GREAT LAKES FISHERY COMMISSION

Project Completion Report[1]

Application of Decision Analysis to Sea Lamprey Management: Preliminary Analysis

by:

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Application of decision analysis to sea lamprey management: preliminary analysis

Completion Report

August 31, 1998

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The Great Lakes Fishery Commission and its agents routinely face decisions regarding the allocation of resources for the management of sea lamprey in the Great Lakes. These decisions span a wide range of issues, from scheduling TFM treatments on individual streams to determining the most appropriate allocation of control resources among lake basins or of funds between control and assessment. While these decisions are made at many different levels, both tactical and strategic, they have one thing in common: *all are made in the face of uncertainty*. It can easily be shown that failure to explicitly consider this uncertainty can lead to inappropriate decision choices, principally because the consequences of perhaps unlikely, but plausible, outcomes of these decisions are not given appropriate weight in the comparison of choices. The purpose of this project was to initiate an exploration of the methods of formal decision analysis as a tool to explicitly consider uncertainty in the decision-making process.

As the study title indicates, the tasks completed so far should be considered preliminary. This project was designed as an initial step towards a more comprehensive study of decision analysis and its application to sea lamprey management. Several objectives have been met in the process of completing this phase of the larger study. First, we selected the St. Marys River control problem as an appropriate case study for the initial application of decision analysis. Second, we developed a simple and preliminary decision analytical framework for ranking alternative decision options for St. Marys River lamprey control. Part of this framework is illustrated in Figure 1, in which we consider the effect on three decision alternatives of uncertainty in the lamprey stock-recruitment relationship. We used this and a related example to demonstrate how decision analysis might work, both at a St. Marys River Control Task Force meeting and a Sea Lamprey Integration Committee meeting during spring 1998. We will also be presenting this preliminary analysis at a professional meeting (Michigan Chapter, AFS) in September. Third, we have acquired the computer hardware and software necessary to support the numerically intensive operations required to complete a decision analysis for all but the most simple of problems. Finally, we have prepared formal proposals for further funding which have been submitted to both the Great Lakes Fishery Commission (attached) and Michigan Sea Grant for their consideration.

