

## Using an Economic Model of Recreational Fishing to Evaluate the Benefits of Sea Lamprey (*Petromyzon marinus*) Control on the St. Marys River

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**ABSTRACT.** *This paper describes efforts to estimate economic benefits of improved sea lamprey (*Petromyzon marinus*) suppression on the St. Marys River. By linking an economic model of recreational fishing in Michigan to fish populations in the Great Lakes, a method is illustrated for estimating economic benefits that accrue to recreational anglers when fish populations increase. Previous economic efforts to evaluate sea lamprey control have taken a basin-wide view to determine optimal steady-state control levels based on economic injury levels, or have focused on whether or not the entire sea lamprey treatment program is justified. While capable of being adapted to either of these types of evaluations, the method presented here was used to estimate benefits to Michigan anglers of several sea lamprey treatments options for the St. Marys River. When estimated benefits are compared to treatment costs, all treatment options examined are shown to have different, but positive, net present value. Thus, the results suggest that sea lamprey suppression efforts on the St. Marys River yield economic benefits that exceed costs, and this holds even though only part of the economic benefits have been measured.*

**INDEX WORDS:** *Lake Trout, Michigan, economics, travel cost method, random utility model.*

### INTRODUCTION

Numerous non-indigenous aquatic species pose threats to native species in the Great Lakes (Mills *et al.* 1993). One of the best known invaders is the sea lamprey (*Petromyzon marinus*). Sea lamprey prey on lake trout (*Salvelinus namaycush*), a key native species in the Great Lakes, as well as other species of recreational and commercial importance. The sea lamprey invaded the upper Great Lakes in the mid-1900s following the completion of the Welland Canal. They spread rapidly through the lakes and along with overfishing devastated fish communities (Smith and Tibbles 1980, Eshenroder *et al.* 1995). The federal governments of Canada and the United

States created and funded the Great Lakes Fishery Commission (GLFC) in 1955 to jointly deal with this invader (Christie and Goddard, 2003). Ongoing stream treatments using selective lampricides have successfully reduced populations of sea lampreys in Lake Superior, Lake Ontario, Lake Erie, and most of Lake Michigan (Heinrich *et al.* 2003, Larsen *et al.* 2003, Lavis *et al.* 2003 Sullivan *et al.* 2003), resulting in restoration of lake trout populations in Lake Superior and increases in their abundance in the other lakes.

Sea lampreys are still believed to be a major impediment to restoration of lake trout in Lake Huron (Eshenroder *et al.* 1995, Morse *et al.* 2003). The sea lamprey population in northern Lake Huron is estimated to be larger than in all of the other Great

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Lakes combined (Schleen *et al.* 2003). Efforts to achieve restoration of lake trout on Lake Huron and northern Lake Michigan have been hampered by the large numbers of sea lamprey that spawn in the St. Marys River (Eshenroder *et al.* 1995), the channel connecting Lake Superior and Lake Huron. The large number of sea lampreys in northern Lake Huron (and Lake Michigan) coincide with vast areas of critical spawning habitat for lake trout (Eshenroder *et al.* 1995). Increasing lake trout populations in the critical spawning areas in northern Lake Huron is crucial for achieving self-sustaining stocks of lake trout—a shared goal of the fishery management agencies in their fish-community objectives for Lake Huron (DesJardine *et al.* 1995).

The primary means of controlling sea lamprey is by treating streams in the Great Lakes basin with the lampricide TFM (3-trifluoromethyl-4-nitrophenol). TFM kills larval sea lamprey before they can migrate to the Great Lakes. However, due to the volume of flow in the St. Marys River, TFM treatment of the St. Marys River was found to be too expensive and of limited effectiveness (Schleen *et al.* 2003, Shen *et al.* 2003). This led the GLFC to search for other control options for the St. Marys River. Potential treatment alternatives were developed for the St. Marys River, yet these treatments have large costs in comparison to existing expenditures on sea lamprey control.

While earlier research has shown that the benefits of the entire sea lamprey control program likely outweigh the costs (Talhelm and Bishop 1980), there remains a need for tools to assess specific sea lamprey treatment decisions. Along these lines, Koonce *et al.* (1993) take a basin-wide, economic injury level approach to determine optimal steady-state levels of sea lamprey. As discussed in Stewart *et al.* (2003), this method requires estimates of a single, fixed value for recreationally harvested lake trout and also requires that trade-offs be assessed in the steady-state. An alternative method is illustrated here in which an economic model of Michigan anglers' demand for recreational fishing in Michigan waters of the Great Lakes is linked to fish populations in the Great Lakes and used to evaluate the economic benefits of spatial and temporal changes in lake trout populations due to suppression of sea lamprey on the St. Marys River. In light of this, the objectives were to estimate the economic benefits to Michigan anglers of the sea lamprey treatment options available for the St. Marys River and to examine whether the portion of benefits that are estimated here exceed the treatment costs.

