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Using Structured Decision Making to Help Implement a Precautionary Approach to Endangered Species Management

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Endangered species protection is a significant risk management concern throughout North America. An extensive conceptual literature emphasizes the role to be played by precautionary approaches. Risk managers, typically working in concert with concerned stakeholders, frequently cite the concept as key to their efforts to prevent extinctions. Little has been done, however, to evaluate the multidimensional impacts of precautionary frameworks or to assist in the examination of competing precautionary risk management options as part of an applied risk management decision framework. In this article we describe how decision-aiding techniques can assist in the creation and analysis of alternative precautionary strategies, using the example of a multistakeholder committee charged with protection of endangered Cultus Lake salmon on the Canadian west coast. Although managers were required to adopt a precautionary approach, little attention had been given to how quantitative analyses could be used to help define the concept or to how a precautionary approach might be implemented in the face of difficult economic, social, and biological tradeoffs. We briefly review key steps in a structured decision-making (SDM) process and discuss how this approach was implemented to help bound the management problem, define objectives and performance measures, develop management alternatives, and evaluate their consequences. We highlight the role of strategy tables, employed to help participants identify, alternative management options. We close by noting areas of agreement and disagreement among participants and discuss the implications of decision-focused processes for other precautionary resource management efforts.

KEY WORDS: Decision making; endangered species; precautionary; risk management

1. INTRODUCTION

Endangered species protection is a significant concern throughout North America. In the United States, the Endangered Species Act (ESA) has just passed its 35th anniversary, with reviews of its impact on species conservation highlighting both successes and failures of the past three decades' experience.[(1)] In Canada, legislation is in place at both the federal and provincial levels to prevent extinctions, and again the verdict on conservation initiatives is mixed.

Two issues help to explain much of this mixed risk management record. The first is the need to balance biological or environmental goals against other societal objectives such as economic benefits, social justice, recreation, or health and safety. Different management strategies can be viewed as being more or less responsive to the differential weights placed on these often competing goals. The second issue

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is that the decisions of risk managers with respect to endangered species are nearly always undertaken in the presence of substantial biological uncertainty and, typically, in the context of substantial uncertainty about how policies might affect a variety of other management goals.

Over the past decade, significant attention has been given to the potential for precautionary risk management approaches to improve the ability of risk managers to strike a balance among competing objectives to address uncertainty. The cornerstone of a precautionary approach generally is considered to be a willingness to undertake conservation-focused management actions in advance of conclusive scientific evidence of harm.[(2)] Precautionary approaches are intended to step into the gap between scientifically supported information regarding how to reduce risks to an endangered population and the needs of decisionmakers to present a defensible rationale for their choices. Unfortunately, only few successes can be found: in most cases, the lofty goals of a precautionary risk management approach have failed to be realized due, in part, to pressures brought on by the different parties involved in a decision.

In this article, we take a critical look at the concept of precautionary management as an aid to effective risk management decision making, emphasizing that good choices on the part of risk managers (and the agencies they work for) require more than good science or better information on key scientific questions. We focus on the benefits of applying a structured decision-making (SDM) process, based on the techniques of decision analysis and behavioral decision theory, as an aid to implementing a precautionary approach. Using the case-study example of an endangered west-coast salmon population, we emphasize the challenges associated with developing a precautionary risk management plan that simultaneously recognizes key sources of uncertainty and is acceptable to both federal regulators and a representative multiparty stakeholder group.

2. BACKGROUND

2.1. The Context for a Precautionary Management Approach

The desire to protect species considered to be at risk, even when important scientific information is lacking, lies behind the attention—and somewhat surprising acceptance—given to the concept of precautionary management. A recent review article noted that "[f]ew principles are better ensconced in the law and philosophy of environmentalism than is the 'precautionary principle.'"[(3)] A precautionary approach often is considered to be synonymous with the adage "better safe than sorry," and both the law and the courts often have applied it in this way: the U.S. Clean Air act, for example, emphasizes the "common sense" of taking affirmative action despite uncertainty regarding environmental impacts, and over a quarter-century ago the U.S. Supreme Court ruled, in the context of risk assessments for hazardous substances (the well-known "Benzene" decision), that agencies are free to be viewed as "risking error on the side of overprotection rather than underprotection" (*Industrial Union Dep't, AFL-CIO v. American Petroleum Inst.,* 1980).

The precautionary principle is famously stated in the U.N. 1992 Rio Declaration on Environment and Development: "Lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental degradations." This one-sentence Rio definition assumes two key elements. First, it presumes the existence of some mechanism to determine what actions will be cost effective, which implies an analytical structure that helps to clarify both consequences (what costs are associated with implementation of a precautionary plan?) and tradeoffs (what balance between conservation and costs is effective?). Resource management agencies concerned with the implementation of measures focused on conservation, such as protection of endangered species or biodiversity, are very familiar with the need to balance potential threats to a species against other considerations. These typically include not only economic effects but also social, cultural, and health or safety factors as well as, in some cases, other environmental concerns (e.g., to the extent that protection of one species might adversely affect another). In the United States, amendments to the 1973 ESA specifically require that economic issues are considered in the designation of critical habitat and set out guidelines for consultation and participation by other "appropriate" parties. In Canada, species designated as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), an independent scientific review panel, are subsequently reviewed under the Species at Risk Act (SARA) so that the various factors at play can be identified and weighted and a decision can be made whether to list a species as officially "at risk" of extirpation.

