Conservation Biology

Special Section

Structuring Decisions for Managing Threatened and Endangered Species in a Changing Climate

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Abstract: *The management of endangered species under climate change is a challenging and often controversial task that incorporates input from a variety of different environmental, economic, social, and political interests. Yet many listing and recovery decisions for endangered species unfold on an ad hoc basis without reference to decision-aiding approaches that can improve the quality of management choices. Unlike many treatments of this issue, which consider endangered species management a science-based problem, we suggest that a clear decision-making process is equally necessary. In the face of new threats due to climate change, managers' choices about endangered species require closely linked analyses and deliberations that identify key objectives and develop measurable attributes, generate and compare management alternatives, estimate expected consequences and key sources of uncertainty, and clarify trade-offs across different dimensions of value. Several recent cases of endangered species conservation decisions illustrate our proposed decision-focused approach, including Gulf of Maine Atlantic salmon (Salmo salar) recovery framework development, Cultus Lake sockeye salmon (Oncorhynchus nerka) management, and Upper Columbia River white sturgeon (Acipenser transmontanus) recovery planning.*

Keywords: collaborative decision making, environmental management, recovery choices, stakeholders, value trade-offs

Estructuración de Decisiones para Manejar Especies Amenazadas y en Peligro en un Clima Cambiante

Resumen: *El manejo de especies en peligro bajo el cambio climático es una labor retadora, y a veces controversial, que incorpora la entrada de una variedad de intereses políticos, sociales, económicos y ambientales. A pesar de esto, muchas decisiones de enlistado y recuperación para las especies en peligro se desenvuelven en una base ad hoc sin referencia a los acercamientos de ayuda que pueden mejorar la calidad de las opciones de manejo. A diferencia de muchos tratamientos de este suceso que consideran el manejo de especies un problema basado en la ciencia, sugerimos que un proceso claro de toma de decisiones es igualmente necesario. Frente a las nuevas amenazas debidas al cambio climático, las decisiones de los administradores sobre las especies en peligro requieren análisis íntimamente relacionados y deliberaciones que identifiquen objetivos clave y desarrollen atributos medibles, generen y comparen alternativas de manejo, estimen consecuencias esperadas y fuentes clave de incertidumbre, y clarifiquen a los balances a través de diferentes dimensiones de valor. Varios casos recientes de decisiones de conservación para especies en peligro ilustran nuestra propuesta de acercamiento enfocado en decisiones, como la recuperación del salmón del Golfo de Maine, el manejo del salmón del lago Cultus y la planeación de recuperación para el esturión blanco del río Columbia.*

Palabras Clave: balance de valores, manejo ambiental, opciones de recuperación, partes interesadas, toma de decisiones colaborativas

Paper submitted August 1, 2012; revised manuscript accepted June 6, 2013.

DOI: 10.1111/cobi.12165

Introduction

Decision making for species at risk is fundamentally about protecting populations that are either in immediate danger of extinction or may become endangered in the foreseeable future. However, these choices are set against the backdrop of a large number of stakeholders with diverse priorities, overlapping jurisdictions, conflicting short- and long-term management objectives, unintended and difficult-to-predict consequences, and high levels of uncertainty. As a result, managers must make difficult judgments that are often both technical in nature (e.g., about data quality or relevance) and value based (e.g., that reflect individual or agency priorities, preferences, and risk tolerances).

In addition, species-at-risk choices are difficult because the stakes in listing and recovery decisions are high and characterized by competing objectives, including economic interests, other environmental concerns, political realities, and public scrutiny. This complexity, combined with constraints on the time, data, and effort that underlie most decision-making processes, can paralyze even the most adept and well-intentioned resource managers. Furthermore, recovery guidelines typically focus on a biological-threats analysis, with minimal reference to how ecological concerns are to be reconciled with conflicting social or economic goals (Bruskotter et al. 2010).

In 1998, the *Society of Conservation Biology* in cooperation with the U.S. Fish and Wildlife Service (USFWS) launched a national review of recovery plans for species listed under the U.S. Endangered Species Act (ESA) (Schultz & Gerber 2002). This review identified ways in which the recovery planning process could be improved and led to the development of criteria and guidelines (Gerber & Hatch 2002). Although a step in the right direction, these criteria fall short of what is required to articulate management objectives clearly, generate a range of responsive recovery plan alternatives, or identify key value trade-offs. As a result, conservation plans are implemented with varying degrees of success and with few opportunities for learning across applications. Guidelines that provide principles for sound decision making, paired with sequenced actions to make defensible conservation decisions and to implement each step, are urgently needed.