## METHODS

Three sea lamprey treatment options for the St. Marys River were examined (Schleen *et al.* 2003, Shen *et al.* 2003). The three options consist of combinations of two recently refined treatments: sterile male release and trapping (SMRT) and granular Bayluscide applications (GB). Sterile male release and trapping reduces reproductive potential by trapping males and females, destroying the females, sterilizing the males, and releasing them to compete with the remaining non-sterile males. Sterile-male release and trapping are done annually to maintain suppression. Granular Bayluscide is a chemical treatment that is effective in killing larval sea lamprey. Like stream treatments with the lampricide TFM, these treatments could be repeated at a five-year interval (Schleen *et al.* 2003) to prevent re-established larvae from reaching metamorphosis. Spot treatments with the bottom-release lampricide, GB, do not appear to cause significant mortality in non-target organisms (Schleen *et al.* 2003). Thus, three sea lamprey treatment options are considered in this analysis. The first option is ongoing sterile male release and trapping (SMRT only). The second option includes ongoing sterile male release along with applications of granular Bayluscide every five years (SMRT + GB). The third option includes ongoing sterile male release along with a *one-time* application of granular Bayluscide (SMRT + GB 1.x). In terms of cost, granular Bayluscide is much more expensive than sterile male release. Applications of granular Bayluscide cost were estimated to cost \$4.2 million dollars (US) per application. Sterile male release and trapping was estimated to cost about three hundred thousand dollars a year or \$1.5 million for a 5-year rotation.

### Recreation Demand Model for Michigan

A repeated-random utility travel cost model of recreational fishing in Michigan is used to estimate economic benefits to recreational anglers in Michigan of increases in lake trout populations in Lake Huron. The travel cost method uses information on travel costs and visitation to estimate the demand for recreation sites (Bockstael *et al.* 1991 or Freeman 1993 for reviews of the travel cost method). The travel cost method is widely used to estimate recreational use-values, the economic benefits from the use of recreation sites. Travel cost methods that are based on the random utility model (RUM) allow recreation demand to be estimated for a whole set of possible recreation sites. For general texts on the

RUM, see Ben-Akiva and Lerman (1985) or Train (1986). For applications of the RUM to recreation site choices, see Bockstael *et al.* (1984), Bockstael *et al.* (1987), Jones and Sung (1993), Feather *et al.* (1995), and Hausman *et al.* (1995). In a repeated version of the RUM, such as the Michigan model, the season is divided into a series of choice occasions in which anglers decide whether to take a trip, and if so, where to fish. For other applications and discussions of the repeated-RUM in the context of recreational fishing, see Morey *et al.* (1991, 1993), Chen *et al.* (1999), and Morey (1999).

The popularity of RUM travel cost approaches is in part due to their ability to accommodate numerous potential recreation sites in a tractable empirical model. Moreover, with RUM, recreation site demand can be linked to the characteristics of the sites (e.g., the catch rate of fish at a site). Such linkages allow the model to be used to evaluate the economic benefits of changes in the site characteristics. Several applications of RUM have been used to assess the benefits changes in fish populations and fish catch rates (Morey *et al.* 1991, Jones and Sung 1993, Morey *et al.* 1993, Schuhmann 1998).

The data describing where and how often anglers go fishing in Michigan were collected in an extensive telephone panel survey that followed anglers during the course of the 1994–95 fishing year. The panel members were recruited from the general population of Michigan residents to ensure that the results would be representative of the general population. The survey asked respondents to report the location, duration, and species targeted for each fishing trip they may have taken (Hoehn *et al.* 1996; Appendix 2 includes a complete list and wording of questions). Computer assisted telephone interviews were used to streamline all interviews and improve response accuracy. Additional techniques to ensure response accuracy included the following: a large pilot survey, fishing logs as memory aides, bounded recall to avoid double counting of trips across panel interviews, and providing multiple opportunities to revise trip counts. To balance the need to collect timely and accurate data against the burden of the interviews, frequent anglers were called more often than infrequent anglers—panel interview frequencies ranged from eight interviews for the most avid anglers to three interviews for the least avid anglers. The model and data used here draw on the work of previous research documented in Hoehn *et al.* (1996).

Here, the survey data are used in two stages. In the first stage, fishing location choices are modeled

using the survey data for anglers who took a fishing trip to the Great Lakes and fished for trout or salmon. In the second stage, the number of Great Lakes trout and salmon fishing trips is modeled. The second stage estimates the propensity of all the anglers in the panel to participate in Great Lakes trout and salmon fishing trips, (the go fishing/don't go fishing level). There are 1,902 potential anglers in the panel data sample; 1,080 of these took some type of fishing trip in 1994 during the April to October open-water fishing season. Of these participants, 90 individuals took Great Lakes trout and salmon trips for a total of 312 trips. Of these trips, 70 are multiple day trips and 242 are single day trips. There are nine choice occasions per month from April to October.

The fishing sites are characterized by their travel costs and catch rates. Travel costs are defined as the sum of driving costs, lodging costs, and time costs. Driving costs are the round trip travel distance multiplied by the estimated per mile driving cost for each sample member. Time costs are defined as each individual's estimated time costs multiplied by the travel time for each trip. The individual specific time cost and driving cost regressions, as well as the lodging cost calculations are documented in detail in Appendix 1 of Hoehn *et al.* (1996). Each site is also described by its catch rate for the trout and salmon species identified earlier. These catch rates are specific to each county and vary on a monthly basis from April to October. These catch rates are based on an analysis of the Michigan creel survey party interview data (described in the next section). The spatial and temporal variation in the catch rates reflects seasonal differences across sites in the abundance of salmon and trout.