The second key element of the Rio definition of a precautionary approach is the assumption, common to nearly all definitions of the concept, of a link between the lack of certainty (concerning the effects of different actions) and scientific evidence: there exists uncertainty because some key pieces of the science puzzle are missing, but this should not prevent going ahead with measures that err on the side of biological caution. The presumption here is threefold. First, that the decision to go ahead with management plan A or B rests on science. Second, that the residual uncertainty is linked to scientific evidence and can be reduced over time though the continued application of science. Third, that scientific evidence is key to decision making.

Each of these assumptions about the development of precautionary policies is, at best, curious and, at worst, flat-out wrong. Although some management decisions are made largely on the basis of scientific evidence, a rich literature demonstrates that underlying the science are numerous value-based choices about what constitutes an impact, what constitutes evidence, and what analyses are appropriate. A precautionary approach is about making better societal decisions, and thus a defensible precautionary approach needs to be embedded within a decision-making framework that integrates the values-based information underlying what is important with the facts-based information detailing the current status of key concerns and how these are expected to be changed by management actions. Scientists provide data and information to regulators and resource managers, and good science is critical to good environmental risk decision making. Yet although science can alert decisionmakers to key sources of uncertainty affecting the design of management actions, science alone cannot tell managers what to do about these issues, nor can scientific expertise directly evaluate the relative importance of the associated social, cultural, health, or economic implications (as noted by the U.S. National Research Council[4]). Many environmental management agencies include scientists who serve as decisionmakers, and this requires a shift in their perspective because "[t]he reality is that science informs. It does not, and fundamentally cannot, decide" (see Reference 5, p. 733). One implication of this is that precautionary approaches may need to be considered for multiple dimensions of a problem or issue, not just with respect to conservation objectives: to the extent that uncertainty also exists with respect to the economic or social or cultural implications of a proposal, then precautionary management strategies might also be important to extend to these other considerations.

2.2. Conservation Risk Management Under Biological Uncertainty

The presence of biological uncertainty is fundamental to the adoption of a precautionary approach. Decisions to list a species as endangered typically arise from recommendations made by panels of scientific experts in light of their determination of the need to protect a species whose existence is threatened. In the usual case, these recommendations are viewed as scientific questions to be answered in an objective, unbiased manner. Yet decisions about when and how strictly to enact precautionary strategies, as noted in the Rio agreement, will reflect "society's chosen level of risk." Further, in many situations faced by risk managers, reducing key sources of uncertainty may have little to do with carrying out "more" or "better" scientific studies. Natural variation, for example, can become better understood over time but will remain even after the collection of additional samples or other information. Many conservation biologists also have noted the importance of linguistic uncertainty, which reflects a lack of precision in the vocabulary used as part of conservation decisions.[6] Not only are key elements critical to development of a conservation plan often vaguely defined (e.g., specification of a species' range) but language imposes artificial cutoffs along a probabilistic continuum of threats (e.g., when does a "threatened" species become "endangered," or at what point does a "cost effective" mitigation action become too expensive?). Clearing up these sources of linguistic uncertainty may have much to do with careful economic or policy analysis, but it is unlikely to have much to do with the insertion of better scientific results.

Further, three decades of work in behavioral decision making clearly shows that the judgments of scientific experts are rarely less affected by numerous biases and errors of attribution than are those of less technically trained people.[7] This can take many forms. One is an overreliance on more familiar and salient sources of information; for ecologists and biologists, this "availability bias" often results in a focus on data obtained as the result of scientific investigations. Yet both theory and experience demonstrate that attention should also be given to alternative data sources that reflect the knowledge held by long-time community residents, resource users (e.g., fishers, hunters, farmers), and aboriginal populations (so-called traditional ecological knowledge).[8] This attention to community-based knowledge is also important in light of the reality that many choices affecting biological conservation are made by multiparty, multiinterest stakeholder groups working in concert with resource managers from government, academia, and industry. Another source of error is overconfidence: numerous experiments, conducted with practicing scientists on questions of direct concern, have shown that there is often an unexpectedly low relationship between confidence and accuracy.[9] Vose,[10] for example, found that experts asked to provide intervals that contain the true value of a sample at least 90% of the time provided judgments that were accurate only 40% of the time; Burgman[11] discusses this phenomenon of "expert frailties" in the context of scientists' conservation risk assessments and listing decisions. A third source of error is the diminishment of the role played by emotions; scientists generally are considered to form opinions based on dispassionate scientific objectivity, but scientific training has consistently been shown to provide little protection against largely unconscious motivations or emotions.[12]

2.3. SDM as an Aid to Resource Management Under Uncertainty

Structured decision making is an organized process for engaging multiple parties in a decision-oriented dialogue that considers both facts (from scientists and other sources) and values (see Table I). It relies on the principles and tools of decision analysis, based on multiattribute utility theory[13] and on behavioral decision research, which emphasizes description findings about how people typically make decisions. Core elements of an SDM application include defining objectives and measures of performance, identifying and evaluating alternatives, and making choices based on a clear understanding of uncertainties and tradeoffs.[14] These elements are common to many conservation initiatives, particularly those involving the integration of scientific findings with the concerns of a multiparty stakeholder group: Maguire (see Reference 15, p. 868) discusses how "[d]ecision analysis can help articulate the many goals of those who have a stake" in the context of invasive species management decisions, and both Landis[16] and Burgman[6] discuss the importance of incorporating stakeholder perspectives as part of ecological risk assessments.