Climate change greatly increases the stakes for decision makers, resource managers, and vulnerable species. For example, managers must account not only for the species they are used to seeing in a particular region, but also other species that may migrate to new areas as they are forced out of their current ranges. Resource managers are also being confronted by higher levels of uncertainty (e.g., regarding predicted changes in temperature, rainfall, and ocean acidification); conflicting priorities across species, space, and time; and management objectives that may reflect politics and profitability as much as science (Hilborn et al. 2011). For all these reasons, managers have a heightened interest in identifying decision-aiding strategies that are both scientifically defensible and robust, in that they are likely to yield satisfactory outcomes across a wide range of future scenarios.

Structured decision-making (SDM) and other decision-analytic approaches are increasingly being used to help resource managers effectively achieve conservation objectives by linking theoretically rigorous and psychologically appropriate approaches (Hammond et al. 1999; Gregory et al. 2012*a*). This interest, due in part to initiatives undertaken over the past decade by the USFWS (e.g., Williams et al. 2007), has seen SDM approaches serve as the foundation for generating recovery frameworks for managing endangered species (e.g., Conroy et al. 2008; Gregory & Long 2009; Martin et al. 2009), for helping environmental managers respond to climate change (Ohlson et al. 2005; McDaniels et al. 2012), and for implementing adaptive-management strategies (Arvai et al. 2006; Gregory et al. 2006; Runge et al. 2011). We applied SDM approaches to endangered species conservation, with a focus on choices that must be made, by resource managers and other decision makers, as part of organizing and implementing conservation recovery plans in ecosystems affected by climate change.

Structured Decision-Making Methods

A central finding of behavioral decision research is that for many categories of decisions, individuals do not have well-defined preferences to consult when making choices. Instead, people's preferences are constructive in nature (Slovic 1995). This means that rather than approaching choices about environmental concerns with clear and stable values, people instead construct their preferences in response to cues that are available from similar past experiences or that are provided during the elicitation process. People also bring to decisions their own cognitive and emotional responses and a set of reasonably predictable judgmental heuristics (Kahneman 2011). For example, individuals and groups typically focus on particularly salient aspects of a decision, make unwarranted assumptions about the similarities between one problem context and another, and tend to be excessively confident in their own opinions (Kahneman et al. 1982).

SDM approaches entail a collaborative and facilitated application of multiple objective decision-making and group deliberation methods to address environmental management problems (Gregory et al. 2012*a*). The intent, shared with other multicriteria evaluation methods, is to provide insight by organizing a decision-making process as a logical series of steps. These steps include defining the problem, identifying objectives and attributes,

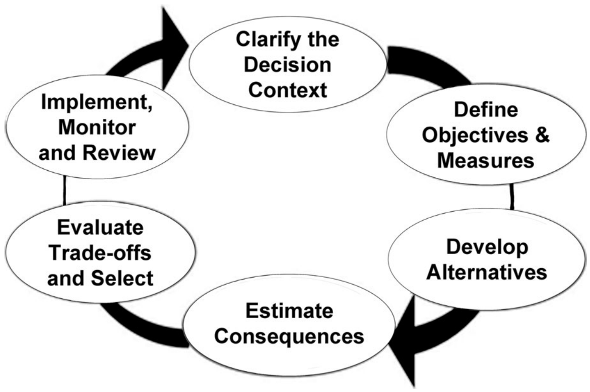

*Figure 1. General structured decision-making framework for application to endangered species recovery plan decisions (Gregory et al. 2012*a*).*

constructing initial alternatives, identifying their consequences in terms of the attributes, and directly confronting key trade-offs (Fig. 1).

Some SDM approaches rely more heavily on quantitative methods, whereas others place more emphasis on dialogue and problem structuring. All applications seek to incorporate the analytic-deliberative risk management philosophy espoused by the National Research Council (1996), which calls for iterative and linked exchanges of information between technical experts, stakeholders, and decision makers. In response, formal or informal checklists for decision quality control are often included as part of SDM approaches to help participants move past overly simple or one-sided conceptions of objectives, information, or management alternatives (Kleindorfer et al. 1993). These include instructions to decision makers to be aware of the tendencies to downplay uncertainty or to be overly optimistic about obtaining additional data within a reasonable timeframe; succumb to motivational errors that promote self-interested positions; focus too narrowly on habitual alternatives; ignore dissenting opinions; and exhibit unwarranted optimism about achieving predicted outcomes.

Of particular interest in the context of decisions about the management of endangered species is the use of techniques that help decompose larger, highly complex problems into a small number of component elements. Revealing and focusing deliberations on a smaller set of key judgments has the potential to encourage better understanding among stakeholders and more transparent communication among them. A clear decision-making focus also helps emphasize the interactive and iterative opportunities associated with creating, evaluating, and implementing management plans for endangered species. For example, objectives may need to be reconsidered in light of new information about the consequences of actions and the participation of new stakeholders, or a promising management alternative may come to light partway through an advisory panel's deliberations. This emphasis on learning over time—central to effective monitoring and adaptive management in response to climate change (Arvai et al. 2006)—is a cornerstone of SDM approaches to endangered species management (Lyons et al. 2008).