Destination sites (fishing locations) are defined by the stretch of Great Lake shoreline within a Michigan county that offers opportunities to catch Great Lakes trout and salmon. While there are 41 Michigan counties that border the Great Lakes, not all provide access to trout and salmon fishing. The following counties bordering a Great Lake were not included in the analysis: Monroe, Wayne, Macomb, Tuscola, Bay, and Cheboygan. With the exception of Cheboygan, these are warm-water areas where trout or salmon fishing is essentially non-existent (these counties had no more than a handful of trout or salmon anglers in 10 years of creel survey data). Cheboygan County was not included because no anglers in the sample fished there and because in 10 years of creel survey data there were no trout or salmon observations from Cheboygan County.

However, unlike the other excluded counties, it is possible to catch trout or salmon from the waters off Cheboygan. By not including this county in the model, any improvements in fishing quality at this county will yield angling benefits that are not accounted for in the estimates from the model. The magnitude of any omitted benefits would depend on the degree to which recreational fishing effort increases at the county.

The repeated RUM that is estimated here is specified as a nested logit with the participation level nested above the site choice level (McFadden (1981) and Morey (1999) provide details on nested logit). In the nested logit, the probability of selecting a site conditional on taking a trip is given by

$$Prob(j|go) = \pi_{j|go} = \frac{\exp(\beta X_j)}{\sum_j \exp(\beta X_j)} \quad (1)$$

where  $go$  refers to taking a trip,  $j$  refers to the possible sites,  $X_j$  is a vector of characteristics describing the sites, and  $\beta$  is a vector of parameters to be estimated.  $X_j$  will include site characteristics such as travel costs and catch rates. The index  $\beta X_j$  is referred to as the indirect utility of taking a trip to site  $j$ . The relative value of the elements of the estimated  $\beta$  are estimates of anglers' preference for different site characteristics.

The probability that an angler chooses to take a trip on any given occasion is given by

$$Prob(go) = \pi_{go} = \frac{\exp(\theta IV + \gamma Z)}{1 + \exp(\theta IV + \gamma Z)} \quad (2)$$

where  $Z$  is a vector of angler characteristics,  $\gamma$  is a vector of parameters to be estimated,  $IV$  stands for inclusive value and  $\theta$  is the parameter on the inclusive value. The  $IV$  is a summary index that describes the utility of the recreation site choices, and it is given by

$$IV = \ln\left(\sum_j \exp(\beta X_j)\right) \quad (3)$$

The use of the inclusive value as a variable is a way of introducing potential correlation in the error terms associated with sites. If  $\theta$ , the estimated parameter on  $IV$ , is less than one, then the estimates suggest that indirect utilities associated with alternative fishing sites are more correlated with one another than they are with the "don't go fishing" alternative (McFadden 1981). The  $IV$  formula is

also used in the calculation of economic value (benefits or costs) associated with changes in site characteristics,  $X_j$  (McFadden 1981, Small and Rosen 1981, Morey 1999). Even though the present model differs, the underlying data and procedures for calculating economic benefits and extrapolating these to the Michigan population are the same as those described in Lupi *et al.* (1998a).

### Catch Rate Modeling

In addition to travel cost, the Great Lake fishing sites are described by catch rates that vary by site, species, and month. The catch rates were estimated using the party interview data collected by the Michigan Department of Natural Resources. Thus, the catch rate data are an independent source of information that is distinct from the telephone interview data on the fishing trip locations discussed above. Negative binomial regression models were used to estimate species-specific catch-per-hour for recreational anglers fishing for trout and salmon in Michigan waters of the Great Lakes (Lupi *et al.* 1998b). Dependent variables were observations on catch and hours fished for angler parties interviewed in Michigan creel surveys from 1986 to 1995. The estimated models relate catch rates to independent variables for year, month, and fishing location. Interactions between months and locations are included to permit spatial and temporal variation in estimated catch rates. Additional variables control for charter boat use, angler party size, and extent of species targeting (fishing for "salmon" versus "chinook"). Separate models are estimated for nine combinations of species and Great Lakes. The nine catch rate models range in size and include from 35 to 110 explanatory variables and from 5,000 to 50,000 observations. The estimation results indicate significant relationships between catch rates and most independent variables, including large positive effects for charter boats and targeting, positive but declining effects for increases in fishing party size, and significant spatial and temporal differences. By using the annual data, the catch rate modeling approach provides predictions of the 1994 catch rates that are specific to species targeted, lake, site, month, and year. The complete set of estimated catch rates for all species and lakes are given in Lupi *et al.* (1998b). The estimates of catch rates for 1994 serve as independent variables describing sites in the recreational fishing model.