In an SDM approach, stakeholders (led by an analyst/facilitator) begin by formally structuring a problem in terms of a small set of relevant issues and interests,[17] defined through explicit objectives or endpoints of concern. Performance measures (also termed performance criteria or attributes) are identified for each: these convey information about the relevant impacts of an action, including considerations such as reductions in risk (reduced probability of extinction over x years), foregone financial values ($ per year), habitat improvements (hectares of habitat), or the degree of protection provided to ceremonial sites (no. of site-days per year) used by local native populations. Participants then identify alternatives, or potential management actions. Each alternative is evaluated based on predictions of how it will affect the performance measures. Making these predictions involves the development of hypotheses about the response of key variables to the management action; a substantial literature outlines relevant methods and potential pitfalls.[17] Competing hypotheses may originate from different knowledge

Table I. Key Steps in a SDM Process

Clarify the decision context	Define the context and scope of the decision, along with budgets and timelines.
Define objectives and evaluation criteria	State key considerations in terms of endpoints or values that could be affected by policies or actions under consideration.
Develop alternatives	Establish a range of well-defined management options, showing diversity in response.
Estimate consequences and identify uncertainties	Make use of best science along with local community and aboriginal knowledge to show anticipated consequences of actions. Include explicit estimates of uncertainty.
Evaluate tradeoffs	Recognize differences in the importance of objectives and how these will influence preferred choices.
Select preferred option(s), implement and monitor	Document the decision process, implement the selected alternative(s), and monitor to improve the basis for making future decisions.

sources, or from within a given knowledge source. Uncertainty about the hypotheses may result in the use of expert judgment, modeling and data collection, or other studies as aids to the evaluation process.(18)

Choosing among alternatives involves making tradeoffs among competing objectives. A structured decision-making process encourages exposure of the tradeoffs and dialogue to address them directly. Methods for making choices should allow stakeholders to state their preferences for different outcomes and therefore for different alternatives, based on good fact-based or technical information about the range of potential consequences. In individual decisions, the context for preferences is purely personal. Public decisions, on the other hand, should be guided by a context that reflects societal concerns; considerations such as the distribution of economic returns, long-term environmental effects, social justice, or cultural implications therefore may prove to be critical. Stakeholders are charged with making choices in the public interest, based on their own perspective but also reflecting what they have learned in the deliberative process from experts and other stakeholders. One of the key tasks of a group facilitator is to help ensure that expressed preferences reflect this larger context and are sufficiently flexible to reflect learning that has occurred over the course of the deliberative process.(5)

3. IMPLEMENTING A PRECAUTIONARY APPROACH: THE CULTUS LAKE EXAMPLE

The Fraser River system of southwestern British Columbia (BC) supports the largest number of individual sockeye subspecies, or populations, of any river system in the world,(19) and is second (after Bristol Bay, Alaska) in total sockeye salmon production. Cultus Lake sockeye stocks are one of eight populations[1] in the late Fraser River salmon runs. Population abundance has declined since the 1950s, with a particularly sharp drop since the mid 1990s (or three generations of returns, since Cultus Lake sockeye follow a 4-year spawning cycle). Reductions in salmon returns throughout the west coast over the past few decades have received front-page attention in local newspapers, and are high on the agenda of politicians and many public-interest groups. The decline is thought to be due to a combination of high exploitation rates and elevated natural mortality rates. Evidence shows the adverse impacts of pollution and regional development (which took away important spawning and rearing areas), and by the late 1990s evidence was accumulating that climate change—in the form of record high temperatures and altered seasonal precipitation patterns—and other factors affecting marine survival also had begun to affect migrating salmon.(20)

A review of the biological status of Cultus Lake sockeye, by an independent scientific panel, was followed by a socioeconomic assessment. The scientific review showed strong evidence for endangered status, whereas the socioeconomic assessment emphasized the high (and immediate) economic and social costs of listing Cultus Lake sockeye stocks under SARA. The core issue is that because Cultus sockeye are indistinguishable (without genetic analysis) from the rest of the populations that migrate back into the Fraser system at the same time, conserving them constrains the harvest of other more abundant, and commercially valuable, sockeye salmon populations.

After closed-door deliberations, the federal minister decided not to list Cultus sockeye stocks under SARA, which meant that there would be no legally binding requirements for sockeye fishing to be reduced or eliminated on the Fraser River in order to protect Cultus Lake stocks. This left the lead agency for management of marine species, the Department of Fisheries and Oceans (DFO), in the position of having extensive discretionary powers with respect to how it might balance conservation of an endangered population against the continuing exploitation of a valuable economic resource. Implementing a precautionary approach to fisheries management, in which decision making and planning processes would involve all interested parties and consider both short- and long-term impacts,(21) was seen as one way to achieve such a balance.

Support for this approach came from the fact that precautionary management is the stated core of the federal Wild Salmon Policy (WSP), developed by the Canadian DFO. The WSP sets out a framework for identification and protection of all wild salmon populations, consistent with the needs of the First Nation food/ceremonial fishery as well as maintenance of healthy commercial and sport fishing sectors. Specifically, a precautionary approach to fisheries management is discussed in terms of principles that include a reminder that "application of the precautionary approach should be based on sound

[1] Population is a biological term, whereas stock is a group of fish defined by management context.

scientific information," that "a high degree of transparency and public involvement are appropriate," and that the precautionary principle constitutes a "distinctive decision making approach within a risk management framework."[(22)]

However, the agency had little substantive experience with application of a multiobjective precautionary approach: as is true for many other resource agencies throughout North America, the language of guiding principles rarely had been put into action. Fraser River sockeye management, as a whole, continued to rely on an informal process of bargaining and trading among the key interests: quantitative analyses were conducted to estimate numbers of returning adults, but little was done in terms of formal or structured analyses of management alternatives. This significantly limited the capacity for making key tradeoffs in a defensible and transparent manner. The combination of inexperience and growing dissatisfaction among stakeholders led the DFO to decide to implement a more structured, analysis-based approach to addressing key tradeoffs in fisheries management, with Cultus Lake sockeye management put forward as a pilot project. The intent was to determine if a more structured approach to decision making could improve DFO's capacity for engaging stakeholders meaningfully in developing management options and in analyzing the tradeoffs among management alternatives.