Key Problems and Applications

We highlight 4 problems associated with conservation of endangered species: vague management objectives, incomplete consideration of alternatives, lack of consideration of uncertainty in consequence estimates, and avoidance of explicit trade-offs. These problems limit the effectiveness of management plans, increase the time or resources required for making decisions, and foster controversies that can slow conservation efforts. To demonstrate how SDM can facilitate endangered species conservation planning, for each problem we describe a recent case study set against the backdrop of uncertainties associated with climate change.

Vague Management Objectives

The importance of clearly defining the decision context and identifying key objectives is illustrated by the ambiguity that characterizes much of the legislation and policies focused on the management of endangered species. The ESA, for example, defines *endangered* as any species in danger of extinction throughout all or a significant portion of its range (section 3.6) and *threatened* as any species likely to become endangered in the foreseeable future throughout all or a significant portion of its range (section 3.19). Yet with no clear definitions of ESA categories of threat and no clear definition of *significance* or *foreseeable future*, it has been left to individual recovery teams or responsible federal agencies to clarify listing and delisting criteria for each species. In contrast, recent adoption of the IUCN quantitative criteria (Mace et al., 2008) has made this issue less problematic for managers tasked with implementing Canada's Species at Risk Act (SARA). A further complication comes from the absence of guidelines for consistently addressing uncertainties about the anticipated spatial effects of climate change or the associated trade-offs across management priorities (Thuiller 2004; Wilson et al. 2009).

The first step in an effective decision-making process is to identify the values and concerns in play to lend maximum insight to decision makers about the potential effects of management options. Although this point is intuitive and widely stated, many consequential ESA decisions proceed without a comprehensive set of clearly articulated objectives. Game et al. (2013) refer to this as "trying to solve an ill-defined problem." Indeed, decision makers' first instinct is often to bypass the discussion of objectives altogether in favor of moving straight to the evaluation of management alternatives. This is understandable because managers often work on species protection decisions for extended periods and thus tend to assume the objectives are clearly understood. However, in our experience, there is often much room for improvement when it comes to accounting for and fully characterizing the range of stakeholders' concerns (Kellon & Arvai 2011; Gregory et al. 2012*a*).

Part of this task is to develop metrics for evaluating the performance of management alternatives through context-specific attributes or performance measures (Tear et al. 2005). For example, riparian habitat may be gained or lost, but how should this habitat be characterized (e.g., which species, which locations, during which seasons)? Similarly, jobs may be gained or lost but what type of jobs (e.g., seasonal vs. permanent) and in which locations? Decision-aiding methods such as SDM highlight the role of performance measures that provide concise, context-specific ways to assess the degree to which different alternatives are anticipated to address each objective (Keeney & Gregory 2005).

Being explicit about objectives and attributes serves 3 other important functions. First, a thorough exploration of decision objectives helps legitimize the balance between scientific or technical concerns and those that are value oriented in nature. Second, exploring a comprehensive set of objectives at the front end avoids many of the biases observed in unaided decision-making processes and helps all stakeholders realize that management problems cannot be solved by focusing on only one dimension. Third, exploring the relations between related objectives helps uncover and encourage discussions about key sources of uncertainty, many of which are especially salient when considering effects of climate change.

An example of the benefits of clarifying objectives comes from the Atlantic salmon (*Salmo salar*) recovery program in the Gulf of Maine a collaborative management effort involving 2 federal agencies (USFWS and National Oceanographic and Atmospheric Administration [NOAA]), the state of Maine (Department of Marine Resources), and the Penobscot Indian Tribe. Its primary goal is to increase the abundance and persistence of wild Atlantic salmon spawning in the Gulf of Maine. Whereas historical populations numbered in the hundreds of thousands, recent annual returns average only about 100 fish due to the effects of climate change on ocean survival rates and other factors, including dams, pollution, and habitat loss due to development.

As part of discussions to develop a formal Atlantic salmon recovery-planning framework, participants from the 3 lead management agencies compared management alternatives (Gregory et al. 2012*b*). They considered fundamental objectives, defined by participants as an increase in the abundance and the distribution of wild Atlantic salmon populations, to be obvious and known. As the analysts and facilitators leading the framework discussions, we encouraged an initial review of objectives along with consideration of performance measures to track progress in meeting them. This discussion generated other objectives including species persistence, financial cost, genetic diversity, healthy ecosystems, urgency, collaboration, flexibility (in terms of adaptive management), and ease of implementation.