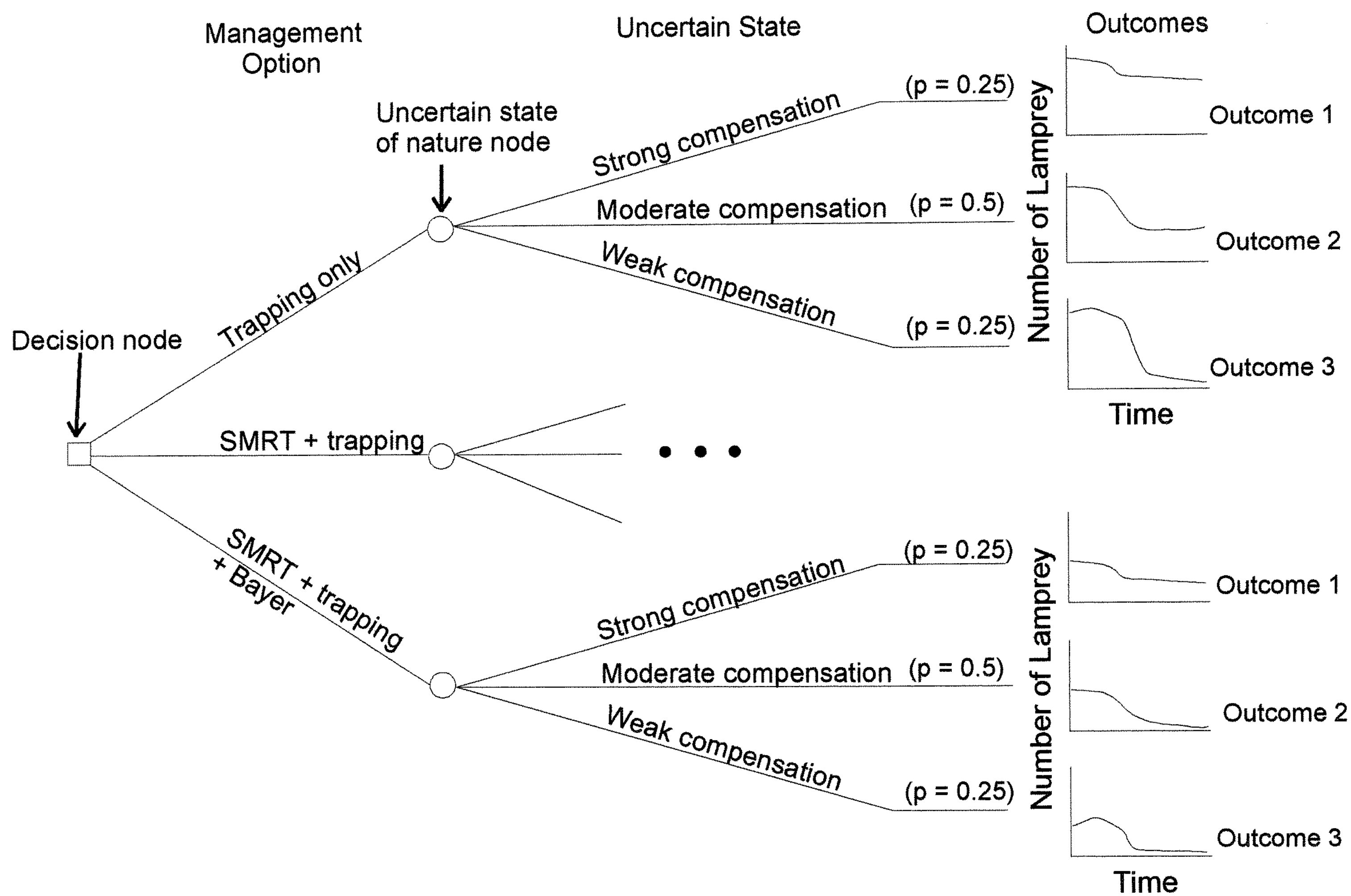

Figure 1. Example of a decision tree. The uncertainty shown in this tree reflects alternative stock-recruitment models (degrees of compensation). Strong compensation rates will reduce the effectiveness of trapping and sterile male release (SMRT), but will have less influence on chemical (Bayer) control. This is reflected in the differing trajectories for lamprey numbers, listed as outcomes. The options are compared by quantifying these outcomes and taking the weighted (by the probability of each state of nature being true) sum of all possible outcomes.

Application of Decision Analysis to Great Lakes Sea Lamprey Management

A proposal for funding to the Great Lakes Fishery Commission

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Introduction

The Great Lakes Fishery Commission and its agents routinely face decisions regarding the allocation of resources for the management of sea lamprey in the Great Lakes. These decisions span a wide range of issues, from scheduling TFM treatments on individual streams to determining the most appropriate allocation of control resources among lake basins or of funds between control and assessment. While these decisions are made at many different levels, both tactical and strategic, they have one thing in common: *all are made in the face of uncertainty*. The purpose of the work described in this proposal is to investigate the development of a procedure for explicitly considering uncertainty in the decision-making process, using methods of formal decision analysis (Clemen 1996).

By applying decision analysis to Great Lakes sea lamprey management issues, we propose to follow a growing trend in marine fisheries management. Throughout the world, fisheries management decision making has had a largely deterministic tradition. By this we mean that decisions have traditionally been made based on the best (point) estimates of the component processes (e.g., mortality, growth rates) and measures of the state (e.g., stock biomass) of the system being managed. In recent years, researchers have made substantial progress in the development of sophisticated statistical tools for stock assessment and fish population forecasting that help us to better characterize and take into account uncertainty about these processes and states (Hilborn and Walters 1992). More importantly, in marine fisheries, management agencies and international commissions have begun to institutionalize the requirement for assessments of uncertainty to be an integral part of stock assessments and the resulting management decisions (Kruse et al. 1993; Smith et al. 1993; Rosenberg and Restrepo 1994; National Academy of Sciences Committee on Fish Stock Assessment Methods 1998).

