Applying Structured Decision Making to Recreational Fisheries Management

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ABSTRACT: *Multiple objectives associated with recreational fishing, combined with multiple uncertainties, pose real challenges for management. We suggest that applying formal decision-making frameworks to partnership-based policy evaluations can prove beneficial to recreational fisheries management. We describe how a sequence of workshops can be used to engage scientists, managers, and other stakeholders and execute the steps of a structured decision-making process that centers on collaborative development of a quantitative forecasting model. This approach should aim to specify objectives and corresponding performance measures, identify critical uncertainties, and aid decision makers in making more informed choices among possible management options. An inclusive, participatory process can increase the transparency by which management decisions are made, provide an opportunity for tradeoffs to be discussed in a tangible way, and promote consensus building. Constructing and documenting a well-specified representation of the management process should also help reduce contention surrounding complex management decisions and promote proactive management.*

Toma Estructurada de Decisiones en el manejo de la pesca recreativa

RESUMEN: diversos objetivos relacionados con la pesca recreativa, combinados con múltiples incertidumbres, representan desafíos reales para el manejo. Se sugiere que al aplicar el enfoque de "toma formal de decisiones" a las evaluaciones de las políticas de participación, el manejo de la pesca recreativa puede beneficiarse. Se describe cómo una secuencia de talleres puede utilizarse tanto para concertar científicos, manejadores y otros participantes, así como también para llevar a cabo las etapas de un proceso estructurado de toma de decisiones, centrado en el desarrollo colaborativo de un modelo cuantitativo de predicción. Este enfoque debiera perseguir la postulación de objetivos precisos, el desarrollo de las correspondientes medidas de desempeño, identificación de las incertidumbres y asistencia a los administradores a tomar decisiones mejor informadas de entre diversas opciones de manejo. Un proceso incluyente y participativo puede incrementar la transparencia en las medidas de manejo, ofrece una oportunidad para que el espacio de negociación pueda discutirse de manera tangible y promueve el consenso. Crear y documentar una representación específica del proceso de manejo, también debiera ayudar a reducir los conflictos que rodean a las decisiones complejas de manejo y a promover un manejo proactivo.

Introduction

Fisheries management often has relied on informal and ad hoc approaches to developing regulations and policies, with management plans simply continuing the status quo or being developed purely in reaction to recent events (Pereira and Hansen 2003; Butterworth 2007). Such approaches have sometimes failed to produce desired effects because objectives, possible actions, and resulting outcomes were treated as simple and known. The need for effective fisheries management decisions has been amplified by the growing number of over-exploited stocks, large-scale ecological changes, and increasing diversity of stakeholders. While overfishing of marine stocks has received a lot of attention (e.g., Worm et al. 2009), freshwater fisheries are also subject to stock depletion (Post et al. 2002; Allan et al. 2005), and the influence of recreational landings on the food web or broader ecosystem can sometimes be substantial (Bence and Smith 1999; Coleman et al. 2004; Cooke and Cowx 2004). Concurrently, non-fishing uses of aquatic systems are increasing, including both alternative recreational (e.g., ecotourism) and nonrecreational purposes (e.g., flood control). As Lyons et al. (2008) suggest, present-day resource management decisions are difficult because of contentious objectives, limited available options, and uncertainty in resource responses to natural or human disturbances. Numerous social, economical, political, environmental, and ecological concerns will continue to influence recreational fisheries management, and many challenges await (Pereira and Hansen 2003; Peterman 2009).

Hilborn (2008) identifies cooperation of stakeholders as one of three elements (restricted access and maintenance of biological productivity are the other two) characteristic of well-managed fisheries that are biologically, economically, and socially successful. However, management of recreational fisheries often fails to include stakeholders in a meaningful and transparent way, which can lead to conflict between user groups and managers (Gale 1992; Ungate 1996). Preferences of stakeholders can ultimately determine the support behind a policy, and successful engagement can produce a more effective, efficient management process (Granek et al. 2008; Prince et al. 2008).

In this article, we reflect on realizable benefits to fisheries management resulting from applying a formal evaluation process that (1) involves stakeholders, (2) explicitly defines objectives and management options, and (3) uses mathematical models to transparently connect management options to expected outcomes and to incorporate known uncertainties. Such approaches are being broadly promoted elsewhere for a variety of decision problems (Hammond et al. 1999; Gregory and Long 2009) and increasingly are being applied in the context of sustainable use of natural resources (Punt 2008; Runge et al. 2008). However, few examples exist for recreational fisheries management in North America, especially in inland freshwater systems. Throughout this article, we will refer to the approach we advocate as "structured decision making" (SDM), although several names exist for complementary decision-making frameworks that promote deliberate options analysis (e.g., "decision analysis"; "management strategy evaluation"; see also Peterman and Anderson 1999; Butterworth et al. 2010). Our primary purpose is to highlight several important process components of applying SDM in the context of evaluating alternative management options for multiple-objective recreational fisheries. We draw from our own experiences to provide examples of how this approach may be applied to real-world recreational fisheries.

Process Overview

We characterize SDM as a strategic process that promotes transparency, collaboration, and an integrated systems approach for supporting more informed and durable decisions. For recreational fisheries, the process typically is initiated once a problem is identified by managers, often through input from anglers. Applying SDM relies on defining management objectives and finding those management options most likely to achieve the objectives. Some basic options available for managing recreational fishery mortality include regulating who can fish, the fishing season, areas open to fishing, the amount of allowable harvest, the length of harvested individuals, and the method of take. Other management options include modifying important habitats or the fish community itself (e.g., stocking fishes, chemical reclamation). These actions and regulations may be used independently or in concert, usually with the overarching goal of preserving the fishing experience (Radomski et al. 2001). In support of this goal, recreational fishery management objectives often fall into generalized categories such as harvest, recruitment, stock composition, abundance, allocation, and angler effort (Irwin et al. 2008). Identifying performance measures that quantify the success in achieving specific objectives (e.g., an average catch rate over time) helps to determine what is fundamentally important to a decision problem and ultimately allows distinguishing among alternative management options based upon their anticipated ability to satisfy objectives (e.g., Hammond et al. 1999).

