ASSESSING STOCKING POLICIES FOR LAKE MICHIGAN SALMONINE FISHERIES USING DECISION ANALYSIS

Michael L. Jones[11], James R. Bence, Emily B. Szalai, and Wenjing Dai

Stocking of hatchery-reared fish is one of the primary management tools available to fishery managers working on Lake Michigan. Since the advent of major salmonine stocking programs in the mid-1960s, hundreds of millions of Chinook salmon, lake trout, rainbow trout, brown trout, and coho salmon have been stocked (Kocik and Jones 1999; Hansen and Holey 2002) to provide recreational fishing opportunities, restore native lake trout populations, and reduce the abundance of alewife. Since the early 1980s, experts recognized (Stewart et al. 1981) that a tradeoff existed between stocking too few predatory fish, thereby allowing alewife abundance to rise to undesirable levels and foregoing potential harvest of predators, and stocking too many predators, thereby exceeding the productivity of the alewife population. The dramatic rise in Chinook salmon mortality rates and the subsequent decline in recreational harvest of this species that occurred during the late 1980s in Lake Michigan are widely viewed as having resulted from excessive abundance of stocked predators during this period (Holey et al. 1998; Hansen and Holey 2002). Therefore, a critical question faced by Lake Michigan fishery managers is "how many salmon and trout should be stocked each year?" Here we describe a decision analysis (DA), the goal of which was to assist fishery managers by assessing the performance of alternative stocking strategies in light of the critical uncertainties that make selecting the best strategy difficult.

M.L. Jones. Michigan State University, Department of Fisheries and Wildlife, East Lansing, MI, 48824-1222, U.S.A.

J.R. Bence. Michigan State University, Department of Fisheries and Wildlife, East Lansing, MI, 48824-1222, U.S.A.

E.B. Szalai. Michigan State University, Department of Fisheries and Wildlife, East Lansing, MI, 48824-1222, U.S.A.

W. Dai. Michigan State University, Department of Fisheries and Wildlife, East Lansing, MI, 48824-1222, U.S.A.

[11] Corresponding author (e-mail: jonesm30@msu.edu).

DA is a methodology, developed in the field of operations research (Raiffa 1968), that is used to rank the performance of alternative choices in terms of their ability to successfully meet one objective or a set of objectives. DA is enjoying increasing application to fisheries management (Peterman and Anderson 1999), primarily because it offers an approach to systematically account for the effect of uncertainty on the performance of alternative decisions. Both fishery scientists and managers have begun to recognize the critical importance of considering uncertainty and risk when evaluating management options (e.g., Rosenburg and Restrepo 1994). Applications of DA involve several steps: (1) identifying management objectives and options, (2) identifying and quantifying critical uncertainties, (3) developing and applying a model to forecast the outcome of management options, (4) ranking options in terms of their performance at meeting objectives, and (5) evaluating the sensitivity of the conclusions of the analysis to various assumptions.

We conducted a DA for Lake Michigan salmonine stocking in four stages:

1. We met with experts, fishery managers, and stakeholders in March 2000 to discuss and agree upon management objectives, options, and critical uncertainties (Table 5).

2. We used historical data on salmonine harvests, diet, growth rates, and prey-fish abundance to estimate parameters of a salmonine prey-fish population model and the uncertainty associated with the parameter estimates (Szalai 2003).

3. We developed a decision model to forecast the consequences—for alewife abundance, Chinook salmon growth, and Chinook salmon harvests—of alternative stocking strategies.

4. We met again with experts, managers, and stakeholders to demonstrate and discuss the model.

Table 5. The management objectives, management options, and critical uncertainties that were identified at the start of a decision analysis of predator stocking in Lake Michigan that were used to guide the development of a forecasting model.

Management objectives	Management options	Critical uncertainties
• Maintain acceptable catch rates for salmonines in the recreational fishery	• Adjustments to annual stocking rates of salmonines	• Alewife recruitment dynamics (how much predation pressure can the alewife population support?)
• Minimize the risks of elevated Chinook salmon mortality caused by poor growth conditions		• Chinook salmon feeding effectiveness (how successful are Chinook salmon at finding prey when the prey become relatively scarce?)
• Maintain a predator-prey balance that minimizes negative effects of alewife predation on native species		• Chinook salmon growth-survival linkages (how strongly coupled is Chinook salmon growth to natural mortality rates?)