In our view, fishery management in the Great Lakes has fallen behind this growing trend. While models have been developed that highlight uncertainties (e.g., Jones et al. 1993; Koonce et al. 1993), these descriptions of biological uncertainty have not been carried through to showing their implications for the evaluation of management options, for example, by using models to forecast a distribution of possible consequences of each alternative management action. For example the model that is currently being used to forecast the consequences of alternative stream treatment schedules for control of sea lamprey in the Great Lakes and to determine the optimal ranking of streams for treatment (IMSL – Integrated Management of Sea Lamprey: Greig et al. 1992) does not fully consider uncertainties. Many of the assumptions required by this model are widely recognized as highly uncertain, yet the optimization presently ignores these uncertainties and identifies the optimal actions from the best point estimates of all parameters and variables. Where uncertainty has been considered, it has typically been included in an ad-hoc, subjective fashion. For instance, sea lamprey control options in the St. Marys River were evaluated using a model similar to the IMSL model with uncertainty included only through a subjective judgment of the relative uncertainty that each option would produce the expected results. (St. Marys River Control Task Force 1997). These examples are typical of the manner in which fishery management options have been evaluated in the Great Lakes, and until recently, elsewhere.

In contrast to that deterministic approach, decision analysis provides a way for decision makers in the Great Lakes region to explicitly take into account various types and magnitudes of uncertainties. As a result, they can make more informed choices. The method of decision analysis is well advanced, having been developed over 30 years ago in business to help make decisions in the presence of economic uncertainties, a situation directly analogous to making decisions in the presence of ecological uncertainties. An important feature of decision analysis is that, rather than using only point estimates of parameter values or state variables to simulate outcomes of alternative management options, several hypothesized values of the parameters or "states of nature" are used and, as a result, several possible outcomes for each management option are generated (Von Winterfeldt and Edwards 1986). Management options can then be compared in terms of their expected results or the risks associated with various uncertain events. In this way, decision analysis provides additional insight into complex decision problems. It has been shown that by taking uncertainties into account in this way decision makers will be more likely to identify the optimal action (Von Winterfeldt and Edwards 1986).

Past decision analyses of fisheries problems have produced two main qualitative results that are directly relevant to Great Lakes sea lamprey management. First, in most cases, explicit consideration of uncertainties leads to a different management option being recommended than if the uncertainties were ignored (Walters 1986; McAllister and Pikitch 1997; Sainsbury et al. 1997; Robb and Peterman 1998). For instance, when uncertainties in density-dependent growth and in size-dependent vulnerability to fishing gear were accounted for, the optimal stocking density for juvenile rainbow trout in British Columbia lakes increased considerably compared to the case where those uncertainties were ignored (Peterman et al. 1998). The second main result from past decision analyses is that commonly used arbitrary adjustments for uncertainty (e.g. reductions in harvest rate such as a 20% "safety margin") that qualitatively try to allow for uncertainties are not necessarily optimal, and can often lead to significant reduction in future benefits either because the adjustment was too large or too small (Frederick and Peterman 1995).

The sea lamprey control program managed by the Great Lakes Fishery Commission involves decisions at many levels, and all of these decisions must be made in the face of uncertainty. Two important examples, one specific and one more general, are (1) the 1997 decision to carry out an expensive treatment of the St. Marys River, and (2) the full implementation of an integrated pest management approach (Sawyer 1980) throughout the Great Lakes basin. The St. Marys River control strategy has been initiated this year, and involves a costly program of chemical and alternative control techniques, for which uncertainty is recognized as considerable about the effectiveness of the control tactics being used. Since the Commission agreed to adopt the integrated pest management (IMSL) approach, considerable effort has been directed at development decision support tools (Greig et al. 1992). These tools have not yet been applied to the goal of setting economically and ecology defensible target levels of sea lamprey control for each of the Great Lakes, although this is currently viewed as a priority. Because these targets will depend on uncertain quantities or processes that affect the costs and effectiveness of alternative control techniques and the benefits derived from a given expenditure on control, it is clear that this broader management issue would also benefit from a formal consideration of uncertainties.