Consistent with the iterative nature of an SDM process, further dialogue led to agreement that neither abundance nor distribution (despite their initial status as obvious, desirable program goals) should be used as fundamental endpoints for Atlantic salmon recovery activities. Fish abundance was problematic because too much uncertainty exists with respect to survival rates for salmon in the marine environment (from the time they leave coastal estuaries until the time they return to spawn several years later in natal streams), particularly with respect to changes in ocean temperatures and currents due to climate change. Distribution could only be assessed at a project level after rivers were selected for implementing specified actions. After additional discussion, 2 new fundamental objectives were agreed to by all participants (Table 1): minimize the short-term probability of Atlantic salmon extinction and maximize the long-term probability of recovery of wild fish. These objectives were expressed in terms of multiple performance measures. Participants recognized that recovery efforts require increased abundance of wild salmon over a wider geographic range (i.e., distributional concerns), access to a functioning ecosystem, and sufficient diversity (in genetics, life history, and morphology) to withstand climate-induced environmental change and natural ecosystem variability. Although many of the specific actions needed to minimize the short- and long-term probability of extinction will differ, these same 4 subobjectives—increasing abundance, maintaining genetic diversity, increasing distribution (both within and across rivers), and improving ecosystem functioning (including habitat connectivity and effects on migratory fish populations)—were included as part of both recovery-program objectives.

Incomplete Consideration of Alternatives

Most conservation processes seek to develop a single plan that meets the existing legislative mandates and that is likely to gain a reasonable measure of support from key stakeholders. The rationale is clear: intense pressure is placed on stakeholders and decision makers to reach a consensus decision because of the belief that it stands the best chance of being successfully implemented. In reality, the deck is often stacked against a single, consensus-focused alternative in terms of its ability to really facilitate

Table 1. Objectives and performance measures for minimizing short-term probability of extinction.*

Subobjectives	*Performance measures*
Increase abundance	increase marine survival increase estuary and coastal survival increase adult spawners through hatchery increase adults via fresh water production of smolts
Maintain genetic diversity	maintain genetic diversity (life history, morphological functions) via conservation hatchery
Increase distribution	maximize geographical area affected by actions across rivers and over geographic range of the government of main distinct population segment
Improve ecosystem functions	increase habitat complexity, connectivity, and community diversity; maximize benefits to other species

**Atlantic salmon recovery planning (from Gregory et al. 2012*b*).*

widespread agreement and in terms of prospects for sustainable, successful implementation.

From a decision analytic perspective, the basis for our concern regarding the incomplete consideration of alternatives is 2-fold. First, an alternative developed to achieve consensus is likely to rely too heavily on compromise among different stakeholders, building on a set of objectives and concerns that serve as a lowest common denominator. As a result, there is often a failure on the part of decision makers to identify the full range of key objectives. Some are omitted because they do not come to mind readily when discussions focus on a single alternative (Keeney 1992), whereas other objectives are downplayed—unconsciously or deliberately—because they are likely to cause conflict within the group. Our experience is that objectives that cause the most conflict are often the ones requiring further exploration.

A second problem is that focusing on a single solution leads to poorly informed trade-offs. Without knowing the range of consequences associated with the performance of objectives across alternatives, important considerations will be omitted even though they may account for the greatest variation in performance for the problem under consideration. For example, the amount of time it takes for a management strategy to be implemented may be left out of discussions even though it's often a critical concern that varies widely among alternatives. The opposite is also likely; an objective is initially identified as critical, but once the full array of alternatives is analyzed, its forecasted performance is seen to be essentially the same across the different options. For example, management costs are often deemed central to many listing and delisting decisions even though the variation in this concern across alternatives is often negligible.

The endangered Cultus Lake (British Columbia, Canada) sockeye salmon (*Oncorhynchus nerka*) population is a genetically distinct stock within the Fraser River sockeye aggregate. Cultus sockeye are especially vulnerable because climate change will affect the physical environment where this species spawns (e.g., peak summer flows in the Fraser River will be lower and stream temperatures will be higher). Because Cultus Lake sockeye are genetically distinct from other salmon that migrate back into the Fraser system at the same time, conservation constrains the harvest of several more abundant populations. For this reason, it was ultimately decided—after completion of a socioeconomic assessment by the Canadian Department of Fisheries and Oceans (DFO)—to not list Cultus populations under the federal SARA. This meant there would be no legally binding requirements for sockeye fishing to be reduced or eliminated on the Fraser River to protect Cultus Lake stocks and left DFO in the position of having to balancing the conservation of an endangered population against the commercial exploitation of other salmon stocks. Implementing an SDM-based precautionary approach to fisheries management was seen as one way to achieve this balance (Gregory & Long 2009).

To generate and evaluate management alternatives, the multistakeholder committee first distinguished between external, climate-induced conditions beyond managers' direct influence (e.g., changes in water temperatures) and other relevant considerations that they could address (e.g., fishing pressure, river restoration efforts). Members then debated the estimated effectiveness of various "menus of possible management actions" that included exploitation rate, spatial location of catches, hatchery enhancement, and habitat restoration. The committee made use of a strategy table (Table 2) that defined different levels of intensity (rows of Table 2) for each of these actions.