3.1. Bounding the Problem and Selecting Participants

Many different groups are interested in Cultus Lake sockeye management, including local and international conservation interests, First Nations (i.e., Native Americans or Tribes), recreationists, commercial fishers, DFO, and the Province of BC. Conserving the Cultus Lake sockeye population is an ecological concern because it is a genetically distinct population within the Fraser River sockeye aggregate, contributing to genetic diversity within the species.[2] sockeye are of significant cultural value to the Soowahlie First Nations band; the lake itself is located on Soowahlie traditional territory, and the Soowahlie band and the Sto:lo people traditionally have harvested Fraser River sockeye (including the Cultus Lake population) for subsistence purposes.[(23)] Cultus Lake stocks are also important to commercial fishers in BC, including First Nations commercial fisheries, and support an active recreational fishery; recent estimates of the annual cost to the commercial fishery, in terms of reductions in catch required to protect Cultus Lake stocks, range from \$60 to 100 million.[3]

The overall goal was therefore to develop a management plan for the Cultus Lake sockeye population that would maximize conservation while allowing stakeholders to continue to benefit from exploitation of Cultus Lake and other late-run salmon populations. Representatives from parties interested in Cultus Lake sockeye management were invited by DFO to participate in a structured decision-making process. After initial discussions, a 12-person consultative committee was formed that included representatives from commercial fisheries, recreational fisheries, conservation groups, the province of BC, and DFO managers. Members of the public were not included because their input is directly through a regional fisheries harvest planning committee (IHPC) that reports to the federal Minister, and First Nations elected to wait and see how the SDM process unfolded and to convey their views through side discussions with one of the environmental representatives. Committee members were invited to attend a series of three workshops occurring at two-week intervals, with the goal of preparing recommendations for Cultus Lake sockeye management. Although there was interest in creating a 4-year management plan (i.e., covering the full 4-year sockeye life cycle) to help accomplish this goal, the analysis was initiated only a month before management choices needed to be made and thus it occurred in a condensed time frame; for this reason only the 2006 harvest year was considered.

This tight schedule created some obvious difficulties, and the "learning curve" for conduct of the SDM process was steep. A practical implication of the one-month time frame for the analysis was that problem bounding excluded full consideration of some elements—tourism potential, First Nation cultural values, and legal implications (to the extent that Cultus Lake management procedures might set

[2] Cultus Lake sockeye populations also occupy an iconic status among fisheries biologists due to W. Ricker's seminal work based, to a large degree, on data collected from Cultus Lake stocks.

[3] Gross *et al.*[(24)] cite the *Canada Gazette* (Oct. 23, 2004, p. 2905) as having stated "lost benefits to fisheries are estimated at \$125 million over a 4-year period if these populations are listed." However, he argues that this figure was not arrived at using a sound analysis.

Table II. Objectives and Performance Measures for Cultus Lake Sockeye Structured Decision-Making Process

Objective	Subobjective	Performance Measure	Desired Direction
Conservation	Probability of meeting recovery plan objectives 1 and 2	Maximize probability	Higher
	Returns in year 2010 and average returns of years 2016 to 2019	Maximize number of fish returning	Higher
	Probability of extirpation by 2036	Minimize probability of extirpation by 2036	Lower
	Percent enhanced fish in 2010 and average percent enhanced fish in years 2016 to 2019	Minimize percent enhanced fish	Lower
Cost	Total costs over 12 years, levelized	Minimize cost	Lower
Catch	Commercial catch in traditional downstream location	Maximize catch	Higher
	Commercial catch available upstream of the Vedder River	Maximize catch	Higher
	Total First Nations food social and ceremonial catch	Maximize catch	Higher
Employment	Employment opportunities directly related to enhancement and freshwater projects	Maximize employment opportunities	Higher

a precedent for other endangered or listed stocks)—that would merit attention as part of a more comprehensive review. On the other hand, the near-term time constraint encouraged participants to work hard and to make rapid progress on a problem that, for many years, had proven largely intractable. This also increased the benefits of using Cultus Lake as a test application for development of a precautionary approach, in that if the SDM process could help here—in a highly contentious management context and under severe time and financial pressures—then chances were good that it also would be helpful elsewhere, under less difficult circumstances.

3.2. Defining Objectives and Performance Measures

The committee defined objectives and performance measures in the first of the series of three workshops. Participants specified the four fundamental objectives of conservation, cost, catch, and employment as well as several related subobjectives; these are shown in Table II. This list of objectives was revisited at several times throughout the process and minor modifications were made.

Performance measures are also specified in Table II; all measures are unidirectional (i.e., maximize or minimize) so as to facilitate subsequent tradeoffs. Selecting effective performance measures is a critical step because they are used to operationalize objectives and thus assist in the choice among management alternatives. Decision analysis theory requires that performance measures be well defined, comprehensive, directly relevant to the decision, and understandable to participants.[25] Additionally, performance measures must pass practical tests: in the Cultus Lake case, the impacts of different management alternatives were measured using a simulation model, and thus the results of model runs needed to be expressed easily through the selected performance measures. Development of a defensible basis for making management decisions in future years also is important. For example, although moving commercial fisheries upstream was not a strategy that could be implemented in 2006 (due to logistics and prior licensing agreements), we retained a performance measure to indicate the foregone commercial harvest that could become available in future years.