We suggest that the best approach to connecting possible management options with their expected outcomes is through use of quantitative systems models as decision-support tools. Group development of quantitative models forces assumptions to be made explicit and is critical for producing adequate simulation tools for evaluating the expected consequences of decisions. Given the multiple-objective nature of recreational fisheries management, we believe that construction of such models—and interpretation of their outputs—should be completed through iterative interactions between scientists and other stakeholders. Here, and throughout the remainder of this article, we use the term "stakeholder" in a broad sense that includes resource managers and decision makers as well as other vested or knowledgeable individuals (e.g., anglers, representatives from nongovernmental organizations, land or business owners).

Wise decisions should be informed by a careful, thoughtful analysis of the problem and the questions that need to be answered to reach a solution. However, analysts are frequently not the decision makers and are even less likely to represent those who are affected by the decision. A decision analysis that does not effectively engage both decision makers and user groups is unlikely to be as good as one that does. The National Research Council Committee on Risk Characterization advocated for the use of an analytic–deliberative process for addressing policy issues that involve significant uncertainty or risk:

> *Risk characterization is the outcome of an* analytic-deliberative *process. Its success depends critically on systematic analysis that is appropriate to the problem, responds to the needs of the interested and affected parties, and treats uncertainties of importance to the decision problem in a comprehensible way. Success also depends on deliberations that formulate the decision problem, guide analysis to improve decision participants' understanding, seek the meaning of analytic findings and uncertainties, and improve the ability of interested and affected parties to participate effectively in the risk decision process. The process must have an appropriately diverse participation or representation of*

the spectrum of interested and affected parties, of decision makers, and of specialists in risk analysis, at each step. [Stern and Fineberg 1996:3]

We have employed a structured sequence of deliberative workshops to stimulate dialogue about how to best represent both biology and management (Figure 1; Irwin et al. 2008; Jones and Bence 2009; Wilberg et al. 2009), very similar in intent to the analytic–deliberative process. Our approach has its origins in the Adaptive Environmental Assessment workshops pioneered by Holling (1978) and Walters (1986, Chapter 2). Over the years, we have moved away from intensive model-building workshops to a punctuated series of workshops that progress from problem formulation at the outset to collective evaluation and interpretation of analytical results at the end. In between these workshops, the focus is on analysis, typically involving construction of quantitative models to forecast possible consequences of alternative management strategies. Collectively, the workshops ensure relevance of—and buy-in for—the analysis, and the analytical procedures ensure sufficient rigor concerning what are inevitably technically complex problems. More specifically, some of the benefits of the interactive workshop sequence derive from a group-level decomposition of the decision problem into those portions requiring objective science and those reflecting value judgments.

The initial workshop(s) focus on problem formulation (Table 1, tasks a–c)—the foundation for all subsequent work. Careful and creative thinking are needed to appropriately frame a decision problem, which may involve recognizing dependent decisions and challenging constraints. Likewise, soliciting different perspectives can help determine whether reframing the problem could better reveal the essential context and lead to a smarter choice (Hammond et al. 1999). For each SDM application, we begin by taking a collaborative approach to defining a decision problem, which involves group discussion and determination of the overall goal for the analysis. This discussion is advanced and honed by specifying three additional defining elements of SDM: management objectives, management options, and critical uncertainties (Table 1, tasks d–f). We ask participants to initially articulate their objectives in broad terms, followed by specification of performance measures. Active collaboration between participants and decision analysts helps to avoid misinterpretations, leading to well-defined performance measures that are critical to realizing meaningful decision advice (Figure 2).