**TABLE 1. Estimated model parameters**

Variables	Parameter	t-Stat
Single day trip, site choice level		
Travel cost	-0.057	-16.6
Catch rate	1.89	2.51
Lake Superior constant	1.04	1.36
Lake Michigan constant	1.89	4.99
Multiple day trip, site choice level		
Travel cost	-0.008	-5.77
Catch rate	4.60	5.19
Lake Superior constant	0.15	0.27
Lake Michigan constant	1.37	4.19
Trip constant	-5.89	-10.0
Participation Level		
Inclusive value	0.17	1.93
Participation constant	-17.2	-8.00
Male	1.56	6.57
Ln(age)	1.74	5.34
Ln(education)	1.81	3.16
Adults in household	-0.11	-1.21
Children in household	-0.20	-2.78
Not currently employed	-0.71	-3.47

Log likelihood values at site choice level, -510; and at participation level, -1,493.

### Estimated RUM Parameters

The nested-logit recreational fishing model was estimated sequentially by applying maximum likelihood techniques to the site choice and participation levels of the model. The choice probability functions used at the two stages of estimation are given above by equation (1) for the site choice level and equation (2) for the participation level. As shown in Table 1, the estimated parameters on the travel cost variables are negative. The estimated parameters on the catch rate variables are positive. Notice that the travel cost parameter for multiple day trips is lower than the travel cost parameter for single day trips, and the catch rate parameter for multiple day trips is larger than for single day trips. This means that catch rates are relatively more important and travel costs are relatively less important determinants of where anglers take multiple day trips than they are for single day trips. This suggests that any changes in catch rates will be more valuable for anglers taking a multiple day trip than for anglers taking a single day trip.

Table 1 also presents the estimated parameters on the Lake Superior and Lake Michigan constants for both single and multiple day trips. The Lake Supe-

rior and Lake Michigan constants for the single and multiple day trips are dummy variables that take the value of 1 if a site lies on that lake and a value of 0 otherwise. Including these constants in the model assures that, on average, the estimated model will predict that the share of trips to each Great Lake will match the shares in the survey data.

The third part of the table presents the participation level results. The estimated inclusive value parameter is significantly less than one indicating that the nested logit is a significant improvement over the multinomial logit formulation. Roughly speaking, the inclusive value parameter estimate implies that the Great Lakes trout and salmon fishing sites are closer substitutes for each other than they are to the "don't go" alternative. This suggests that, relative to an un-nested version of the model, the total number of Great lakes trout and salmon fishing trips will be less responsive to changes in fishing quality than will be the allocation of trips across sites. In addition to the inclusive value parameter, Table 1 also presents several other parameter estimates for variables that entered the model at the participation level. Males, older individuals, and more educated individuals are more likely to take Great Lakes trout and salmon fishing trips. Conversely, individuals with more adults or more children living in their household are less likely to take Great Lakes trout and salmon fishing trips (though the effect of adults is not significantly different than zero at conventional levels of significance). In addition, individuals who do not have a paying job are less likely to take Great Lakes trout and salmon fishing trips.

Recall that the catch rate models provide estimates for catch rates specific to three specific groups: lake trout, salmon, and other trout. The combined catch rate variable used in the model presented in Table 1 was derived by taking the sum of these three catch rates at each site in each month. That is, the catch rate for trout and salmon at site  $j$  in time  $t$  is given by

$$CR_{j,t}^{T+S} = CR_{j,t}^{lake\ trt} + CR_{j,t}^{salmon} + CR_{j,t}^{other\ trt} \quad (4)$$

where the subscript  $j,t$  represents site  $j$  at time  $t$ , and the superscripts represent the species groups with T+S meaning "trout and salmon." Several preliminary models were estimated using the three separate catch rate variables, one for each of the species groups. A general finding after estimating under a variety of model specifications was that the para-

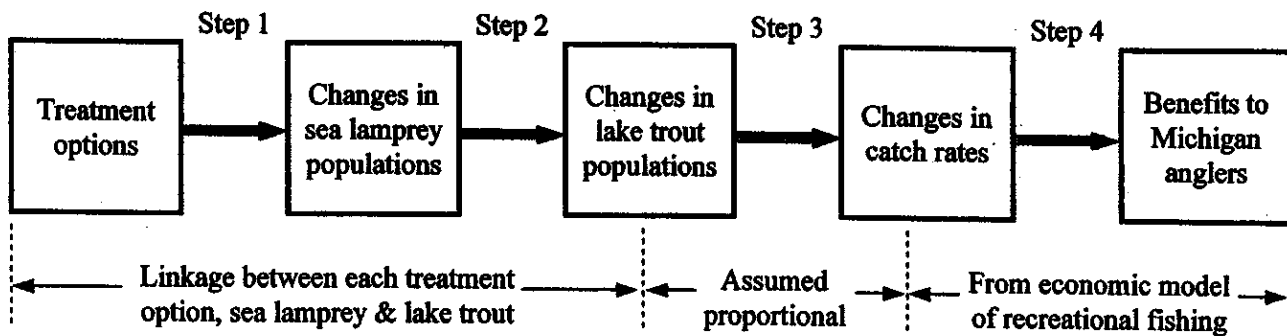


FIG. 1. Steps required to link treatment options to economic value.