3.3. Developing Management Alternatives

Only after developing agreed-upon objectives and performance measures was the committee ready to take on the key task of defining alternatives. This sequence is typical of a decision-focused process to management of an endangered species—start with value-based objectives before considering management options—and is in marked contrast to the usual sequence that begins with the presentation of a leading set of management actions (aka “alternative-focused” rather than “value-focused”) and then moves to evaluating these alongside several slightly modified variants. The SDM process also is iterative: the committee created an initial set of alternatives in the first meeting, and these were refined as part of the second and third meetings in light of their predicted performance and new information about consequences that was presented to the group.

A key consideration with respect to development of management alternatives is that the Fraser River sockeye fishery is a mixed-stock fishery: different salmon stocks commingle as they migrate back to the Fraser River to spawn after spending much of their adult life in the Pacific Ocean. The Cultus Lake population is harvested concurrently with other runs, seaward of the mouth of the Fraser. The implication is that, in order to reduce harvest pressure on the Cultus Lake population, some combination of the following two actions would have to be taken.

(1) Reducing the exploitation rate on the entire late run.
(2) Moving the commercial fishery to other areas on the Fraser River (upstream of Cultus Lake).

Neither of these options yielded an easy solution from the perspective of adopting a precautionary management alternative. Option 2 would have the effect of moving the fishery to an entirely new area, and for a variety of reasons—including commerical licensing restrictions and First Nation traditional rights—it is viewed as a long-term and partial solution. Another problem with Option 2 is that, because salmon stop feeding during their upstream migration, their flesh is of a lower commercial quality once they reach upstream areas. Option 1 therefore has been favored, but as a result of the mixed-stock allocation problem, it has been only partially successful: numbers of Cultus Lake sockeye, for all four returning-year stocks, have continued to decline over the past 20 years, and for two of the four stocks annual runs are now in less than 1,000 fish.[4] These low returns, coupled with the continuing high costs to the commercial fishing sector, mean that for the past decade Cultus Lake sockeye populations have played an important, albeit highly contentious, role in the planning of the entire late run Fraser fishery.

Influences on the performance of alternatives—how well a precautionary management option might satisfy participants' expressed objectives—are both external and internal. For example, relevant external considerations included marine conditions and climate change; however, these were outside the mandate of the consultative committee. Internal considerations, which can be influenced by management actions, included five primary factors: the exploitation rate (i.e., a realistic estimate of the likely percentage of Cultus Lake stocks that would be harvested), the late-run harvest differential,[5] the location of the fisheries, hatchery enhancement options, and freshwater habitat restoration projects.

In creating alternatives the committee made use of a strategy table (see Fig. 1). This showed the five leading management actions, as described below, in columns and their different levels, over a realistic range, in rows.

1. Exploitation rates for Cultus Lake stocks ranged from 5% (considered to be the lowest realistically possible) to 40%, including the 10–12% exploitation rate used for 2005.
2. Differential late harvest exploitation rates were restricted to those specified for the Cultus Lake population; as 10, 20, or 30% different from the rate specified for Cultus, or as unconstrained by Cultus.
3. Fishery location options were downstream only (as per the status quo), moving the fishery upstream of the Vedder River, and a mix of downstream and upstream locations.
4. Enhancement options for Cultus Lake sockeye currently use hatchery fish obtained from a captive brood stock. Other enhancement options include continuing the current captive brood operation on an ongoing basis, doubling the current smolt production for 2006 (from 50,000 to 100,000), doubling the current smolt production on an ongoing basis, or undertaking larger levels of enhancement that could produce either 150,000 or 250,000 smolts per year.
5. Freshwater habitat enhancement options were also considered. One action involves removal of Northern Pikeminnow from Cultus Lake because this species may prey on salmon fry. Another action is to remove Eurasian watermilfoil, an invasive plant, from Cultus Lake because it provides habitat for

[4] The 2006 returning sockeye population is one of the two relatively stronger Cultus Lake runs.

[5] The late-run harvest differential refers to the difference in harvest rate between the Cultus Lake sockeye stock and the harvest rate on the remaining late-run stocks. This was only relevant to fisheries upstream of the Vedder River.

Cultus Exp Rate	Lates Harvest Differential	Location	Enhancement	FW Projects
5	0, As Cultus	SQ – Downstream Only	None	None
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
40	Unconstrained		Max Enhancement	Current Pikeminnow (<5%)
25			Ongoing dbl current cap	Moderate Pikeminnow (5-20%)
			Max 250k	Full Pikeminnow (+20%)
			150K	Hire Stewardship Co-ordinator

Fig. 1. Strategy table with status quo management actions circled.

predators such as Pikeminnow. In considering various freshwater management alternatives, the committee specified continuing with current levels of milfoil and Pikeminnow removal projects, or increasing the rates by either a small amount (moderate) or substantially (full). The option of hiring a habitat stewardship coordinator, to oversee activities in Cultus Lake and thus increase the effectiveness of management actions, also was identified.

Fig. 1 shows the starting point for these discussions from the committee's first meeting, which defined status quo management actions (shown by the circled actions) as those undertaken in 2005. The committee then created five other possible management alternatives that represented a wide spectrum of interests, ranging from a conservation-focused alternative to one maximizing commercial fishing opportunities as well as other alternatives designed as compromises between competing objectives (see Fig. 2 for one example). These were summarized using a consequence matrix, which showed the set of alternatives across the top in columns and the performance measures (detailing the concerns expressed in the objectives) used to evaluate each alternative along the side as rows. As discussed later, a key aspect of the structured decision-making process is that information regarding the consequences of these options led to their further refinement and to the creation of new management options that sought to find a middle ground among the competing interests; participants referred to these as "spread the pain" alternatives (as shown in Fig. 3).