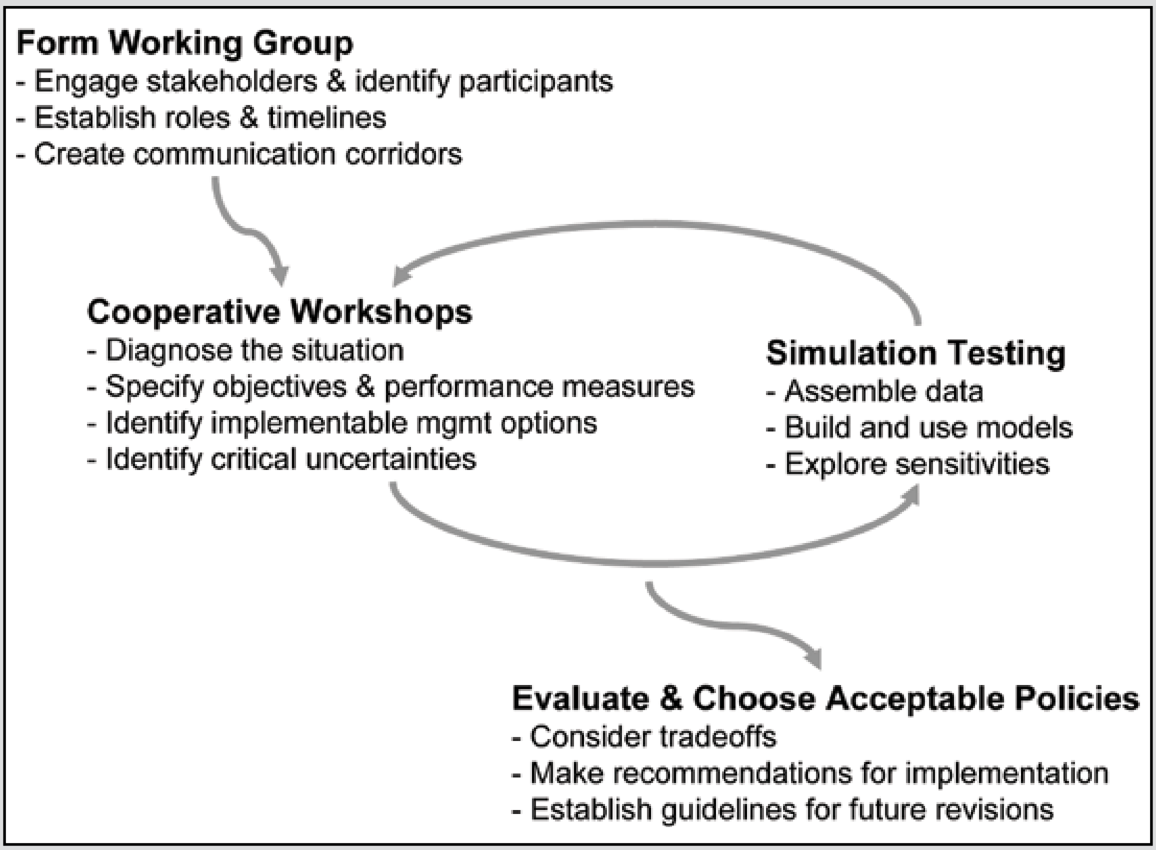

FIGURE 1. A simplified flowchart of suggested components for a structured decision-making process, where iterative interactions improve identification of an implementable management policy that aims to meet multiple objectives for a recreational fishery.

TABLE 1. Synopsis of process components (i.e., tasks) that follow problem recognition and serve to provide more informed decision making. The progression through a sequence of cooperative workshops (a four-workshop sequence is highlighted here) is an effective technique for advancing through the process while allowing for iterative interactions and promoting transparency. Thus, workshop goals will often connect to multiple tasks that have either primary or secondary importance (e.g., previous steps might be revisited or refined; shown here as italicized numerical values). Examples are given related to evaluating alternative harvest policy options for yellow perch in southern Lake Michigan

Task	Workshop	Examples related to a harvest policy evaluation
a) Problem recognition		Elevated concerns that previous policies were not or would not be robust against recent or impending events
b) Diagnose the situation and form working group	1	Identified status of fishery and invited working group participants (e.g., managers, system experts). Introduced the SDM process. Defined scope of decision problem and established roles of participants
c) Introduce goals and expectations for the process	1, *2, 3*	Confirmed goals (e.g., evaluate alternative harvest policies) and revisited process description as needed. Determined timelines for project
d) Specify objectives and performance measures	*1*, 2, 3	Identified desirable and undesirable outcomes (e.g., avoidance of low harvest, preservation of minimum spawning stock size), corresponding performance measures, and timelines over which performance should be considered. Discussed alternative methods of summarizing performance of harvest policies
e) Define the available management options	2, *3*	Identified implementable management policies (e.g., biomass-based harvest control rules)
f) Discuss structure of forecasting model	2, 3	Identified uncertain states of nature (e.g., future productivity of the stock) and other critical uncertainties. Collaboratively determined model structure based upon understanding of biology, management objectives, and alternative options
g) Evaluate performance of alternative options	*2*, 3, 4	Forecasted expected outcomes, allowing for uncertainty. Evaluated tradeoffs to consider relative changes in performance metrics (e.g., harvest vs. years of low spawning stock biomass)
h) Choose or provide advice on acceptable options	4	Collaboratively identified a suite of acceptable options. Informed decision makers of process results

Next, we seek a broad set of potential management options (e.g., control harvest or enhance habitat) but eventually drill down to specific actions (e.g., adjust bag limits) that are the means to implement the various management options. Finally, uncertainties are identified that are believed to most critically limit the ability to predict outcomes of management actions. For recreational fisheries, commonly encountered uncertainties include aspects of fish recruitment dynamics and angler numerical responses to changes in fishing success. Identifying uncertainties drives how random variability will be incorporated into the forecasting model(s). The second stage of the process involves presentation of preliminary analytical results for feedback and model refinement in response to this feedback, followed by updated reporting from the analytical team (Table 1, task g). The closing stage involves discussion of and recommendations based on the final analytical results (Table 1, task h). We suggest that these final steps should focus on careful consideration of tradeoffs that emerge when viewing the forecasted consequences of a particular management strategy from the perspective of multiple objectives (see Mendoza and Martins 2006 for a more thorough review of methods for multicriteria decision making).

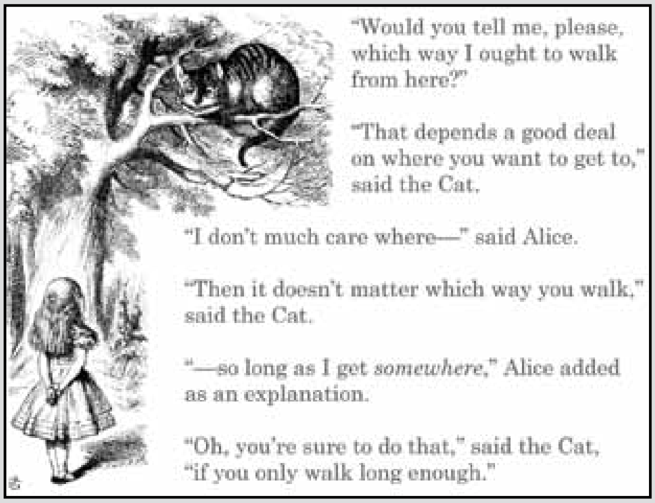

FIGURE 2. Alice could benefit from specific objectives and corresponding performance measures to inform her decision making. From Lewis Carroll's (1866) *Alice's Adventures in Wonderland*; original illustration by John Tenniel.