meters on the catch rates for individual species were fairly unstable and were often insignificant. Some specifications resulted in the lake trout parameter being insignificant and sometimes even negative, while other specifications resulted in the salmon catch rate being very low and insignificant. Interestingly, in almost all specifications examined, it was not possible to reject the restriction that all species of Great Lakes trout and salmon had the same parameter. One difficulty that bears on this result is that the species-specific catch rates are significantly correlated with one another which complicates attempts to identify their separate effects. A second difficulty relates to the correlation between species-specific catch rates and the lake specific constants. Another explanation may be that anglers who are targeting a specific species may not care about the catch rates of other species when they make their site choices. While the later effect could be examined by treating fishing trips targeting salmon as distinct alternatives from trips targeting lake trout, the present study did not have enough fishing trip observations to make that distinction.

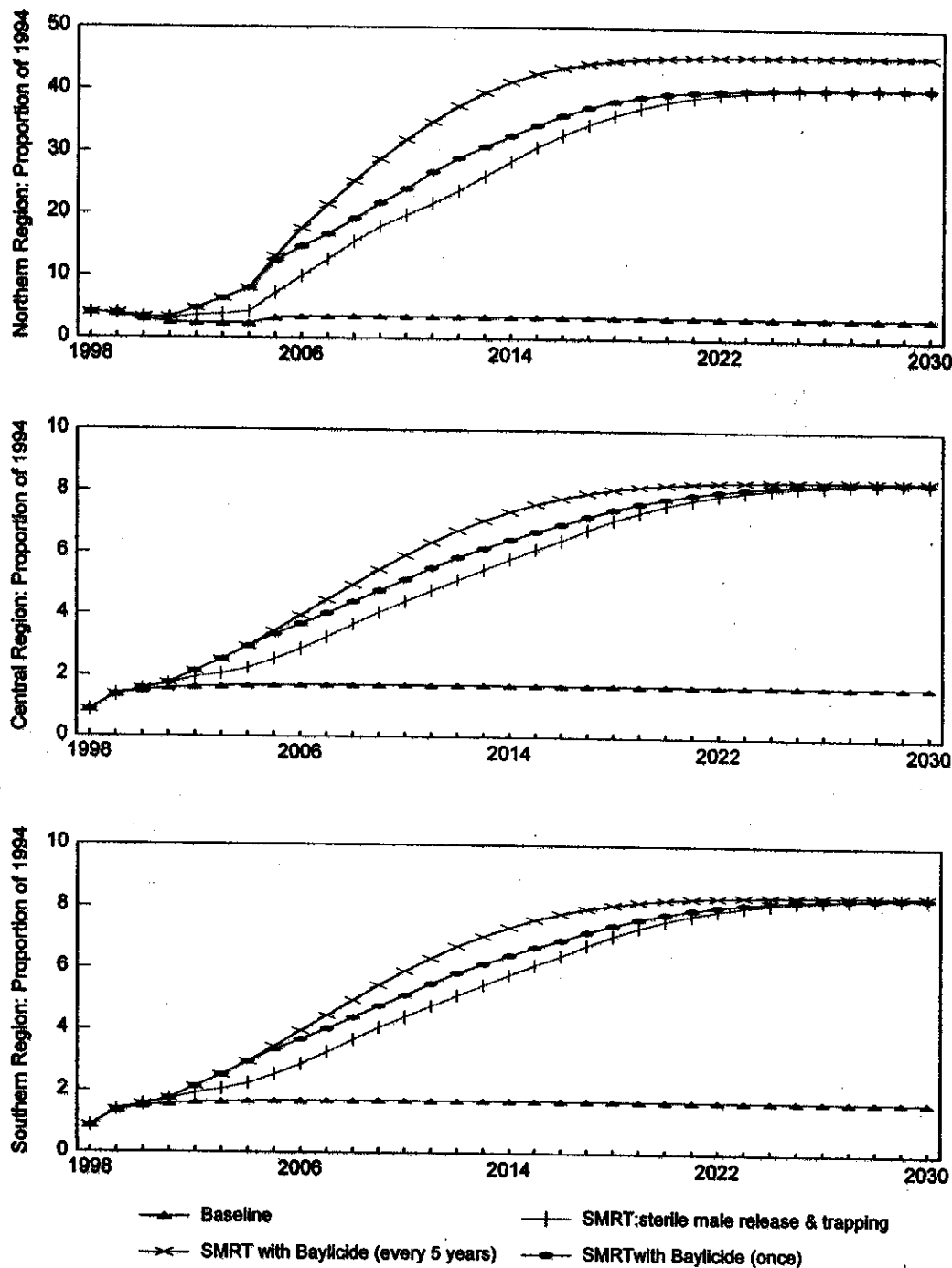
The implication of the result that the catch rate variables have the same parameter is that each of the species is equally important, or substitutable, to anglers, and thus equally valuable. Put differently, it means that when making a Great Lakes trout and salmon fishing site choice, anglers prefer high catch rates, and there were not significant differences in this preference among trout and salmon species. This result has potentially important implications for the current analysis as well as for future analyses of anglers' preferences regarding fish-community objectives. Whether the result accurately characterizes the general population of anglers, or whether it may be due to present data and sample

size limitations is recommended as an area for future research.