The methods for quantifying uncertainties in the parameters of the forecasting model are described in detail in Szalai (2003). Briefly, we developed an estimation model similar to statistical catch-at-age models to reconstruct the historical dynamics of Lake Michigan prey-fish (alewife, bloater, and smelt) populations, but including salmonine predators rather than fishing as an additional source of mortality. The model estimated prey-fish abundance and recruitment from 1962-1999 and the effective search rate of Chinook salmon (i.e., how successfully Chinook salmon can feed when prey fish become relatively scarce). Data sources for model estimation included the U.S. Geological Survey bottom-trawl time series of alewife and bloater catches, recent hydroacoustic survey data on prey fish, and various agency data sets on salmonine catches, sizes-at-age, and diets. Estimated alewife abundance and recruitment were used in a subsequent step to estimate the parameters of a Ricker-type stock-recruitment relationship for alewife. Finally, we used estimates of Chinook salmon mortality rates and size-at-age from the late 1980s and early 1990s (during the period of Chinook salmon collapse and recovery) to model the dependence of mortality on growth. We hypothesized that reduced growth results in an increased probability of elevated mortality, potentially due to disease. We hypothesized further that, when elevated mortality occurs, there is a delay after growth rates recover before mortality rates decline again. This model is consistent with observations during the period of elevated Chinook salmon mortality, but there is great uncertainty because evidence supporting this relationship comes from a single event. For each of the estimation models, we used Monte Carlo-Markov Chain methods to describe the uncertainty associated with all model parameters.

To evaluate stocking policy alternatives, we developed a model that forecasts the future abundances of alewife and both abundances and sizes of Chinook salmon that result from a specific policy. The model includes all major stocked salmonine species as predators, but the abundances and sizes of species other than Chinook remain fixed over time (unless they are altered by a policy action). The model also includes alewife, bloater, and rainbow smelt, but only alewife abundance varies over time. The other predators and prey are included in the model to reasonably represent alternative sources of predation mortality on alewife and alternative prey for salmonines when alewife become scarce.

Because the parameters of the model are uncertain, we repeated each simulation multiple (1,000) times, each time selecting a different set of parameters from the probability distribution of plausible parameter values. Therefore, each stocking policy can have a variety of possible outcomes. We compared the performance of different policies by looking at the distribution of outcomes, the median outcome, and the proportion of outcomes that exceeded or fell below a threshold value deemed to be undesirable. For this report, we consider five alternative stocking policies and six performance indicators (Table 6).

Table 6. Alternative stocking policies and performance measures used to evaluate achievement of objectives in a decision analysis of predator stocking in Lake Michigan.

Stocking policies	Performance measures
• Status quo–continue stocking at current levels • Reduce only Chinook salmon stocking by 50% • Feedback policies—stocking is reduced 50% if fall weight of age-3 Chinook salmon falls below 7 kg and is restored to current levels if fall weight increases above 8 kg: – Option 1: reduce stocking of only Chinook salmon by 50% – Option 2: reduce stocking of all species by 50%, except lake trout – Option 3: reduce stocking of all species by 50%	• Median forecasted average annual Chinook salmon harvest (number harvested per year) • Proportion of outcomes with Chinook salmon harvest below 100,000 fish per year • Median forecasted Chinook salmon weight (kg) • Proportion of outcomes with Chinook salmon weight <6 kg • Median alewife biomass (kt) • Proportion of outcomes with alewife biomass >500 kt*

* The value of 500 kt is an arbitrary threshold that is indicative of a relatively large alewife biomass in the status quo simulations. It is not based on an independent assessment of alewife biomass levels that are considered detrimental to native fish species, but does represent a relatively large biomass compared to recent (1980-1999) levels in Lake Michigan. This value may seem high relative to estimates reported elsewhere; the difference derives from the fact that this value represents an estimate of biomass for the entire population (all age-classes), as opposed to swept-area estimates of those alewife vulnerable to bottom trawling.

A wide variety of outcomes are possible from a particular policy (Fig. 17). For continued stocking at current levels (status quo), we forecasted average annual Chinook salmon harvests ranging from 6,500 to 360,000 fish per year. For this policy, forecasted average harvests lower than 100,000 fish per year were relatively common (29.7% of the time) (Table 7), with the most-common result being between 50,000 and 75,000 fish harvested per year

(Fig. 17, solid bars). In contrast, a policy in which stocking of all salmonines is reduced by 50% when age-3 Chinook salmon weights measured in the fall decline below 7 kg (and restored to status quo levels when fall weight recovered to 8 kg) resulted in a substantially lower proportion of outcomes (15.7%) with harvests below 100,000 fish per year (Table 7), although the range of possible future harvests was only slightly narrower (18,000-315,000 fish per year).

Fig. 17. A comparison of the distribution of forecasted Chinook salmon harvests (numbers of fish) for two contrasting stocking policies. Shaded bars are for a policy representing continued stocking at current levels. Open bars represent a feedback policy with reductions in stocking of all species when forecasted Chinook salmon age-3 weight falls below 7 kg, and increases in stocking to current levels if age-3 weight subsequently rises above 8 kg.