Quantitative Evaluation of Options

In our work, applying SDM has revolved around the collaborative development and use of a quantitative forecasting model (Figure 3). Because the underlying system is usually moderately complex and substantial uncertainties often remain, we incorporate a modeling approach that integrates system processes and accounts for uncertainty. Thus, a stochastic simulation model is usually the result. We believe that many of the benefits associated with SDM accrue through the collective process of model building, which includes explicitly identifying assumptions. Collaborative model development helps to establish a set of common assumptions that is reflected in the model's structure (e.g., accounting for age classes is necessary

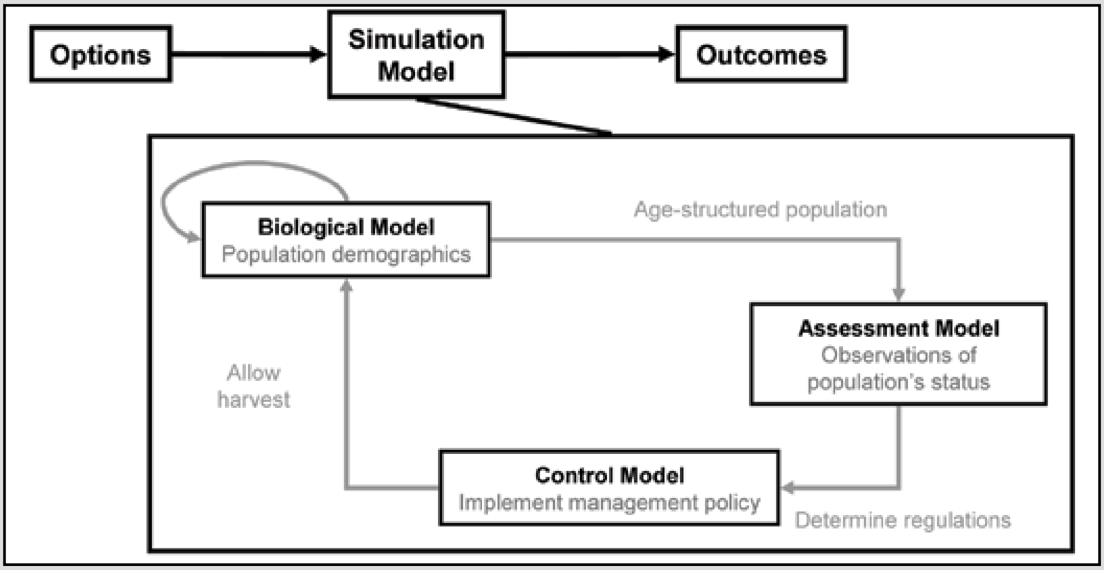

Figure 3. Simplified structural representation of a simulation model used to forecast expected outcomes of alternative magagement options.

to accurately simulate population changes over time, or the angler population should be divided into avid and occasional fishers) as well as in the mathematical functions that determine system dynamics (e.g., fish recruitment can be adequately described by a stochastic Ricker function). Overall, the group model-building process helps organize what is known (or what is not), and the fundamental purpose is to forecast expected consequences of alternative management options (Irwin et al. 2008; Jones et al. 2009).

Incorporating known uncertainties about how the managed system operates is an important aspect of the modeling exercise. We strongly suggest that the modeling group should not be constrained to identifying a single correct way to model every process. Rather than arguing about which single characterization of the system is correct, we suggest that it is better to consider different plausible representations and work to assign probabilities to these alternatives, even if only expert opinion is available to judge these probabilities. A useful approach is to capture different assumptions or hypotheses of future ecosystem states (i.e., uncertain states of nature; e.g., Hilborn 1987) by specifying alternative model structures (represented by different mathematical functions), each with an associated probability of being the truth. Likewise, parameters for a single mathematical function can be drawn from an underlying probability distribution. Often both approaches are used. For example, in our work on yellow perch (*Perca flavescens*) harvest policies, we considered two model structures related to stock recruitment: one in which all recruits in a region of the lake were produced by adults from that region and a second where recruits in a region could be offspring from adults in other areas of the lake. These alternative hypotheses were assigned probabilities based on group discussions, with the specific parameters of the stock recruitment functions also selected from distributions based on follow-up analyses for each case (Irwin et al. 2008; Wilberg et al. 2008). Allowing for alternative representations is a powerful way of moving forward without complete agreement among participants. We have found that proponents of specific hypotheses considered unlikely by other participants are much more likely to remain engaged in the process if their hypothesis is included, even if it is assigned a low baseline probability. For example, Ihde et al. (in press) considered a substantial decrease in recreational fishing effort for king mackerel (*Scomberomorus cavalla*) because of record high fuel prices, even though many participants thought this was unlikely. Although these scenarios were not used to formulate final recommendations, including them as part of the analysis allowed the process to continue forward when participants disagreed about future system behavior. Sensitivity analyses can be used to further consider the effects of different assumptions (Irwin et al. 2008; Wilberg et al. 2008).