We propose a two-year study with the following broad objectives:

- develop a full decision analysis of the St. Marys River, as a case study of merit in its own right, and to demonstrate the application of the methodology to a specific, relevant case; and
- examine the overall IMSL decision-making process at a strategic level, and particularly the target setting process, with a view towards designing a decision analytical framework for determining control targets at the "whole-basin" level;

By achieving the first objective we expect to (1) clearly demonstrate how decision options faced by managers are affected by uncertainty, and (2) develop and rank ideas for future research and adaptive management aimed at reducing critical uncertainties. We expect our findings will have important and immediate implications for the management of the St. Marys River. At a more general level, however, the case study should provide the Commission and its agents with a clearer idea of the benefits of more systematically considering uncertainty in general and of decision analysis in particular. Achievement of the second objective will provide the Commission with a full scoping of the steps involved and the level of effort required for the development and application of a decision analytical framework for the target setting process. Together these two steps should provide the Commission with a well-informed basis for considering the future use of decision analysis as a management tool.

We are seeking funding for two years for this project. We have also submitted a proposal to Michigan Sea Grant which has as a component a decision analysis for the St. Marys River case study. We have budgeted the current proposal using the assumption that the Sea Grant proposal will not be funded. If the latter proposal is funded, the budget for this work can be revised appropriately.

Approach

Objective 1. St. Marys River Case Study

Lake trout wounding rates in northern Lake Huron significantly exceed those in any other region of the Great Lakes (Ebener 1995). It is widely believed that this is due to the presence of a hitherto uncontrolled population of lampreys in the St. Marys River, the connecting channel between Lake Superior and Lake Huron. In 1997, the Great Lakes Fishery Commission decided to implement a costly control program in the St. Marys River during 1998-99, whose forecasted effect will be to immediately reduce the number of parasitic lamprey entering Lake Huron from the St. Marys River by more than 50%. The program includes an extensive chemical treatment of the infested areas of the river and an aggressive trapping and sterile male release program. In four years the Commission will be faced with a further, equally important decision: whether to re-treat the river with costly chemicals, to rely on the less expensive trapping and sterile male release program to maintain lamprey abundance at acceptably low levels, or a combination of the two. We will direct our analysis towards this decision issue. By utilizing information that currently exists (e.g., knowledge of population biology of lamprey, historical estimates of lamprey abundances) and new information gathered during the first round of controls (1998-2002), we expect to be able to derive quantitative estimates of critical uncertainties (e.g. parameters of the stock-recruitment relationship for sea lamprey in the St. Marys River, variability in the spatial distribution of larval lamprey and its effect on the proportion of larvae killed by a chemical control action) and use these estimates in our decision analysis.

To complete the St. Marys River case study we will need to address the following sub-objectives, which comprise the main elements of a formal decision analysis:

1. define an appropriate set of management objectives and decision options for each case study, in consultation with agency management personnel and other stakeholders;
2. determine the critical uncertainties ("uncertain states of nature") that limit our ability to confidently forecast the consequences of decision options;
3. assign probabilities to alternative (and uncertain) states of nature;
4. modify existing models of sea lamprey dynamics to forecast the outcomes of the decision options of interest, given alternative states of nature;
5. incorporate the components described above into a decision tree;
6. use the decision tree to organize the analysis to rank management options, using the management objectives developed through sub-objective 1 as the criteria for ranking; and
7. evaluate the sensitivity of the rank order of management options to alternative management objectives or model parameter assumptions.