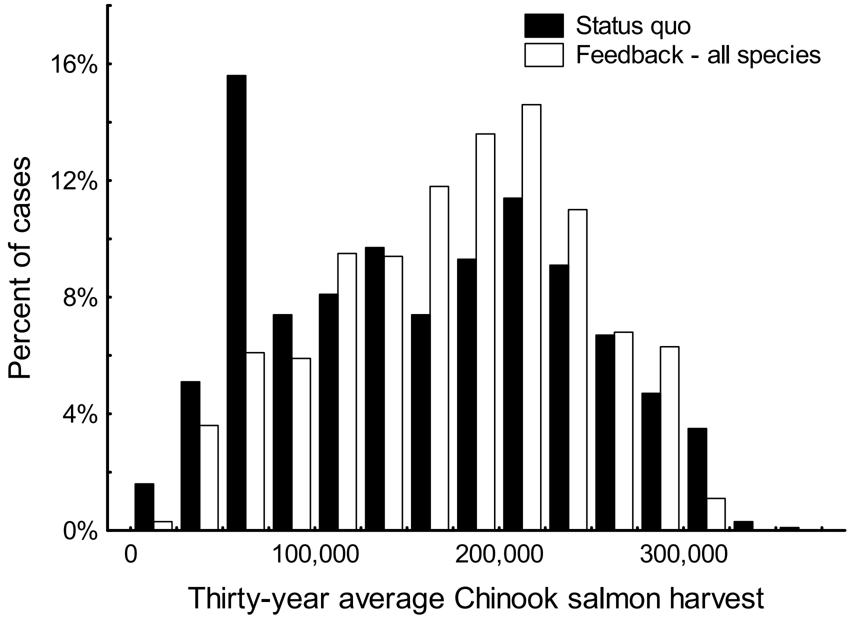

Table 7. Values of performance measures for five stocking policies (see Table 6) in a decision analysis of predator stocking in Lake Michigan.

	Harvest		**Weight**		**Alewife**	
Stocking policy	**Median Chinook harvest**	**Proportion of harvests <100,000**	**Median Chinook weight (kg)**	**Proportion of weights <6 kg**	**Median alewife biomass (mt)**	**Proportion of biomasses >500,000 mt**
Status quo (current level)	160,000	29.7	7.0	47.6	417,000	47.8
Reduce Chinook 50%	126,000	35.4	9.9	41.2	667,000	53.6
Feedback option 1: reduce Chinook only	156,000	28.1	8.4	44.6	510,000	50.2
Feedback option 2: reduce all but lake trout	176,000	19.6	10.7	37.3	766,000	56.7
Feedback option 3: reduce all species	182,000	15.7	11.6	33.9	870,000	59.5

The feedback policy in which stocking of all salmonines was reduced by 50% (option 3) resulted in the best outcome relative to two performance measures (Chinook harvests and Chinook weights, Table 7) but had the worst performance with respect to the third measure (alewife biomass). This was true for both the medians and the proportions of extreme cases (Table 7). The feedback policy that targeted only Chinook salmon (option 1) had performance characteristics similar to the status quo policy—lower harvests, lower Chinook salmon weights, and lower alewife biomass than feedback option 3. If all species other than lake trout were included in stocking cuts, performance with respect to Chinook salmon harvests and weights improved but at the expense of increased alewife biomass. This policy was not quite as effective as option 3 at meeting Chinook salmon harvest and weight objectives but resulted in lower median alewife biomass.

The policy analysis presented above suggests two important consequences for decision makers seeking an appropriate policy for salmonine stocking. First, feedback policies, where stocking levels are dynamically adjusted in response to evidence of a deteriorating situation, substantially reduce the risk of poor outcomes with respect to the Chinook salmon harvest and growth performance measures, particularly if the policy actions include all or the majority of predators in the lake. None of the policies considered here involved increasing stocking in the face of a growing alewife population, a strategy that could reduce the risk of high alewife biomass, which is an outcome of the policies analyzed here. Second, the uncertainties included in the forecasting model, particularly with respect to alewife recruitment, give rise to a very wide range of possible outcomes from a single policy. We expect that policies can be found that reduce the range of likely outcomes relative to the policies shown here. Nevertheless, we believe that any feasible strategy will still admit a substantial possibility of undesirable population trajectories for Chinook salmon and alewife. Flexibility and careful monitoring will be essential to good management of this fishery.

The results of this DA provide important insights for Lake Michigan fishery managers and stakeholders, but there are a number of important extensions of the analyses presented here that should be considered for future work. First, we have only begun to explore the range of possible policies that could be used to manage stocking. Other priorities should include upward adjustments to stocking to reduce risks of extremely high alewife biomass and exploration of stocking triggers other than Chinook salmon weight (e.g., alewife recruitment indices). Second, the sensitivity of the decision model to uncertainties other than those explicitly included in the analysis should be investigated. One obvious example is uncertainty about future wild production of salmonines. Finally, we need to explore methods for effective communication of the results of this analysis to managers and stakeholder groups.