The expected cause–effect linkages that connect management actions to performance measures define the rules of the forecasting models (i.e., the representation of processes by equations). However, the connection between management actions and performance measures is uncertain because of partial observability, partial controllability, and natural variation (Williams et al. 1996), in addition to the structural uncertainty described above. Partial observability (i.e., assessment or observation uncertainty) results from imperfect observational methods. Partial controllability, also known as "outcome uncertainty" or "implementation error," arises from the difference between what is intended by a management action and what

Making an assessment of the yellow perch.
(Photo credit: David Kenyon, Michigan DNRE Photographer)

actually happens. For example, quotas or other regulations may be imposed to achieve a fishing mortality target, but because quotas will often not be perfectly achieved, the mortality target will be missed. Natural variation differs from these other sources of uncertainty in that it is generally assumed to be irreducible. Structural uncertainty, partial observability, and partial controllability can be reduced by investments in more research, more intensive sampling, and greater management control (e.g., enforcement), respectively. Quantitative models that explicitly incorporate unknowns can be used to explore the anticipated pay-off from reducing uncertainty (Jones et al. 2009), which often is of interest to many participants. While accounting for uncertainty is important, we believe it is also important to keep in mind that models are simplifications and, as such, they will likely not fully describe all uncertainty about how a system works.

The scope and complexity of the forecasting model depends not only on how the group believes the system operates but also upon the range of objectives and management options being considered. For example, a critical management challenge in the Laurentian Great Lakes is to achieve cost-effective control of the exotic, parasitic sea lamprey (*Petromyzon marinus*). In our work evaluating management strategy variants for sea lamprey control, managers and biologists quickly identified analyses supporting an improved model representation of lentic habitats as a priority based on evolving treatment tactics that were incorporating these areas (Jones et al. 2009). Because the analytical team will likely need to devote substantial efforts to data analyses, model development should be constrained to those analyses that are able to help inform choices among possible management actions. Priority analyses provide needed information on the processes that link management options to performance measures and ideally would both reduce and describe uncertainty about the linkages. Practical limitations to the scope of modeling and supporting analyses that can be accomplished (due to limits on expertise, data, or time) often lead to iterative refinements of performance measures. For example, although some participants in our work on salmonine stocking and yellow perch harvest were interested in recreational license sales as a performance measure, we ended up limiting the scope to not incorporate the license buying behavior of anglers. Participants ultimately agreed that forecasts of changes in harvest could serve as sufficient proxies for a license sale performance measure.

The experiences shared during a collaborative model-building exercise allow participants to gain an improved understanding of the implications of how the problem, options, and objectives are defined. We have seen participants reevaluate how a particular objective should be captured by performance measures once preliminary simulation results became available. For example, refinement of a harvest performance measure might reveal that avoiding a series of low-catch years is more important to stakeholders than attempting to maximize catch for a given year. Likewise, some participants might be willing to accept a lower average performance over an extended time period as long as short-term performance is not substantially adversely affected. Discussions about time horizons are particularly relevant to group model development, because the distributions of outcomes forecasted by the model will later be used to distinguish the various options available to management (Butterworth 2007; Irwin et al. 2008). These examples further emphasize the need for iterative interactions between the analytical team and other participants.

Most previous attempts to quantitatively evaluate alternative management strategies have been for data-rich fisheries, but we believe that data limitations should not be viewed as prohibitive. Similarly, Mahon (1997:2211) states "… for management of developing-country resources, it may be most effective to use a structured decision-making method to formulate a management strategy for a fishery." Regardless of the supply of data, a management option will be chosen, and it can be chosen based on either implicit or explicit assumptions about how the choice is expected to influence performance measures of interest. We suggest that an approach that uses collective judgment, in the form of a quantitative model, to forecast what will happen should be highly preferable to making judgments without being explicit about what is assumed. When formal evaluation of alternative options is lacking, a working group will likely rely on intuition or the literature to judge which options are most likely to best achieve objectives. While a limited decision-making time frame might necessitate such a reduced approach, we urge that in such cases rigorous simulation testing continue to be pursued to either reinforce the initial recommendations or to establish justifiable reasons for modifying them (see Bence et al. 2008).

Collaboratively Choose Acceptable Option(s)

We have found that an effective way to arrive at agreed-upon recommendations is through discussion of the expected consequences of options, with a focus on evaluating the degree to which the range of established objectives are met. Deliberation over performance of options allows participants to discuss and weigh tradeoffs among performance measures, and it allows for consideration of important factors that were not included in the modeling. For example, extraction-based objectives (e.g., maximize yield) frequently conflict with preservation-related objectives (e.g., maintain age diversity of spawning stock). Some outcomes deemed important by some members of the group will invariably not have been included in the model. For example, in our yellow perch decision analysis (Irwin et al. 2008), several participants were concerned about the difficulty of changing regulations on a frequent (e.g., annual) basis. Although this difficulty was not explicitly included in the model as a performance measure, it affected the final consideration of options. Thus, the SDM process can allow for consideration of other facets of the decision or options that were not directly included in the quantitative model, such as fairness, enforceability, and difficulty of enactment. During such deliberations, the list of possible options remaining under consideration often can be rapidly reduced by eliminating those options that have identifiable characteristics of unacceptable performance. In the cases we have dealt with, near-consensus views around one option or a set of acceptable options are typically achieved during one- or two-day meetings (Irwin et al. 2008; Ihde et al. in press). Thus, a real and tangible benefit of applying SDM is "the opportunity to provide relevant information through an integrated, participative team approach to problem solving" (Lane and Stephenson 1995:220).