Step 1. Management objectives and decision options

Clearly defined management objectives are critical to decision analysis. To choose among a set of possible alternative actions, it is necessary to have some standard against which the performance of the actions can be measured. This standard is determined by the management objective. For the St. Marys River, the management objective might be to maximize the abundance of mature lake trout in northern Lake Huron, averaged over some future time period. Or it could be to minimize the time to achievement of some target level of lake trout adult abundance. A given set of alternative actions can have very different relative ranks depending on the management objective they are seeking to achieve (e.g., Robb and Peterman 1998). An appropriate set of management objectives thus needs to be determined at the outset, so that the models used to forecast outcomes of alternative actions generate quantities that are appropriate for the chosen objectives.

An equally important initial step is to define a list of alternative management actions to be considered in the analysis. These actions, either singly or in some combination, constitute the decision options that the analysis is designed to compare. For example, two decision options that we are likely to compare would be (1) trapping adults only and (2) trapping adults as well as releasing sterile males. As was true for the management objectives, it is essential that a complete set of decision options be determined at the outset, so that models are developed that can forecast the consequences of options that are deemed feasible and appropriate.

We will consult with the St. Marys River Control Task Force, and other stakeholders and experts, to develop this set of objectives and options. The objectives are likely to be related to reductions in the production of parasitic lamprey from the St. Marys River and increases in the abundance of large, mature lake trout in northern Lake

Huron. We are also likely to consider objectives that trade off increasing benefits (more lake trout) against the costs of the control options, perhaps using the economic injury level approach described by Koonce et al. (1993). We are likely to consider a range of options that comprise various combinations of adult trapping, sterile male release, and chemical treatment of the river itself, similar to those considered by the St. Marys River Control Task Force (1997).

Step 2. Critical uncertainties

The next step in the decision analysis process is to identify the critical uncertainties that prevent us from forecasting, with certainty, the outcome of a decision. Decision analysts refer to these uncertainties as "uncertain states of nature," whereas other scientists might refer to them as "alternative hypotheses" about how the ecosystem operates. Typically in decision analysis, uncertain states of nature are described in terms of alternative parameter values for a single model or sets of alternative models to describe the same process.

Many uncertainties surround the St. Marys River case study. The effectiveness of a sea lamprey control action can depend on lamprey reproductive success, larval population dynamics, larval spatial distribution patterns, transformation rates, parasitic phase survival, the magnitude of other sources of parasitic lamprey, and the abundance and distribution of host populations. This list is not complete, but it illustrates the variety of possible sources of uncertainty.

It will not be practical for us to explicitly consider all possible sources of uncertainty in our decision analyses. We propose to use two approaches to reducing the list to a manageable set of "critical uncertainties". First, we will modify existing models to explore the relative sensitivity of these models to uncertainty in the various parameters they include. Second, we will solicit the views of the experts on the St. Marys River Control Task Force as to which uncertainties they consider to be of greatest importance. Many of the task force members are research biologists who have considerable technical knowledge and experience with this system.

We will examine the model used by the St. Marys River Task Force (1997) to forecast the consequences of the control actions to be implemented in 1998/99. This model uses an empirical stock-recruitment relationship to forecast future recruitment of sea lamprey, a description of the spatial distribution of larvae in the river to determine the effect of lampricide treatment, simple assumptions about transformation rates and parasitic phase survival, and a statistical lake trout catch-at-age model (Sitar 1996) to forecast the future patterns of lake trout abundance in northern Lake Huron resulting from a control option (G.L. Christie, Great Lakes Fishery Commission, personal communication). We will use this model in a sensitivity analysis (Vose 1996) to compare the sensitivity of the model's performance measures (which will be directly relevant to the management objectives) to small perturbations in individual parameters. We recognize two important shortcomings of sensitivity analysis: (1) it ignores uncertainty in model structure and (2) it ignores the fact that some parameters are likely to be far more uncertain than others. Despite these shortcomings, we feel a preliminary sensitivity analysis will provide us with some guidance towards choosing critical uncertainties.