#### Linking the Sea Lamprey Treatments to Economic Values

In order to use the RUM to value changes in the fishery, establishing a link between the treatment options and variables that enter the RUM is needed. While the obvious variable is catch rates, Figure 1 emphasizes that a complex chain of information is needed in order to evaluate the treatment options. First, the effect that treatments will have on sea lamprey populations needs to be established. Second, changes in sea lamprey populations must be linked to changes in the lake trout populations. Third, one needs to map the changes in lake trout populations into changes in lake trout catch rates. Finally, the economic model is used to estimate the use-values that accrue to anglers due to increased catch rates. Thus, the diagram illustrates one pathway in which changes in management actions result in changes in value. Anderson (1994) refers to this as marginal analysis to emphasize that the objective is to identify how value changes in response to some management action.

Projections of the effects of the control options on sea lamprey populations were developed by Schleen *et al.* (2003). Their model estimates the extent of mortality on larvae caused by lampricide applications and the effects of reduced recruitment caused by trapping and sterile male release. The effects of sea lamprey predation on lake trout were estimated using the catch-at-age model of Sitar 1996, Sitar *et al.* 1999, and Schleen *et al.* 2003) (the first two linkages in Fig. 1). The effects of the three treatment options as well as the no treatment option were generated from these two models. For each treatment option as well as for the no treatment op-



**FIG. 2.** Proportional change in estimated annual abundance of mature lake trout (age 8+) by regions of Lake Huron for each treatment option.

tion, there is a time series of lake trout population levels for various regions of Lake Huron. The projected age 8+ lake trout population levels in the three regions are presented in Figure 2.

The third step in Figure 1 involves relating lake

trout populations to the catch rates that are used in the recreational angling model. To relate changes in lake trout populations to changes in catch rates, we assumed that a proportional relationship holds for each site. Thus, an X% increase in the lake trout

**TABLE 2.** *Estimated recreational angling benefits per year for the projected changes in lake trout populations in 2015 for each St. Marys River treatment option, the estimated changes in number of age 8+ lake trout, and relative changes in abundance of age 8+ lake trout.*

	Option 1 Sterile male release & trapping	Option 2 Sterile male release & trapping with Baylucide every 5 years	Option 3 Sterile male release & trapping with Baylucide once
Estimated benefits to Michigan anglers in 2015	\$2.62 mil	\$4.74 mil	\$3.33 mil
Estimated population increase (absolute) <sup>†</sup>			
Northern region	62,000	90,000	71,000
Central region	122,000	156,000	135,000
Southern region	137,000	175,000	152,000
Lake Huron (total)	321,000	421,000	357,000
Estimated population increase (proportional) <sup>‡</sup>			
Northern region	30.8	42.6	34.3
Central region	6.1	7.6	6.7
Southern region	3.2	3.9	3.5
Lake Huron <sup>§</sup>	4.8	6.0	5.3

<sup>†</sup> Projected absolute increase in the number of mature lake trout in each region.

<sup>‡</sup> Projected factor increase in number of mature lake trout in each region (2015 regional population / 1994 regional population); e.g., 30.8 indicates a projected 30.8-fold increase.

<sup>§</sup> Projected factor increase in number of mature lake trout for all of Lake Huron (2015 lake population / 1994 lake population).

population associated with a site increases the lake trout portion of the catch variable for that site by X%. Referring to equation (4), when Lake Huron lake trout populations increase by X%, only  $CR_{lake}^{site}$  is increased by X%. Since only the lake trout portion of the catch rate variable in the recreational angling model is adjusted, the overall catch variable will increase by less than X%.

To complete the linkage, the regional lake trout population estimates were translated into proportional changes in regional lake trout populations by dividing by the region's lake trout population levels in 1994, the year of the angling site choice survey. The absolute and proportional changes over time in the populations of mature lake trout for each region are presented in Figure 2. For each county in the recreational demand model, a time series of catch rate changes is derived by multiplying the 1994 catch rate for lake trout by the proportional change in lake trout population for the region associated with the site. This approach preserves the spatial variation in catch rates that existed in 1994.

## RESULTS

### Valuation Results

Table 2 shows the estimated annual benefits that would accrue to Michigan's recreational anglers in the year 2015 if lake trout catch rates were to increase by the factors in the table. The estimates of the economic use-values associated with each of the policy options in the year 2015 are: \$2,617,000 for Option 1; \$4,742,000 for Option 2; and \$3,333,000 for Option 3 (Table 2). These are estimates of the economic use-values accruing to Michigan resident anglers, in 1994 U.S. dollars. The estimates reveal that each of these options yield substantial benefits in the future. The table also shows that, as one would expect, the treatment options that yield the largest lake trout population increases have the largest benefits. The absolute changes in population are largest in the southern region and smallest in the northern region. However, since the current population level in the northern regions is so low, the proportional increases in population are much larger in the north than in the south.