Other SDM processes have used the construction of a utility function (e.g., Peterson and Evans 2003) as a basis for identifying an optimal decision among a set of alternatives. Construction of a utility function provides the benefit of explicitly articulating value judgments about the relative importance of different outcomes and metrics of outcomes. However, we have not been successful in this approach because attempting to specify a single utility function that captures all potential tradeoffs has severely limited the flexibility required for discussing complex, real-world resource management issues. This appears to be the case more broadly; several recent harvest policy evaluations focused on examination of tradeoffs rather than on development of an overarching utility function (Bence et al. 2008). One reason may be that the importance of some performance measures may change in response to others, which would lead to a very complicated utility function. For the yellow perch decision analysis, we attempted to develop alternative utility functions, based on different weightings of selected performance measures; however, participants had a very hard time basing interpretations on formal utility functions. During later discussions of individual performance metrics and tradeoffs, the group decided that maintaining recent policies resulted in an acceptable level of expected benefits and risks. Thus, we have found that discussions focused on tradeoffs, accompanied by simulation results that quantify them, can help guide stakeholders to acceptable management options that achieve a compromise. These compromises appear to be more difficult to identify if a single utility function encompassing all objectives is simply constructed a priori. In our experience, decision makers are more interested in an open discussion of alternatives that helps them to identify good decisions as opposed to a more constrained process that endeavors to yield the optimal decision.

Lessons Learned

The SDM process begins by diagnosing the problem, specifying objectives and corresponding performance measures, and defining available management options. It then continues through development of models that account for critical uncertainties and allow for an evaluation of tradeoffs. Our experience with applying deliberative decision-making frameworks has led us to identify key process characteristics that we believe are critical for success. First, the overarching purpose for applying SDM to management of recreational fisheries needs to be made clear at the outset. An open discussion of *why* SDM is being utilized is necessary for establishing a consensus view of the overall scope of the management challenge and forming common expectations for *what* the process will produce. Participants need to appreciate the value of engaging in the process but at the same time retain a realistic perspective on what the process can achieve. In our opinion, decision analyses inform decision making, they do not replace decision makers. Without exception, our experience has been that successful SDM processes have yielded valuable advice to decision makers—these processes have not, however, fully automated decision making. On the other hand, the inclusive process makes it much easier for managers to determine the extent to which a particular strategy appears to perform well *and* is supported by a user group. Second, it is vital to set the analytical context early in the process. Simple up-front explanations of technical approaches that will be used—and why they are necessary—can help to cement a common view of the problem among participants and greatly facilitate their willingness to engage in discussions of analytical results during later stages.

The success of an SDM process lies not only with how it is designed but also with *who* is involved. The specific makeup of an SDM working group is going to be case specific, but the validity and acceptance of the results will often depend critically upon who is involved in the process and at what stages they were involved (Miller et al. 2010). The working group should include individuals with required expertise and system knowledge, respected members of key stakeholder groups, and a modeling team with skills in collaborative model building. Careful thought should be given to group membership and group size; challenges are often caused by late entrants, attrition, or a perception of exclusiveness. For some individuals, participation may require substantial in-kind contributions (e.g., charter captains forgoing time on the water; Miller et al. 2010). We like to work with groups of 10–20 persons. A relatively small group is more likely to form good working relationships among all participants, which of course greatly increases the odds of achieving consequential results. Once assembled, a diverse group of people with differing objectives may not easily find common ground on an issue. Thus, we believe that a facilitation team is necessary to guide group interactions and ensure that participants are actively engaged throughout the process. This team could include experienced analysts (i.e., the modeling team) acting as the facilitators or independent facilitators; we have had success with both of these options (Irwin et al. 2008; Miller et al. 2010). Neutrality of the facilitation team can help prevent some participants from dominating an activity, and effective facilitation helps elicit multiple viewpoints when they exist.

Appropriate time allowances and monetary expenditures for working through an SDM process depend on several factors, including (1) the urgency and importance of the issue; (2) the familiarity of the participants with one another, the management framework, and the SDM approach in general; and (3) the amount of background analysis needed to develop and use forecasting tools. Applying SDM to recreational fisheries management will likely require a year or more to complete, as has been the case with commercial fisheries (Butterworth 2007). Advancing through SDM is usually not a simple linear progression because several key tasks allow for feedback. For instance, the analytical team may initially misinterpret other participants' views on objectives, options, or system dynamics, due to what has been termed "linguistic uncertainty" (Regan et al. 2002). We believe that well-timed feedback through group examination of the preliminary model structure and results can help participants crystallize their thinking and refine their input. Allowing for judicious refinement of the quantitative model, with its agreed-upon assumptions, avoids confusion ensuing from participants who rely on different mental models of how they individually expect a system to respond to a particular management action. In other words, iterative development of quantitative models can greatly assist in reducing linguistic uncertainty, thereby increasing efficiency.

SDM participants should also recognize that a tradeoff exists between continually updating simulation models with additional data (or exploring additional alternative policies) and moving forward with the implementation of a selected policy. At least three aspects of project management can be helpful in finding an acceptable balance between progressing through an SDM process and dealing with unexpected issues as they arise. First, an SDM process should include a clear and realistic timeline for completion (Butterworth 2007; Miller et al. 2010). The timeline could include progress markers that, once reached, restrict revisiting completed stages and thus avoid continual backtracking to revisit completed steps once reasonable levels of agreement are attained (Butterworth 2007). Second, including a schedule for planned reviews can help maintain productive project advancement by allowing for group consideration of whether policy adjustments are warranted based on obtaining new information. Because SDM may develop more questions than can realistically be answered within the scope of time allotted to a single evaluation, some pragmatic allowances for adapting the framework postimplementation may also be needed. Third, managers should therefore make proactive attempts to anticipate and formally identify potential triggers (or forms of crises that would require a response) not considered by the simulation-tested management options. For example, collection of new data may undermine key assumptions made in the modeling (e.g., observing a more extreme sequence of poor recruitment years than previously recorded), and it may be important to discuss when management actions should depart from the agreed-upon policy. In this regard, state-dependent management policies may better position managers to (1) respond to unexpected future states of the ecological system; (2) avoid unnecessary efforts to "reinvent the wheel;" and (3) avoid unjustified postimplementation tinkering with the policy (Jones and Bence 2009; Butterworth et al. 2010).