Step 3. Probabilities of alternative states of nature

Decision analysis works by casting the critical uncertainties into a set of alternative hypotheses about the state of nature, and assigning a probability of occurrence to each alternative. These probabilities should reflect both existing data and the "degree of belief" of scientists and decision makers that each alternative is the true state of nature. Unlike classical statistical hypothesis testing, where we estimate the probability of a single (null) hypothesis being true, given a set of data, here we seek to describe the probability placed on a range of alternative hypotheses being true, again given the available data. Decision analysis therefore calls for a Bayesian approach (Ellison 1996) to determining the degree of belief in alternative hypotheses about the critical uncertainties we have identified.

Wherever possible we will use directly relevant data sets to determine the probabilities of alternative states of nature. For example, it is likely that the stock-recruitment relationship for St. Marys River sea lamprey will emerge as a critical uncertainty for the sea lamprey case study. The sea lamprey control agencies have been monitoring adult returns of sea lamprey to the St. Marys River since 1970. These data have been analyzed for their fit to a Ricker stock-recruitment function (R. Young, Department of Fisheries and Oceans Canada, personal communication). We propose to re-analyze these data using Bayesian methods to estimate the joint posterior probability density function (pdf) of the Ricker model parameters and use this pdf to define alternative states of nature with regard to this uncertainty (for an example of a similar approach see Robb and Peterman 1998). Following conventional practice, we would assume a log-normally distributed error term and therefore use an appropriate likelihood function (Hilborn and Walters 1992). We would probably use an "uninformative prior" for this analysis, but would discuss alternative choices of priors with sea lamprey experts.

Assigning probabilities to some of the critical uncertainties using a Bayesian analysis of directly relevant data may prove difficult or impossible, simply because of a lack of such data. In these cases there are two alternatives. First, we may be able to use a meta-analysis of other data sets to infer something about uncertain parameters for our case studies. For example, while there may be little data on length or age at transformation for St. Marys River lamprey larvae, such data do exist for other Great Lakes streams. We could use a comparative analysis of other streams to determine a range of probable transformation rates. Second, decision analysts often rely upon expert judgement to derive plausible estimates of probabilities of uncertain states of nature. We will use expert elicitation techniques if necessary, but we recognize that these methods must be used extremely carefully to avoid biases (Morgan and Henrion 1990; Anderson 1998).

Step 4. Model development

The uncertain states of nature in a decision analysis are normally represented by a set of alternative models, or a range of parameterizations of a single model. The model(s) are used to forecast the outcomes of each of the decision options under consideration. The model's outputs must include quantities that can be used to rank these outcomes with respect to the stated management objectives of interest. For example, if an objective is to maximize the benefit-cost ratio for sea lamprey control actions, the model must forecast both the costs of each control option and the benefits due to reduced lamprey abundance.

We expect to adapt the model developed by the St. Marys River Control Task Force for our case study. The existing model is essentially a modified stock-recruitment model that does not explicitly represent several processes and life stages that we will be interested in considering. We expect that the adapted model will include the following elements:

- a stock-recruitment relationship to describe the reproductive success of lamprey at differing spawning stock sizes (including a rule to account for the effect of sterile male releases);
- a larval growth and survival component that forecasts the supply of parasitic lamprey to northern Lake Huron and represents (implicitly) the spatial distribution of larvae relative to chemical control;
- a damage component that forecasts the effects of changes in parasitic lamprey abundance on lake trout survival rates; and
- a lake trout population model that forecasts changes in lake trout abundance ultimately resulting from the control actions.

Previous and ongoing work by the St. Marys River Control Task Force (stock-recruitment, larval distribution), a graduate research project at Michigan State University on a sea lamprey predation model for northern Lake Huron (M. Rutter, MSU, personal communication), and a lake trout demographic model (Sitar 1996) will all provide valuable inputs to our modeling.

Step 5. Decision tree

To complete the decision analysis, the various elements described earlier are combined into a decision tree. A decision tree provides a helpful visual illustration of the way in which the analysis works. We present a simple example for the sea lamprey case study in Figure 1.