Combining these actions helped the group generate several distinct management alternatives, whose estimated consequences were compared with reference to the status quo. These alternatives represented interests that ranged from conservation to maximized commercial fishing opportunities and included strategies representing a compromise among these (and other) competing objectives. Simulation modeling was then used to estimate the effects of each alternative and to lay the groundwork for their further refinement. Several of the compromise alternatives were preferred, by all committee members, to the status quo management plan, and this insight led to immediate changes in management of Cultus Lake sockeye. This same decision-aiding structure has been used successfully over the past several years as a framework to monitor agency success, guide discussions among stakeholders, and assist in the choice of specific management actions.

Table 2. A strategy table for Cultus Lake sockeye, with status-quo management actions noted (from Gregory & Long 2009).

	Cultus exploitation rate	*Late run harvest*	*Location*	*Enhancement*	*Freshwater projects*
Lower	5	0, as Cultus*	SQ—downstream only*	none	none
intensity ↑	10–12 (2005)*	10	mixed	current: captive brood*	current milfoil*
	20	20	Upriver (Vedder)	current ongoing	moderate milfoil
	30	30		double current smolt	Full milfoil
Intensity	40	unconstrained		max enhancement	current pikeminnow (<5%)*
↓	25			ongoing double current cap	moderate pikeminnow (5–20%)
				max 250 k	full pikeminnow (+20%)
Higher intensity				150 k	hire stewardship coordinator

**Status-quo management actions.*

Lack of Consideration of Uncertainty

Uncertainty about the effects of climate change on species of interest adds to the complexity within which recovery planning and listing decisions are made. Acquiring information can be costly in terms of time and resources. Yet information is essential, particularly when concerns such as climate change lead to development of process-based models to clarify uncertainties fundamental to the construction of management alternatives (Cuddington et al. 2013). Addressing uncertainty also is critical when controversy stemming from disagreements among experts—representing different management agencies or different stakeholder perspectives—is a primary impediment to the design or implementation of management actions. In such cases, decision-analytic approaches can be used to learn more about the assumptions underlying experts' opinions and, through structured interviews or elicitations, provide additional clarification regarding the reasons experts differ in their assessments of the uncertainty associated with proposed management actions (Burgman 2005; Gregory et al. 2012*a*).

Decision-focused tools can help overcome managers' tendencies to put off making important decisions because of the high levels of uncertainty and complexity that the required choices entail. Too often, managers effectively define a responsible decision-making process as one that requires further research so that management actions can be selected under greatly reduced uncertainty. They invoke mantras such as *do no harm* or rely on the popular precautionary principle. But because all decisions about endangered species include some degree of uncertainty (regarding economic, social, political, and environmental concerns), these approaches are often short sighted because they do not account for the fact that failing to act can also cause harm. For this reason, SDM encourages managers to evaluate discrete decision opportunities and to openly incorporate uncertainty and stakeholders' tolerance for risk as considerations that may substantially affect the choice among alternative strategies. In this sense, managers should approach decisions characterized by uncertainty in the same way as previously discussed: identify objectives and performance measures, generate alternatives, identify consequences associated with confronting versus delaying a decision, and evaluate the associated risks and benefits.

In 2007, a joint United States-Canadian Technical Working Group was tasked with developing recommendations in support of an official recovery plan for upper Columbia River white sturgeon (*Acipenser transmontanus*). North America's largest and longest lived freshwater fish, white sturgeon in the upper Columbia have experienced almost complete recruitment failure over the last 2 decades or more and are now listed under endangered species legislation in both the United States and Canada. Despite agreement that hydroelectric dams built along the Columbia River have had a major detrimental effect, the question of which specific mechanisms—including different flow rates, toxic emissions, and fish introductions related to climate change—are responsible for ongoing recruitment failure is a subject of considerable uncertainty and controversy.

We worked with a technical committee of resource managers to examine plausible hypotheses that could explain recruitment failure and help members identify and prioritize short-term management actions and longer term research initiatives. A generic effects-pathway structure (or influence diagram) was created after considerable discussion. As shown in Figure 2 (which highlights one of the hypotheses, labeled "LC1"), this approach provided common ground for discussions of the different causes of recovery failure, their different physical and biological effects, and the importance of climate change and other factors as explanations for the observed failure to recruit. Selected expert participants were asked to argue either for or against the acceptance of each hypothesis, with the influence diagram providing a consistent framework for these