Because fisheries management tends to proceed through a series of linked decisions (Punt 2008), documentation should occur throughout the SDM process (Butterworth et al. 2010). As Larkin (1977:8) states "… 'deliberate' means that someone will not only *deliberate*, but in so doing will *document* the reasons for the decisions made." Proper documentation, at the least, provides a shared history and can be particularly important for advancing anticipatory thinking. For instance, the decision-making process for recreational fisheries should include discussions of how to support monitoring programs that incorporate learning (McDaniels and Gregory 2004), and the SDM process can help indentify which information would be most valuable to collect. Monitoring within the SDM framework is consistent with the ideas of "adaptive monitoring," where a well-conceived and well-executed monitoring program is iteratively driven by questions rather than the initial choice of which indicator to monitor (Lindenmayer and Likens 2009). Formally identifying linkages within and among decisions will enhance implementation of adaptive management based on what has been learned (Williams et al. 2009). Thus, we consider the required investments (or various "costs") of applying SDM to be worth incurring because they contribute to constructing a well-specified representation of management process, thus facilitating more informed discussions of acceptable and unacceptable outcomes.

While the products of SDM are intended to have real-world applications, we suggest that the SDM process itself produces benefits and can provide value well beyond formally stated goals. For example, the process generally leads to improved identification of important unknowns on which to focus future research (Miller et al. 2010), and SDM is particularly well suited to opening lines of communication. By working together, the process helps forge or repair relationships among participants while building trust and understanding that may well translate to future successes in addressing other issues (McCool and Guthrie 2001). Although adopting SDM will likely not be a quick fix for the challenges facing recreational fisheries management, we promote its use based on our own positive experiences and expectations for long-term benefits arising from using deliberate, integrated, interdisciplinary, and anticipatory decision-making frameworks. We especially value the participatory nature of the process as well as its ability to bring a wide variety of information to bear on a problem. As Johannes (1998) correctly points out, the choice is not between providing perfect or imperfect advice but rather between providing imperfect or no advice.

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References

Allan, J. D., R. Abell, Z. Hogan, C. Revenga, B. W. Taylor, R. L. Welcomme, and K. Winemiller. 2005. Overfishing of inland waters. Bioscience 55:1041–1051.

Bence, J. R., M. W. Dorn, B. J. Irwin, and A. E. Punt. 2008. Recent advances in the evaluation and implementation of harvest policies. Fisheries Research 94:207–209.

Bence, J. R., and K. D. Smith. 1999. An overview of recreational fisheries of the Great Lakes. Pages 259–306 *in* W. W. Taylor and C. P. Ferreri, editors. Great Lakes fisheries policy and management. Michigan State University Press, East Lansing, Michigan.

Butterworth, D. S. 2007. Why a management procedure approach? Some positives and negatives. ICES Journal of Marine Science 64:613–617.

Butterworth, D. S., N. Bentley, J. A. A. De Oliveira, G. P. Donovan, L. T. Kell, A. M. Parma, A. E. Punt, K. J. Sainsbury, A. D. M. Smith, and T. K. Stokes. 2010. Purported flaws in management strategy evaluation: basic problems or misinterpretations? ICES Journal of Marine Science 67:567–574.

Carroll, L. 1866. Alice's adventures in wonderland. Macmillan and Co., London.

Coleman, F. C., W. F. Figueira, J. S. Ueland, and L. B. Crowder. 2004. The impact of United States recreational fisheries on marine fish populations. Science 305:1958–1960.

Cooke, S. J., and I. G. Cowx. 2004. The role of recreational fishing in global fish crises. BioScience 54:857–859.

Gale, R. P. 1992. Is there a fisheries management revolution in your future? Fisheries 17(5):15–19.

Granek, E. F., E. M. P. Madin, M. A. Brown, W. Figueira, D. S. Cameron, Z. Hogan, G. Kristianson, P. De Villiers, J. E. Williams, J. Post, S. Zahn, and R. Arlinghaus. 2008. Engaging recreational fishers in management and conservation: global case studies. Conservation Biology 22:1125–1134.

Gregory, R., and G. Long. 2009. Using structured decision making to help implement a precautionary approach to endangered species management. Risk Analysis 29(4):518–532.

Hammond, J. S., R. L. Keeney, and H. Raiffa. 1999. Smart choices: a practical guide to making better life decisions. Broadway Books, New York.

Hilborn, R. 1987. Living with uncertainty in resource management. North American Journal of Fisheries Management 7:1–5.

Hilborn, R. 2008. Knowledge on how to achieve sustainable fisheries. *in* K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard, Jr.,