Does the spatial pattern of changes in fish population matter? In the above scenarios, the proportional changes in catch rates (Table 2 and Fig. 2) are much larger in the northern region than in the other regions as seen in Table 2. The final row of Table 2 also presents the simple lakewide average proportional change in lake trout population. One might ask whether the spatial delineation of the changes in lake trout population affects the estimated economic values. It turns out that the spatial (regional) composition of the catch rate changes makes a substantial difference for the estimated economic values. If the average lakewide change in population were applied to all sites at Lake Huron, then the estimated benefits of option 1 would be about \$8 million in 2015. The estimated value based on the lakewide average population change is larger because the southern portions of the lake that are closer to population centers get a larger catch rate change when the lakewide average lake trout population change for the lake is used than they do when the regional changes are used. The outcome illustrates the economic result that, all else being equal, changes in fishing quality will be more valuable the closer they are to users. This is a reflection of the use values that are measured by the travel cost method.

### Net Present Values

When considering whether treatment is economically beneficial, the estimated economic benefits for the different treatment options in the year 2015 that are reported in Table 2 only reveal part of the picture. From Figure 2, it is clear that the proportional changes in lake trout population grow at different rates over time which means the economic benefits will also grow at different rates over time. Moreover, the timing and amount of the treatment costs differs across the treatment options. When costs and benefits vary over time, economists typically compare alternatives based on their "net present value." The net present value of a project is the amount of money that, if invested today at some interest rate, will generate the same stream of net benefits as the project. Net benefits are simply the benefits minus the costs. For benefit-cost analyses of U.S. government projects, interest rates (or discount rates) in the range of 7% are commonly used for computing net present values, although lower rates are often applied to investments with long-lived environmental impact (Stiglitz 2000, page 288). Because of the sensitivity of net present val-

ues to the discount rate, as well as the many different views on an appropriate discount rate (Stiglitz 2000), many benefit-cost analyses report net present values under a range of rates.

The net present value of recreational angling benefits minus treatment cost was calculated for each option using a variety of discount rates (Table 3). The results show that all three treatment options are estimated to have positive net present values at reasonable discount rates, even though only the recreational fishing benefits linked to improved catch rates have been estimated here. Option 1 has positive net present values at discount rates up to about 25%. Options 2 and 3 have positive net present value for discount rates up to about 15%. Option 2, which involves baylucide every 5 years combined with annual sea lamprey trapping and release of sterile males, has the largest net present values at discount rates at or below 4%. Option 3, which involves an initial baylucide treatment with annual sea lamprey trapping and release of sterile males, has the largest estimated net present value for discount rates between 4.1% and 6.4%. At discount rates above 6.4%, option 1, which involves annual sea lamprey trapping and release of sterile males but does not incur the higher costs of baylucide, has the largest net present value.

Inspection of Table 3 reveals that the estimated net present values are relatively similar across the three treatment options. The similarity of net present values might seem inconsistent with the estimated benefits, which do differ across policies. For example, the estimated benefits in the year 2015 (Table 2) were 1.8 times larger for option 2 than for option 1. The reason that the net present values are fairly similar across the three treatment options is that the costs are highest for the options with the fastest and largest growth in lake trout populations. Thus, in the net present value calculations, low discount rates favor option 2 because lower discount rates allow more weight to be put on the future benefits, which are highest with option 2, and lower discount rates place less of a penalty on the larger up front costs associated with baylucide treatments. At higher discount rates, option 1 is preferred due to the increased emphasis higher discount rates place on the initial treatment costs of baylucide and the decreased emphasis that high discount rates place on benefits in the longer term. Similar logic applies to a comparison of options 1 and 2. While option 2 grows fastest and leads to a larger lake trout population, it also has large recurring costs. Alternatively, option 1 has the lowest costs, but it

**TABLE 3.** Estimated net present value (thousands of U.S. dollars) of the St. Marys River treatment options under alternative interest rates.†

Interest Rates	Option 1 Sterile male release & trapping	Option 2 Sterile male release & trapping with Baylucide every 5 years	Option 3 Sterile male release & trapping with Baylucide once
3.0%	93,340	96,470*	95,630
4.0%	59,370	60,860*	60,840
5.0%	40,410	40,730	41,180*
6.0%	28,720	28,160	28,910*
7.0%	21,030*	19,800	20,720
9.0%	11,960*	9,780	10,880
12.5%	4,940*	1,840	2,990
15.0%	2,690*	(740)	360
25.0%	(40)*	(3,730)	(3,000)

†Negative numbers are in parentheses. Values based on partial benefits estimate that measures only the use-value that accrues to Michigan resident anglers as a result of the changes in lake trout catch rates.

\*Option with largest net present value (present value of Michigan angling benefits minus present value of costs).

has the slowest growth in lake trout populations. Thus, option 2 has greater net present values than option 1 at lower discount rates (< 6%) with the converse holding at higher discount rates.