3.4. Estimating the Consequences of Management Actions

Much of the information needed to evaluate the six initial alternatives—the entries in the cells of the consequence matrix—was not readily available. The one-month time frame for the consultations placed strong demands on the analysts and modelers, and some typical methods for addressing severe uncertainty—such as expert judgment elicitations[26] or additional field studies—were simply not possible. As a result, two primary tasks for the consultants (in conjunction with DFO staff) between meetings 1 and 2 were (1) to determine whether additional alternatives should be considered at this stage and (2) to populate the matrix in order to help participants begin to focus more clearly on a set of preferred alternatives. This was done through interviews with managers, through further development of existing simulation models, and through the analysis of data from similar case studies within the region or in the published literature.

Fig. 3 shows the resulting consequence matrix, introduced to the consultative committee at the start of meeting 2. It displays nine alternatives (including three additional alternatives identified through interviews) along with estimated results for all

Cultus Exp Rate	Lates Harvest Differential	Location	Enhancement	FV Projects
5	0, As Cultus	SQ – Downstream Only	None	None
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
40	Unconstrained		Max Enhancement	Current Pikeminnow (<5%)
25			Ongoing dbl current cap	Moderate Pikeminnow (5-20%)
			Max 250k	Full Pikeminnow (+20%)
			150K	Hire Stewardship Co-ordinator

Fig. 2. Strategy table with management actions circled for an alternative designed to compromise between competing objectives.

Objective	Attribute	Direction	Status Quo	Preservation	Commercial	Terminal Benefits	Spread the Pain 1	Spread the Pain 2	Max Rebuilding	Spread the Pain 3	Sports Compromise
Conservation	% meeting Rec Plan Objective 1	H	73%	76%	82%	80%	72%	80%	84%	79%	81%
Conservation	% meeting Rec Plan Objective 2	H	32%	33%	33%	34%	31%	35%	34%	33%	34%
Conservation	No of returns in 2010	H	6.3	7.8	12.5	8.7	6.5	8.6	13.2	8.0	8.9
Conservation	No of returns in 2016-2019 (ave)	H	16.9	24.3	47.7	31.1	16.8	30.1	53.8	28.7	35.7
Conservation	Probability of extinction	L	2.4%	1.1%	0.0%	0.3%	3.4%	0.2%	0.0%	0.4%	0.2%
Conservation	% Enhanced fish 2010	L	27%	21%	56%	34%	26%	35%	52%	37%	46%
Conservation	% Enhanced ave fish 2016-2019	L	33%	29%	45%	41%	32%	42%	41%	45%	46%
Costs	Total Costs	L	$ 171	$ 309	$ 588	$ 488	$ 171	$ 523	$ 588	$ 328	$ 500
Catch	Total Downstream	H	1,925	304	6,601	3,391	3,391	4,642	1,925	4,618	4,642
Catch	Total Upstream	H	637	2,884	504	2,365	2,365	2,335	3,054	2,131	2,335
Catch	Total First Nations	H	777	739	769	796	796	768	797	768	768
Jobs	Total FTEs	H	1.60	2.80	4.10	3.70	1.60	3.30	4.10	2.50	4.10

Fig. 3. Consequence table showing initial objectives and alternatives developed by the consultative committee.

12 performance measures. Using this consequence table, the consultative committee was able to compare alternatives in terms of their predicted consequences. The process of discussing and choosing among alternatives resulted in modifications to the consequence table entries and improved presentation of the options, designed to make the results and the associated tradeoffs easier to understand. This was done using a software tool called ViSTA, developed by Compass Resource Management and described later, which uses a color scheme to facilitate the comparison of alternatives.

3.5. Evaluating Tradeoffs

Variation across the alternatives is shown in terms of different scores on each of the various management-relevant objectives. Fig. 4 redraws the consequence table from Fig. 3 using ViSTA's color

Objective	Attribute	Direction	Units	Status Quo	Preservation	Commercial	Terminal Benefits	Spread the Pain 1	Spread the Pain 2	Max Rebuilding	Spread the Pain 3	Sports Compromise
Conservation	% meeting Rec Plan Objective 1	H	%	73%	76%	82%	80%	72%	80%	84%	79%	81%
Conservation	% meeting Rec Plan Objective 2	H	%	32%	33%	33%	34%	31%	35%	34%	33%	34%
Conservation	No of returns in 2010	H	# 000	6.3	7.8	12.5	8.7	6.5	8.6	13.2	8.0	8.9
Conservation	No of returns in 2016-2019 (ave)	H	# 000	16.9	24.3	47.7	31.1	16.8	30.1	53.8	28.7	35.7
Conservation	Probability of extinction	L	%	2.4%	1.1%	0.0%	0.3%	3.4%	0.2%	0.0%	0.4%	0.2%
Conservation	% Enhanced fish 2010	L	%	27%	21%	56%	34%	26%	35%	52%	37%	46%
Conservation	% Enhanced ave fish 2016-2019	L	%	33%	29%	45%	41%	32%	42%	41%	45%	46%
Costs	Total Costs	L	!Yr An Ave $00	$ 171	$ 309	$ 588	$ 488	$ 171	$ 523	$ 588	$ 328	$ 500
Catch	Total Downstream	H	# 000	1,925	304	6,601	3,391	3,391	4,642	1,925	4,618	4,642
Catch	Total Upstream	H	# 000	637	2,884	504	2,365	2,365	2,335	3,054	2,131	2,335
Catch	Total First Nations	H	# 000	777	739	769	796	796	768	797	768	768
Jobs	Total FTEs	H	# FTEs	1.60	2.80	4.10	3.70	1.60	3.30	4.10	2.50	4.10