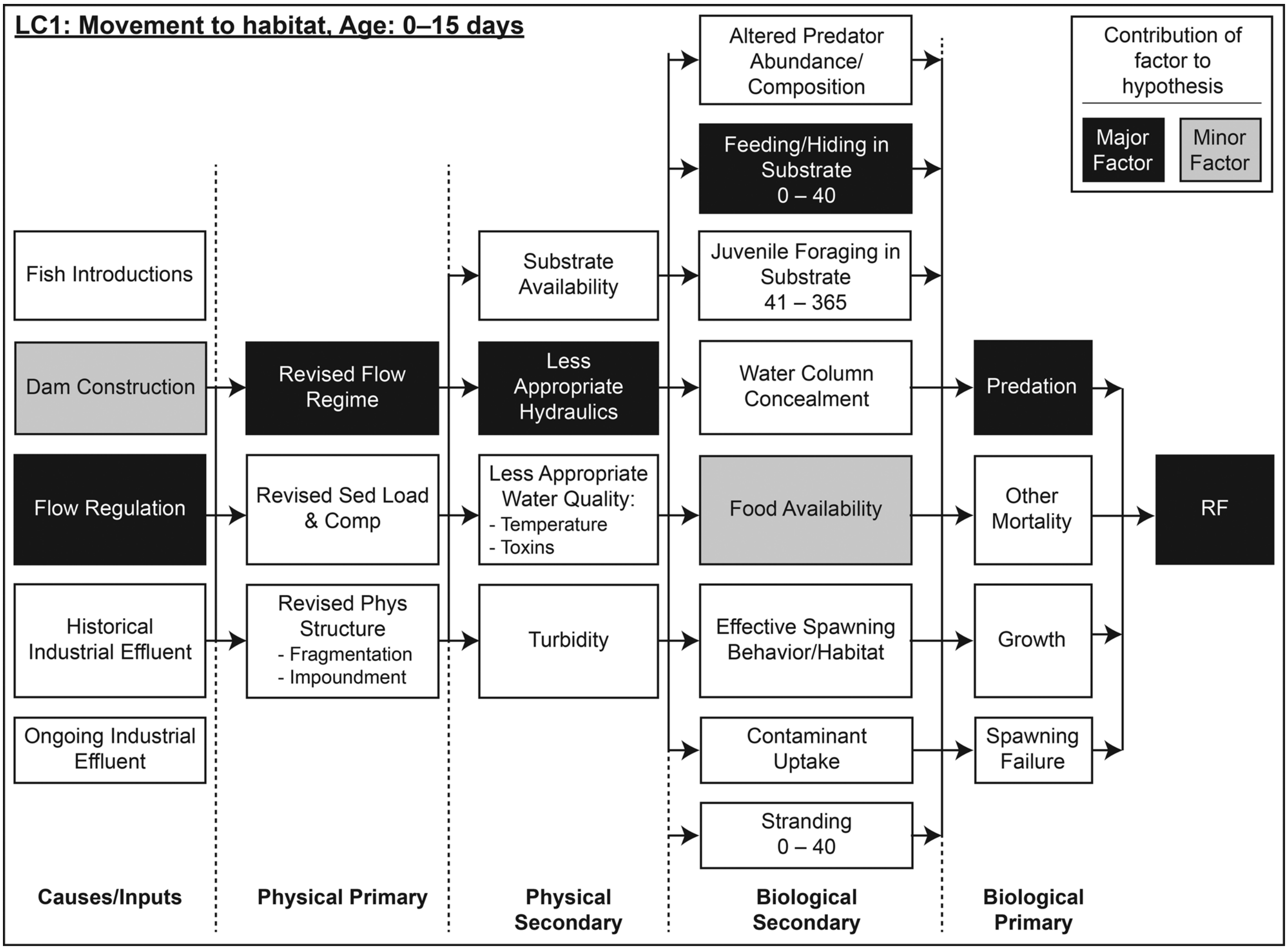

*Figure 2. Example effects pathway showing the primary cause and major physical and biological reasons for recruitment failure of upper Columbia River white sturgeon (Gregory et al. 2012*a*).*

deliberations. As SDM-based facilitators, we led a discussion that asked for judgments concerning the percentage of recruitment failure associated with each hypothesis, the expert's confidence in their assessment, and the likelihood that further research would confirm that the hypothesis accounts for at least 20% of ongoing recruitment failure (Gregory et al. 2012*a*). This resulted in a sharply reduced set of key hypotheses and established a consistent foundation for continued discussions about the timing and cost of specified management actions versus research initiatives as inputs to the overall recovery-plan framework.

Avoidance of Explicit Trade-Offs

When integrating biological information into ESA policies, scientific issues associated with species' recovery are often in conflict with other goals. As a result, the chance of species recovery given any specified management action depends not only on biological aspects such as population dynamics and habitat extent, but also on the ability of a plan to simultaneously address a diverse set of social, economic, and political concerns. Many decision makers respond to this reality by focusing on a reduced set of objectives or by seeking to avoid explicit trade-offs altogether, in part due to the increased cognitive demands placed on them as the number of objectives increases (Hammond et al. 1999; Wilson & Arvai 2006).