The decision options are listed on the left side of the tree and the outcomes on the right. They are connected by a series of uncertainty nodes, representing the uncertain states of nature. Each management option can result in a variety of possible outcomes, depending on the true state of nature. Because we are uncertain of the true state of nature, the statistical expectation for the outcome of a particular action is the weighted sum of all possible outcomes (weighted by the probability of each state of nature being true). The reason that considering uncertainty (and thus a decision analysis) is so important, is that this probability-weighted expected outcome is often quite different from the outcome that would be predicted by the same model using simply the best point-estimates for each parameter. This is because in many cases, relatively unlikely biological states of nature may lead to such large consequences that they will skew the weighted average outcome away from the deterministic mean outcome, which would lead to a different management action being optimal than in the deterministic case. For example, a particularly strong compensatory response by larval lamprey populations, while relatively unlikely, may have such a strong negative effect on the success of trapping and SMRT options that

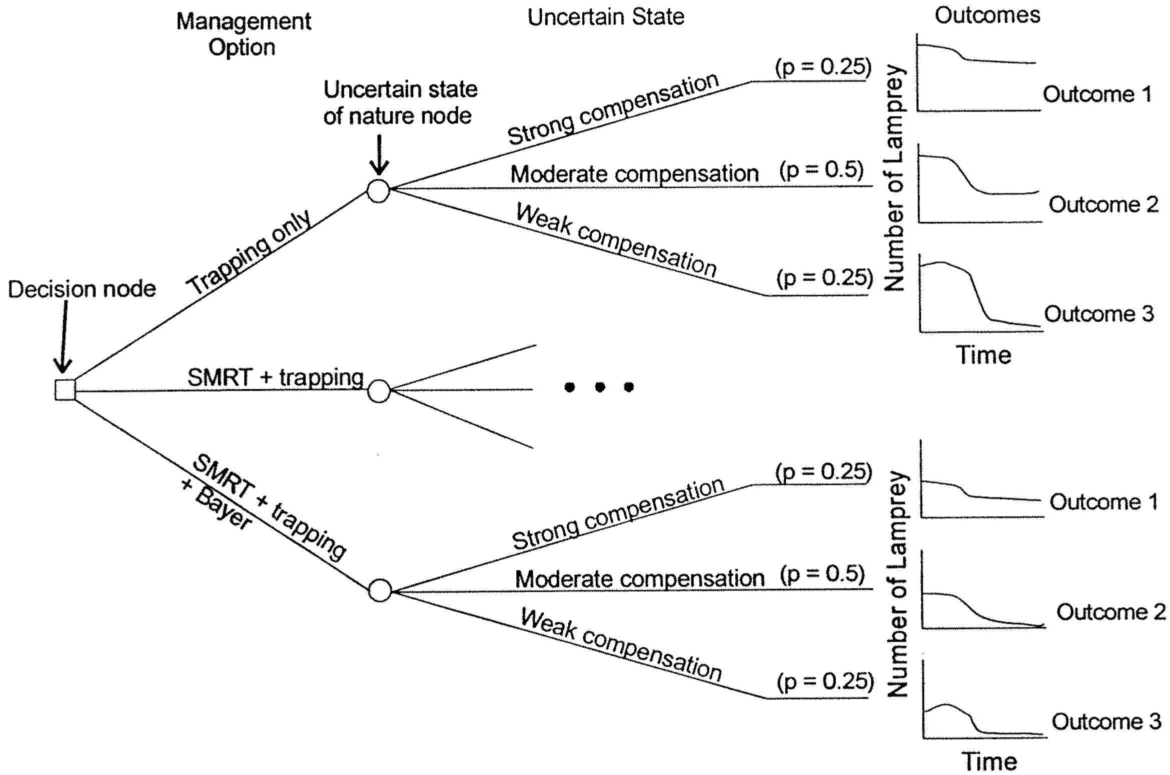

Figure 1. Example of a decision tree. The uncertainty shown in this tree reflects alternative stock-recruitment models (degrees of compensation). Strong compensation rates will reduce the effectiveness of trapping and sterile male release (SMRT), but will have less influence on chemical (Bayer) control. This is reflected in the differing trajectories for lamprey numbers, listed as outcomes. The options are compared by quantifying these outcomes and taking the weighted (by the probability of each state of nature being true) sum of all possible outcomes.

these options tend to be favored much less than might be the case for an analysis simply based on our "best-guesses" of compensation levels.