Fig. 4. Amended consequence table using color codes to highlight differences among alternatives with respect to key management objectives.

scheme.[6] The "Status Quo" option is selected, and accordingly, ViSTA has highlighted the Status Quo column in the consequence table in blue. Where another alternative performs better than the selected alternative in terms of a specific performance measure, the appropriate cell turns green. Red cells, in contrast, indicate poorer performance relative to the selected alternative, and yellow indicates "no significant difference" between alternatives for the selected performance measure (where this can be altered depending on the context: in one case a 5% difference might be designated as negligible whereas in another case an insignificant difference might be 10 or 20%).

This presentation also highlights a key goal of the analytic-deliberative process that was followed as part of the Cultus Lake consultations, which is to simplify the choices facing committee members. As an example, Fig. 4 shows no significant differences among any of the alternatives for the performance attribute that measures total first Nations catch. Though this criteria is important, it was not helpful in distinguishing among the different alternatives: the minimum threshold set by the consultative committee for First Nation catch requirements was met by all alternatives. For this reason, this performance measures was removed from the decision process. Similarly, the ViSTA color scheme made it easy for participants to see when one alternative was superior to another based on the selected evaluation criteria. In such cases, the inferior alternative was considered "dominated" by another alternative and, following discussion, was removed from the decision process.

At the end of this refinement process, only three of the initial nine alternatives remained. At this point, the committee agreed that one precautionary alternative had a number of features that made it a good compromise solution: it included a full-scale Pikeminnow removal program, a continuation of the current milfoil removal program, and employment of a habitat stewardship coordinator. We then created (through discussions) five new variations of this alternative that kept these broadly accepted features but varied the exploitation rate (20, 25, 30, or 40%) and enhancement production (100 or 150 K smolts per year). By the end of meeting 3, two of these five alternatives were selected to go forward to the IHPC: both showed a production level of 150,000 smolts; one of the alternatives had an exploitation rate of 25% and the other an exploitation rate of 40%.

3.6. Discussion

Participants on the Cultus Lake committee all agreed that the SDM process introduced rigor into their thinking and movement into their negotiations about objectives, alternatives, and tradeoffs in relation to development of a precautionary approach to

[6] For the approximately 4% of people who are color-blind, the colors show in shades of gray: blue is the darkest, followed by red and then green, with yellow showing as off-white.

management of Cultus Lake sockeye. This rigor was of three types: a structural rigor helped to simplify a complex problem and focused discussions on possible management actions; an analytical rigor permitted modelers to focus their efforts on key uncertainties; and a discursive rigor enabled deliberations among participants to move forward as they focused attention on the more important dimensions of the problem.

The committee agreed on freshwater projects best suited for conserving Cultus Lake sockeye. In particular, these included increasing Pikeminnow removal to a full-scale level; continuing the 2005 level of milfoil removal efforts; and employing a habitat stewardship coordinator. The committee also agreed that a salmon enhancement level of 150,000 smolts should be part of any management plan for Cultus Lake sockeye. Discussions emphasized the need for an ongoing planning process, beyond 2006, and noted that First Nations cultural impacts, tourism, other broad-scale ecological impacts, along with the effects of moving some commercial catch to upriver areas, should receive attention as part of future consultative committee deliberations.

The committee did not come to an agreement on a commercial exploitation rate for late-run Fraser sockeye within the allotted time period.[7] One member expressed discomfort from a conservation standpoint at the precedent that would be set by agreeing on an exploitation rate greater than 25%, whereas another participant was uncomfortable with a commercial exploitation rate below 40%. Several members stated that the high level of uncertainty associated with the benefits of salmon enhancement made it difficult to determine an optimal balance between commercial exploitation rates and enhancement levels, and the participant who was uncomfortable with an exploitation rate greater than 25% noted that an exploitation rate of 30% might be tolerable if uncertainties could be accounted for more rigorously. In this regard, several participants also noted that catching more fish now, based on the assumption that benefits from enhancement could compensate in the future, would not be consistent with general understanding of a precautionary management approach.

[7] As part of subsequent discussions, however, the SDM framework was used to help reach an agreement on exploitation rates.

4. CONCLUSION: A MULTIOBJECTIVE PRECAUTIONARY APPROACH TO ENDANGERED SPECIES DECISIONS

The decision-focused SDM process helped implement a precautionary approach to Cultus Lake sockeye management in a number of ways. It is instructive to compare the process used at Cultus Lake to guidelines developed by the United Nations (see Reference 21, section 3.2) for implementing a precautionary approach in fisheries management planning processes. These guidelines can be summarized into five key points, which state that risk management and resource planning processes should:

1. Include all interested parties;
2. Consider a range of management alternatives in order to identify a plan acceptable to a broad range of interested parties;
3. Include long-term effects (a minimum of two to three decades);
4. Explicitly consider precautionary actions for avoiding undesirable outcomes;
5. Account for biological and outcome uncertainty in planning and decision-making processes.

The Cultus Lake SDM process began by identifying and inviting relevant stakeholders to participate actively (as per point 1, above). At the first meeting the participants considered a range of management alternatives and, by meeting 2, they were actively engaged in developing a variety of management alternatives to accomplish their objectives (thus addressing the second of the five points). The third point—long-term management goals—was not the focus of the Cultus Lake deliberations, which emphasized near-term objectives associated with the current year (2006) fisheries management decisions. The conservation objective, however, included three measures that explicitly considered the medium- and long-term effects of the management alternatives. As noted in Table I, these were the average number of returns over the years 2016 to 2019; the probability of extirpation by the year 2036; and the average percent of enhanced fish among the Cultus Lake population over the years 2016 to 2019.