Decision makers also need to grapple with difficult trade-offs in which deeply held ethical or "protected" values may be affected (Baron & Spranca 1997). In such circumstances, it is not surprising that some stakeholders may resent attention to issues such as costs when they believe moral concerns such as health, environmental quality, or justice are involved. In addition, it is not uncommon for certain objectives to be highlighted (and others to be avoided) in endangered species deliberations because they touch on emotionally charged issues (Sunstein 2000). One salient example of this is the charismatic megafauna debate that grips many high-profile deliberations about species threatened by climate change (Gerber et al. 2000; Boykoff & Goodman 2009).

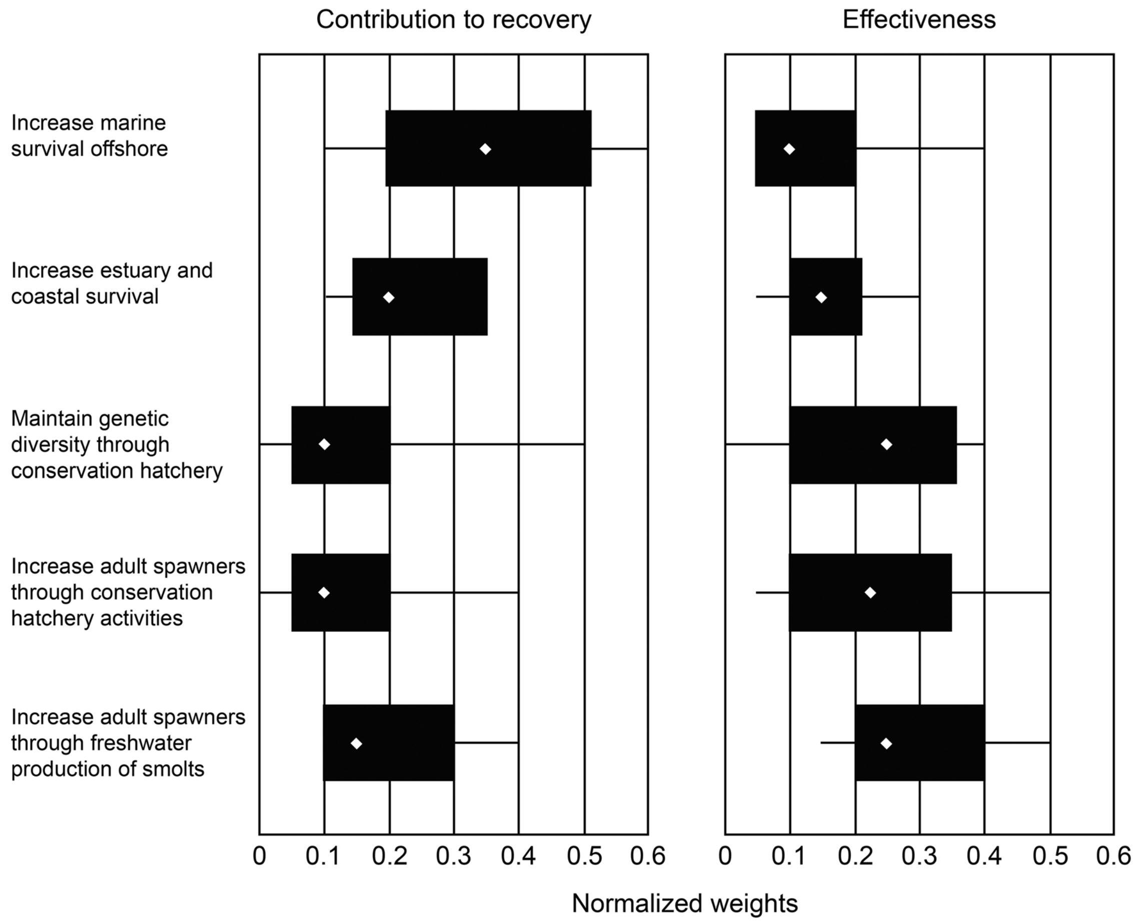

*Figure 3. Assessed contributions to recovery and to the effectiveness of Atlantic salmon recovery plans of 5 categories of management activities (Gregory et al. 2012*b*).*