and M. J. Kaiser, editors. Fisheries for global welfare and environment. World Fisheries Congress 5, Tokyo, Japan.
Holling, C. S., editor. 1978. Adaptive environmental assessment and management. John Wiley and Sons, London.
Ihde, T. F., M. J. Wilberg, D. H. Secor, and T. J. Miller. (in press). FishSmart: harnessing the knowledge of stakeholders to enhance U.S. marine recreational fisheries with application to the Atlantic king mackerel fishery. Proceedings of the 5th World Recreational Fisheries Conference.
Irwin, B. J., M. J. Wilberg, J. R. Bence, and M. L. Jones. 2008. Evaluating alternative harvest policies for yellow perch in southern Lake Michigan. Fisheries Research 94:267–281.
Johannes, R. E. 1998. The case for data-less marine resource management: examples from tropical nearshore finfisheries. Trends in Ecology & Evolution 13(6):243–246.
Jones, M. L., and J. R. Bence. 2009. Uncertainty and fishery management in the North American Great Lakes: lessons from applications of decision analysis. Pages 1059–1081 in C. C. Krueger and C. E. Zimmerman, editors. Pacific salmon: ecology and management of western Alaska's populations. American Fisheries Society, Symposium 70, Bethesda, Maryland.
Jones, M. L., B. J. Irwin, G. J. A. Hansen, H. A. Dawson, A. J. Treble, W. Liu, W. Dai, and J. R. Bence. 2009. An operating model for the integrated pest management of Great Lakes sea lampreys. The Open Fish Science Journal 2:59–73.
Lane, D. E., and R. L. Stephenson. 1995. Fisheries management science: the framework to link biological, economic, and social objectives in fisheries management. Aquatic Living Resources 8:215–221.
Larkin, P. A. 1977. An epitaph for the concept of maximum sustainable yield. Transactions of the American Fisheries Society 106(1):1–11.
Lindenmayer, D. B., and G. E. Likens. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology & Evolution 24(9):482–486.
Lyons, J. E., M. C. Runge, H. P. Laskowski, and W. L. Kendall. 2008. Monitoring in the context of structured decision-making and adaptive management. Journal of Wildlife Management 72(8):1683–1692.
Mahon, R. 1997. Does fisheries science serve the needs of managers of small stocks in developing countries? Canadian Journal of Fisheries and Aquatic Sciences 54:2207–2213.
McCool, S. F., and K. Guthrie. 2001. Mapping the dimension of successful public participation in messy natural resources management situations. Society and Natural Resources 14:309–323.
McDaniels, T. L., and R. Gregory. 2004. Learning as an objective within a structured risk management decision process. Environmental Science & Technology 38(7):1921–1926.
Mendoza, G. A., and H. Martins. 2006. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. Forest Ecology and Management 230:1–22.
Miller, T. J., J. Blair, T. F. Ihde, R. M. Jones, D. H. Secor, and M. J. Wilberg. 2010. FishSmart: an innovative role for science in stakeholder-centered approaches to fisheries management. Fisheries 35(9):424–433.
Pereira, D. L., and M. J. Hansen. 2003. A perspective on challenges to recreational fisheries management: summary of the symposium on active management of recreational fisheries. North American Journal of Fisheries Management 23:1276–1282.
Peterman, R. M. 2009. Fisheries science in the future. Pages 167–184 *in* R. J. Beamish and B. J. Rothschild, editors. The future of fisheries science in North America. Fish and Fisheries Series, Springer Science + Business Media B.V., Dordrecht, The Netherlands.
Peterman, R. M., and J. L. Anderson. 1999. Decision analysis: a method for taking uncertainties into account in risk-based decision making. Human and Ecological Risk Assessment 5(2):231–244.
Peterson, J. T., and J. W. Evans. 2003. Quantitative decision analysis for sport fisheries management. Fisheries 28:10–21.
Post, J. R., M. Sullivan, S. Cox, N. P. Lester, C. J. Walters, E. A. Parkinson, A. J. Paul, L. Jackson, and B. J. Shuter. 2002. Canada's recreational fisheries: the invisible collapse? Fisheries 27(1):6–17.
Prince, J. D., H. Peeters, H. Gorfine, and R. W. Day. 2008. The novel use of harvest policies and rapid visual assessment to manage spatially complex abalone resources (genus *Haliotis*). Fisheries Research 94:330–338.
Punt, A. E. 2008. Refocusing stock assessment in support of policy evaluation. Pages 139–152 *in* K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard, Jr., and M. J. Kaiser, editors. Fisheries for global welfare and environment. World Fisheries Congress 5, Tokyo, Japan.
Radomski, P. J., G. C. Grant, P. C. Jacobson, and M. F. Cook. 2001. Visions for recreational fishing regulations. Fisheries 26(5):7–18.
Regan, H. M., M. Colyvan, and M. A. Burgman. 2002. A taxonomy and treatment of uncertainty for ecology and conservation biology. Ecological Applications 12(2):618–628.
Runge, M. C., J. R. Sauer, M. L. Avery, B. F. Blackwell, and M. D. Koneff. 2008. Assessing allowable take of migratory birds. Journal of Wildlife Management 73(4):556–565.
Stern, P. C., and H. V. Fineberg, H. V., editors. 1996. Understanding risk: informing decisions in a democratic society. National Academy Press, Washington, DC.
Ungate, C. D. 1996. Resolving conflicts in reservoir operations: some lessons learned at the Tennessee Valley Authority. Pages 23–27 *in* L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society Symposium 16, Bethesda, Maryland.
Walters, C. J. 1986. Adaptive management of renewable resources. MacMillan, New York.
Wilberg, M. J., T. F. Ihde, D. H. Secor, and T. J. Miller. 2009. FishSmart: a stakeholder-centered approach to improve fisheries conservation and management. International Council for the Exploration of the Sea Conference and Meeting 2009 0:15:1–38.
Wilberg, M. J., B. J. Irwin, M. L. Jones, and J. R. Bence. 2008. Effects of source-sink dynamics on harvest policy performance for yellow perch in southern Lake Michigan. Fisheries Research 94:282–289.
Williams, B. K., F. A. Johnson, and K. Wilkins. 1996. Uncertainty and the adaptive management of waterfowl harvests. Journal of Wildlife Management 60(2):223–232.
Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2009. Adaptive management: the U.S. Department of the Interior technical guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC.
Worm, B., R. Hilborn, J. K. Baum, T. A. Branch, J. S. Collie, C. Costello, M. J. Fogarty, E. A. Fulton, J. A. Hutchings, S. Jennings, O. P. Jensen, H. K. Lotze, P. M. Mace, T. R. McClanahan, C. Minto, S. R. Palumbi, A. M. Parma, D. Ricard, A. A. Rosenberg, R. Watson, and D. Zeller. 2009. Rebuilding global fisheries. Science 325:578–585.