressey et al. 1993; Murray et al. 1999; Gladstone 2000, Margules and Pressey 2000; Sala et al. 2002; Roberts et al. 2003
Species ecology, movement, and dispersal distance at different life stages	Murray et al. 1999; Roberts 2000; Sala et al. 2002; Hilborn et al. 2004; Sale et al. 2005
Habitat types at relatively fine spatial scales	Pressey et al. 1993; Murray et al. 1999; Gladstone 2000; Roberts et al. 2003
Socioeconomic information	Murray et al. 1999; Sala et al. 2002; Hilborn et al. 2004;
Stakeholder input	Gladstone 2000
Fishing effort and impacts	Gladstone 2000; Sala et al. 2002; Hilborn et al. 2004; Sale et al. 2005
Biogeographic regions	Murray et al. 1999; Sala et al. 2002; Roberts et al. 2003a
Multi-species interactions and ecological functions	Sala et al. 2002
The effectiveness of other reserve designs	Murray et al. 1999; Sale et al. 2005; Botsford et al. 2003; Hilborn et al. 2004
Past, present, and future uses and threats	Pressey et al. 1993; Murray et al 1999; Roberts et al. 2003a
Likelihood of natural disasters	Pressey et al. 1993; Murray et al. 1999; Roberts et al. 2003a
Political considerations	Roberts 2000
Hydrodynamics and currents	Murray et al. 1999; Sale et al. 2005

many alternative network configurations that allow for the realization of conservation objectives will emerge from a systematic process (Pressey et al. 1993; Gaston and Rodrigues 2003), which implies that the benefits from a reserve network may be quite robust to deviations from the particular network that emerges as "optimal" in some objective sense. This robustness alone raises questions about the value of the information sources that might be used to objectively guide MPA network design.

In recognition of the high costs of detailed assessments, many researchers have examined the performance of "surrogate" methods for delineating protected areas, motivated by interest in whether reserve networks can be created that protect species diversity without the costly acquisition of actual species distribution data (e.g., Vanderklift et al. 1998; Ward et al. 1999; Gladstone and Alexander 2005). These studies have yielded mixed results, likely due to differences among studies in spatial scale, study systems, levels of protection, and measures of success. Additionally, while surrogate methods have been demonstrated to be less costly than full biodiversity surveys in various systems (Balmford et al. 1996; Smith 2005; Marshall et al. 2006), there has been little effort to quantify differences in costs of different survey types for marine areas (but see Drummond and Connell 2005), how these differences in cost compare to losses in efficiency or effectiveness of reserves designed based on surrogates, or the benefits of other uses for the resources saved on assessment. Such analyses are critical in determining if surrogates provide an adequate means of delineating marine reserves.

In the MPA example, the x-axis of Figure 1 represents resources allocated to detailed ecological and socioeconomic surveys, and the solid line represents the degree of certainty with which the best (or one of the best) network configurations can be identified. The dashed line could represent a number of different options, for example, resources to assess a larger number of potential sites. Assessing more sites would increase the chances of identifying multiple candidate locations for a reserve, thereby allowing negotiations among stakeholders and increasing the likelihood of compliance (Pressey et al. 1993; Margules and Pressey 2000; Stewart et al. 2003). Alternatively, the dashed line could represent resources to acquire or protect additional areas. All else being equal, increasing the number of reserves in the network lowers the risk of failing to protect a critical location. Finally, the dashed line could also represent resources available to ensure compliance with regulations. In at least one set of reserves, there is evidence that individual reserves with the highest levels of compliance show the greatest level of success (Samoilys et al. 2007). Furthermore, an important temporal trade-off also occurs with detailed assessments of potential reserve networks. It takes time as well as money to assemble a complete biodiversity data set. A less time consuming, but also less thorough, assessment process could allow more rapid decisions about which areas to protect, resulting in a more rapid (but less certain) realization of benefits and lowering the risk of losing biodiversity in the interim between assessment and protection. A more extensive assessment process would result in a longer delay in realizing the benefits of protection.

Delineating MPAs differs from commercial stock assessments and sea lamprey control in that MPA placement is often a one-time decision, while harvest management of fisheries is a sequential decision-making problem in which managers have opportunities to learn from their past actions and adapt their future decisions accordingly (although a formal adaptive management process is rare in this context; Walters 1997, 2007). The fact that MPA placement decisions are to a certain extent irreversible will certainly influence the value of information used to direct their placement, as the cost of being wrong could be quite high. This does not, however, mean that a trade-off no longer exists between gathering this information and investing in other valuable areas of marine reserve management.