In developing a recovery program for endangered Atlantic Salmon populations, the SDM-based process encouraged thinking about 2 primary aspects of the problem: the biological significance of the anticipated contribution of an action to recovery of the species and its anticipated technical effectiveness. By using expert elicitation techniques and structured discussions based on experts' subjective judgments, 3 important insights followed from these decomposed judgments (Gregory et al. 2012*b*). First (as shown in Fig. 3), the large differences in many of the assigned weights were surprising to participants and, as a consequence, initiated useful discussions. For example, the 90% confidence limits on the assessed contribution to recovery of "increasing marine survival offshore" varied widely among participants, with some assigning this activity category an average weight of 0.2 (so that this single attribute received 20% of the emphasis in their decision) and others giving it a weight of 0.5 (equal to the combined contribution of all other activity categories). Second, judgments for both the relative contribution of an action to recovery and the effectiveness of the action differed across the 5 activity categories. However, there was general agreement on rank orders when judgments were shown as averages: increasing survival rates for salmon in the marine environment is most important for recovery and hatchery and freshwater activities are judged most likely to be effective. Third, actions associated with marine survival offshore—including learning more about the uncertain effects of climate change—were thought to make the highest expected contribution to recovery but had the lowest effectiveness score, whereas hatchery activities were scored lowest in terms of their contribution to recovery but were given relatively high effectiveness scores.

These results highlight one of the fundamental (yet previously hidden) dilemmas facing managers in allocating resources. The leading cause of population decline, marine survival, is also the category for which management actions are least likely to be effective, whereas hatchery activities were rated high in effectiveness but relatively low in terms of their anticipated contribution to recovery. By decomposing the implications of management actions, the use of decision-aiding approaches helped experts review and discuss their respective opinions and helped decision makers distinguish between actions focused on additional research (e.g., reasons for low levels of marine survival) and implementation of direct, near-term mitigation actions (e.g., increasing production from conservation hatcheries).

Discussion

Endangered species management under conditions of climate change involves a complex mix of social, ecological, and economic issues that require resource managers and other decision makers to employ good science and good decision-making skills. We emphasize the relevance of SDM and other multiattribute decision-aiding approaches to the creation of sound recovery programs that combine analytical and deliberative methods drawn from decision analysis and the behavioral sciences. SDM approaches are particularly relevant to facilitating effective management in situations characterized by high levels of uncertainty, disagreements among participants about the objectives guiding actions, and a confusion between fact-based and value-based arguments.

Although both credible scientific information and thoughtful deliberation should inform choices about endangered species, neither data nor dialogue can be viewed as the sole input. Effective management in the face of climate change places a priority on decision-making processes that help stakeholders create and compare policy alternatives across a range of consequences that reflect best judgments of future outcomes and incorporate uncertainty about these estimates. This information must be presented to, and discussed openly with, stakeholders in a way that clearly communicates and highlights key elements of the management opportunities and that leads to the implementation of effective plans (Gunderson 2013).

For many resource managers, development of decision-making skills may prove to be at least as important for the effective management of threatened and endangered species as their training and skills as scientists. Rarely do we observe efforts aimed at increasing the literacy of endangered species managers in the decision sciences or providing them with access to analytical techniques that would help them focus discussions among stakeholders. Yet in light of climate change and other sources of uncertainty that often block progress toward agreement on a management plan, the use of formal decision-aiding methods has helped realign and refocus discussions among technical experts by identifying different objectives (e.g., for Atlantic salmon recovery planning), developing new hypotheses for addressing recruitment failure (e.g., for upper Columbia River white sturgeon), and by creating a framework for generating and evaluating new management alternatives (e.g., Cultus Lake sockeye). In each case, discussions that had meandered for several years were reorganized and provided with a structure that facilitated better communication among participants and returned stakeholders' and managers' emphasis to focused discussions about the pros and cons of alternative management actions.

Structured decision-aiding approaches clearly have their limits; some technical experts will continue to hold firm to their views despite evidence from peers to the contrary, and some decision makers will not be pleased with the transparency involved in stating specific management objectives or identifying uncertainties associated with the estimated outcomes of actions. Yet participants in these case studies generally were enthusiastic about the use of an SDM approach and thought it helped identify areas of agreement, which built common ground, and highlighted areas of disagreement, which led to the use of a variety of techniques (e.g., influence diagrams, expert judgment elicitations) intended to move the discussion forward when differences of opinion threatened to block further progress. Significantly, in each of these cases new actions were implemented which managers considered better from the standpoint of reducing risks to endangered and threatened species, and improved decision-focused frameworks were established to guide future species recovery and conservation planning.

Although we focused on endangered species management and climate change, the benefits of explicit decision-aiding methods are broadly relevant to the field of conservation decision making. For example, Game et al. (2013) identified common mistakes in conservation priority setting and suggest that many priority-setting exercises violate key principles of good, defensible decision support. The authors argue that this leads to poor resource-allocation decisions and lends the prioritization a false credibility. For endangered species, the consistency in decision processes that comes from adoption of SDM and other decision-aiding approaches is likely to be particularly helpful in making progress on the large backlog of species proposed for listing.

Acknowledgments

We thank NOAA and the U.S. National Science Foundation (award numbers SES-1231231 and SES-0924210 to Decision Research) for their funding and support. Special thanks to Graham Long, who co-led several of the SDM examples. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the sponsors.

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