Step 6. Ranking outcomes

To determine the preferred option among the set of decision options being considered, the final step is to rank the probability-weighted outcomes. The ranking is done by quantifying the outcomes in units that are relevant to the management objectives. It is unlikely that the same option will rank highest regardless of which objective is used as the criterion for ranking. For example, an objective that puts a high value on a *rapid* recovery of mature lake trout populations in northern Lake Huron (i.e., due to a high discount rate), may favor more costly control options relative to other objectives that compute benefits from longer-term, average responses. Of course the ranking of some options will be more robust to alternative objectives than others. In addition to summarizing the option that ranks highest for each objective, we will seek options that appear to rank relatively high across all or a large number of objectives.

Step 7. Sensitivity analyses

Although decision analysis attempts to explicitly consider the major uncertainties that affect a decision, it is also appropriate to evaluate the effect on a decision of other sources of uncertainty. Fortunately, it is relatively straightforward to do this. The decision analysis is simply redone using alternative assumptions about other uncertain parameters. If the rank order of decision options is unaffected by alternative assumptions about a particular uncertainty, then we can conclude that the characterization of that uncertainty is relatively unimportant. Such sensitivity analyses will also identify for decision makers how robust the recommended management action is to various uncertainties.

Sensitivity analysis is a critical component of any decision analysis. We propose to make a sensitivity analysis the focus of a workshop involving the St. Marys River Control Task Force and other Commission and control agent personnel. We will conduct preliminary sensitivity analyses in advance of the workshop and then will invite participants to identify those areas of uncertainty which they feel need further exploration. We will bring to the workshop computer versions of the decision models that will allow us to conduct interactive sensitivity analysis while the participants are present. Based on past experience using interactive models in a workshop setting (e.g., Koonce and Jones 1994) we expect this interaction to be a powerful means of informing participants and fostering an appropriate balance of belief and skepticism in our analysis.

We also propose to use sensitivity analysis to rank future research, monitoring, and adaptive management activities. Once the decision tree is constructed, it is possible to investigate (simulate) how reducing uncertainty about a particular component or process (e.g., the stock-recruitment relationship for sea lamprey) affects the ranking of decision options. If the rankings do not change much, the value of investing in future research programs to reduce that uncertainty is clearly less than if the rankings are highly sensitive. If the outcomes are quantified in economic terms, the actual value of reducing uncertainty can be computed by comparing the expected value of the highest ranking decision choice with current uncertainty to the same expected value if uncertainty is reduced. In this way one can obtain an economic rationale for investing in research and experimental, adaptive management programs (Holling 1978, Walters 1986) that are designed to reduce uncertainty (Morgan and Henrion 1990). This type of result can be especially useful for placing a value on adaptive management experiments, where resistance is often encountered because of perceived economic risks of the experiment.

Objective 2. IMSL Target setting analysis

In the early 1990s the Great Lakes Fishery Commission sponsored the development of a protocol to facilitate the achievement of its Strategic Vision (Great Lakes Fishery Commission 1992) in the area of sea lamprey control. This protocol, known as the IMSL Management Protocol, provides the conceptual foundation for an integrated process for specification of "sea lamprey control programs for the Great Lakes that are economically, environmentally, and socially acceptable." (Greig et al. 1992, p. 2.1). At the heart of the protocol is the determination of target levels of sea lamprey abundance for each lake. The protocol proposes that these target levels should reflect a balance between the costs of reducing lamprey abundance and the benefits to be derived from this lowered abundance. It refers to defining an economic injury level (EIL) for

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