DISCUSSION

Our three examples illustrate what we believe to be an important and underappreciated challenge facing resource managers. We admit that it is often difficult to determine objectively the appropriate level of investment in information gathering to inform decisions about conservation and management. The starting point for the solution must come from taking a more holistic perspective on management. Most of the debate about how to assess systems such as commercial fisheries or marine reserves has concentrated on comparisons of alternative strategies for information gathering. We believe that more important questions arise at a higher level: what are alternative uses for these same resources, and would better management result from shifting effort from more refined assessments to these alternatives? The answer to such questions can only come from framing the resource management problem to make these trade-offs explicit; that is, treating assessment as part of a larger management system.

Viewing assessment as a component of a larger management regime requires a broad view of the entire interconnected management process. Sea lamprey management has benefited from an institutional arrangement in which a single decision-making body (the Great Lakes Fishery Commission) is centrally responsible for allocating resources between assessment and other management activities; in fact, this allocation is a critical element of their decision-making process. Elsewhere, management decisions are often not made with the benefit of this holistic perspective, but we do not see any obvious institutional impediments to adopting this view. We encourage fishery agencies, at the regional, national, and international level, to examine their management systems and identify opportunities to take a more holistic approach to resource allocation.

The technical challenges of confronting these trade-offs may seem daunting, but we believe examples exist that illustrate the approach towards which we are pointing. Specifically, fisheries scientists, especially in Australia and South Africa, have for several years been developing and applying methods referred to as "management procedures" or "Management Strategy Evaluation" (MSE) for simulating a complete fishery management system, including assessment (e.g., Butterworth and Punt 1999; Geromont et al. 1999; Punt and Smith 1999). These simulations have been used to evaluate the contribution of different levels of assessment to better decisions, and it is not difficult to imagine expanding these simulations to make explicit the trade-off between, for example, increased assessment and increased enforcement for capture fisheries. Similarly, an MSE-style simulation could be used to evaluate trade-offs for marine reserves such as the inter-temporal trade-off (act now or wait for better data) discussed above. We have, in fact, used an "operating model" of sea lamprey control to examine the trade-offs discussed in our first example (M.L.J., unpublished data).

Balmford and Gaston (1999) provide another excellent example of explicitly examining the trade-off between resources used for detailed assessments and those used for land purchase in creating reserve networks in terrestrial systems. They concluded that detailed surveys allow the creation of more efficient reserve networks, and conducting such surveys will reduce the amount of land required to protect a given level of biodiversity. In their examples, the costs of conducting biodiversity surveys are more than offset by the reduction in land acquisition costs, and they conclude that biodiversity surveys are generally a good value for terrestrial systems Their results demonstrate wide variations in the costs of land purchase, effective maintenance, and surveying, and they acknowledge that few data exist for the calibration of their model, even in terrestrial systems. Research of this type on marine systems would help to determine the value of biodiversity surveys relative to the loss of efficiency in marine reserve networks created using incomplete data.

Treating assessment as a component of a larger management process will doubtless raise questions that demand empirical evaluation, particularly when modeling provides equivocal answers. The most informative evaluations of the costs and benefits of different assessment strategies will come from adaptive management experiments, in which decisions are made based on different levels of information, implemented on the scale relevant to management, and monitored (Walters 1986). Despite the intuitive appeal of these types of large-scale management experiments, they are risky and difficult to implement, particularly in contentious systems such as commercial fisheries and MPAs (Walters 1997, 2007). Nonetheless, adaptive management studies may be the only way to truly understand the impacts of different assessment and resource allocation programs, particularly if modeling and past experience cannot resolve critical uncertainties (Walters 2007). Furthermore, as ecosystem management becomes more widely accepted as the goal of management (Pikitch et al. 2004), developing realistic parameter and variability estimates to be used in predictive models will become even more difficult, further necessitating the use of management-scale experiments to truly determine the outcomes of various assessment methods.

CONCLUSION

Our purpose here has not been to suggest that information gathering generally tends to be over-valued in resource management. In some cases, compelling arguments have been made in favor of more assessment: for example, increases in resources allocated to assessment and monitoring to assist in the prevention and early detection of invasive species is predicted to reduce the costs of often irreversible economic and ecological damages caused by invasions (Lodge et al. 2006). Instead, our goal is to argue that the funds to support all aspects of resource management are nearly always far less than managers would wish to have, and that limited resources create important, high-level challenges concerning their allocation. We maintain that the value of investing in information gathering should be explicitly considered in relation to the opportunity costs associated with other valuable areas of management. We urge decision makers to make these trade-offs an explicit part of their management systems. As well, research on the value of information across natural resource fields has not given enough attention to quantifying these trade-offs. We urge researchers to help fill this gap so as to ensure the most effective and efficient use of limited resources and aid progress towards achieving common conservation and management goals.

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