The Cultus Lake example provides strong evidence that decision-aiding techniques can help to address the development of an explicitly precautionary management approach (the fourth point noted above) through setting objectives and designing effective performance measures.[8] So long as the objectives include avoiding specific undesirable outcomes, and clear performance measures are designed to evaluate management alternatives on this basis, an SDM approach can help to expose and to express tradeoffs between alternatives in terms of their ability to avoid undesirable outcomes. Decisionmakers can then use this information to help select a preferred alternative. For example, one specific undesirable outcome identified for Cultus sockeye was extirpation by the year 2036. This was one of the conservation objectives, and minimizing the probability of extirpation in the year 2036 was one of the metrics that the participants used to compare the alternatives. In this case, recommended precautionary actions to avoid extirpation include both salmon enhancement and freshwater projects.

As in any assessment of ecological risks, effective evaluation criteria should also expose tradeoffs between degrees of uncertainty associated with the alternatives.(27) In the decision process used for Cultus sockeye populations, DFO technical staff used simulation modeling to estimate the impacts of each management alternative under three different assumptions for several key uncertain model parameters. Given more time, additional analyses could have been completed to further explore the implications of these sources of uncertainty for the final set of preferred alternatives (those under discussion as part of meeting 3). An obvious recommendation is that management agencies should encourage revisiting uncertainty analyses so that improvements can be made over time in information quality; for Cultus Lake, subsequent work has included Bayesian analyses using a stochastic population model that includes both structural and implementation uncertainty.(28)

Implementing a precautionary approach to resource management typically involves difficult tradeoffs between competing objectives, and often these will be focused on tradeoffs between conservation and exploitation. The difficulties faced by stakeholders in dealing with these tradeoffs are a primary reason for the failure of many endangered species deliberations, in addition to the frustration and anger that often are experienced by participants (on all sides of the question). In this context, we found that the SDM approach was helpful in aiding the implementation of key elements of a precautionary approach: (1) identifying a range of conservation, economic, and social objectives and linking these to management alternatives; (2) making key tradeoffs explicit; and (3) highlighting which considerations were, and which were not, important in the specific context of actions that are possible for managers to undertake. It also was effective in allowing a consistent framework for consideration of a range of management alternatives and for considering both the short- and long-term effects of the management alternatives. The primary drawback of the Cultus Lake process with respect to precautionary management was the existence of severe time constraints, which limited the capacity for understanding key sources of uncertainty and for fully addressing uncertainty as part of fisheries management plans.[9]

Although the committee's discussions would have benefited from additional time (beyond their one-month duration) and a more complete representation of stakeholders' interests, the SDM approach was useful for including and actively engaging stakeholders in the process of developing management recommendations for Cultus Lake sockeye. In previous years, participants had often taken positional approaches, focusing only on the objective(s) that mattered most to them; this is not uncommon in debates about conservation of endangered species.(1) We found that using a decision-focused approach highlighted the importance of fundamental management objectives and helped to focus participants on key tradeoffs among these objectives. Using ViSTA added value by enabling the participants to compare management alternatives visually, using a readily accessible presentation format. Although this did not lead to a consensus, the committee gained valuable insights into what issues mattered most to each participant as well as key areas of agreement and disagreement.

The approach also helped to shift the focus of precautionary management efforts, as part of deliberations among consultative committee members, from debates about competing biological studies to shared decision making and recognition of the

[8] There is increasing interest in using SDM for fisheries management processes where endangered species are involved. Additional research in this topic area has included recovery planning for endangered Atlantic salmon in the State of Maine and for White Sturgeon in the Upper Columbia river.

[9] Experience gained during planning for the 2007 fishing season (based in part on the decision-aiding methods described in this article) has helped to ease some of these time pressures, as has the use of SDM methods by DFO to help develop a broader, regional fisheries management plan for the Fraser River.

need to address tough management choices. When available scientific information is considered to be insufficient—a fundamental reason why precautionary strategies might be considered—conservation efforts often lurch from one ill-informed management attempt to another.[10] The use of consequence matrices and strategy tables to create, test, and refine precautionary management alternatives for Cultus Lake sockeye both encouraged a systematic approach to generating options and facilitated learning over time. So long as the management structure remains sufficiently flexible, this learning can continue to be translated into improved management strategies as new information becomes available.

Finally, in the context of endangered species protection and habitat restoration, it is well known that stakeholders often become polarized. A decision-aiding approach can help to break through such adversarial situations by encouraging a focus on fundamental values and providing tools that facilitate informed and interactive deliberations. It thus can help implement a precautionary approach to resource management by focusing participants on the performance measures and tough choices that underlie the decision at hand, as opposed to the production of information. The use of a decision-focused approach helps to clarify what specific information is needed for decision making and what is available or missing, as well as—just as importantly—what information is not necessary. Decisionmakers are provided with a defensible trail describing what management actions were considered, which were accepted or rejected, and why. From the perspective of both process and substance, this has important advantages over more conventional, and less transparent, approaches.

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[10] In his characterization of the unsuccessful conservation efforts intended to save the Hawaiian crow, M. Walters refers to conservation efforts as "little more than impromptu experiments."(29) Long-term participants in many deliberations to address management of endangered populations would find this same characterization depressingly accurate.

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