### CONCLUSION

An economic model was used to estimate some of the recreational angling benefits associated with three options for suppressing sea lamprey in the St. Marys River. The three options are (1) ongoing sterile male release and trapping by itself, (2) ongoing sterile male release and trapping along with a Baylucide application once every 5 years, and (3) ongoing sterile male release and trapping along with one application of Baylucide. When estimated angling benefits are compared to treatment costs, all treatment options are shown to have different, but positive, net present value. Thus, the results suggest that the sea lamprey suppression efforts on the St. Marys River yield economic benefits that exceed costs, and this result holds even though only part of the economic benefits have been measured.

The present research also demonstrates a novel way to evaluate the economic benefits of sea lamprey control. That is, an economic model of recreational fishing demand is linked to alternative means of suppressing sea lamprey on the St. Marys

River. As discussed in Stewart *et al.* (2003), previous economic efforts to evaluate sea lamprey control have taken a basin-wide view to determine optimal steady-state control levels based on economic injury levels (Koonce *et al.* 1993) or have focused on whether or not the entire sea lamprey treatment program is justified (Tahlem and Bishop, 1980). While capable of being adapted to either of these types of evaluations, the method presented in this paper allows for the incremental assessment of specific treatments affecting portions of any basin. For example, the method could again be used at the St. Marys River to estimate the recreational fishing benefits of different Baylucide repeat cycles and different levels of effort for sterilization and trapping. In order to apply the model and framework to other policy questions, one would need to know how lake trout populations are affected over time with and without a policy action. For a given spatial and temporal pattern of change in lake trout populations, the model can be applied to estimate the associated economic benefits that accrue to recreational anglers. While the method is presently limited to valuing changes in recreational harvest (catch rates), the approach is flexible in that the economic analysis can be conducted for an entire time path of changes in lake trout populations, regardless of whether a steady state is achieved. As the results demonstrate, accounting for the temporal distribu-

tion of costs and benefits affects the economic analysis because costs often outweigh benefits in early years of any investments in the fishery. Finally, the approach demonstrates an alternative method that could be used to set sea lamprey targets without setting a fixed value for each sport-harvested lake trout.

There are several important caveats to bear in mind when considering the present model and estimated results. The estimated benefits used to calculate the net present values are based only on the estimated recreational use-value accruing to Michigan recreational anglers. There are likely other economic benefits associated with the treatment options that have not been measured. Potentially important benefits that have not been measured include such things as: benefits to non-resident anglers that fish in Michigan; benefits to anglers that fish in Canadian portions of the Lake Huron; benefits due to possible increases in catch rates in northern Lake Michigan; benefits from commercial harvest; potential reductions in stocking costs; and values that the general public might have for rehabilitation of native fish stocks and related improvements in ecosystem health. Moreover, the changes in lake trout catch rates are based on changes in growth of age 8+ lake trout which likely over-states the growth in the population of lake trout entering the recreational fishery (about age 5+). In addition, the analysis does not account for uncertainties associated with projected lake trout population growth for each scenario. If the realized growth in lake trout populations is less, or the catch rates do not respond proportionally, then the recreational angling benefits would be lower.

In addition to caveats associated with the policy scenario and scope of the model, there are uncertainties associated with the economic value estimates. A sensitivity analysis of all assumptions underlying the results has not been conducted. Nevertheless, uncertainty associated with the measurement of travel costs will affect the estimated values and additional data wouldn't necessarily reduce this effect. In addition, the long-time frames involved before lake trout populations fully increase means it is not possible to assess, *ex post*, the validity of the model predictions. While the significance of the estimated parameters and conformity with demand theory (a negative travel cost parameter), are suggestive of model validity, the approach used here relies on cross-sectional observations of behavior to predict how behavior will change when lake trout populations increase. Finally, it is not known how

much error in the estimated results might be due to the relatively small sample size of angling trips that target Great Lakes trout or salmon (312 trips). Naturally, larger sample sizes would be preferred in any future efforts.

Several important research issues have been raised in the course of this project. A key issue regards anglers' preferences for alternative species of trout and salmon. In the model applied here, there were insufficient data to identify potential differences in anglers' preferences for various trout and salmon species. As a consequence, the model treats all these species as equally valuable and implicitly holds the allocation of fishing effort constant across species. There are many possible research steps that might shed more light on this issue. One approach would be to incorporate more data into further refinements of the recreational angling model. It is possible that the current number of trips targeting trout and salmon is not large enough in the sample to significantly and reliably identify the separate effects of species-specific catch rates. Since it is also possible that the targeting behavior of anglers might mask significant catch rate effects, collecting additional data might permit the modeling of anglers' species target decisions in addition to their site choices. Another possibility would be to directly question anglers about their species preferences and their preferences for alternative lake management plans. The information about anglers' species preferences could be used to augment the travel cost data, while the information on preferences for lake management plans would permit the estimation of some of the non-use values associated with native species restoration. Finally, because the general public may hold economic values over lake management alternatives, preferences for lake management plans could be collected from the entire public, as opposed to anglers alone.

#### ACKNOWLEDGMENTS

Funding for this project was provided by the Great Lakes Fishery Commission, Michigan Sea Grant College Program, Michigan Department of Natural Resources, and Michigan Agricultural Experiment Station. We thank Shawn Sitar and James Bence for providing information and population models for the policy scenarios. We have benefited from discussions with Douglas B. Jester and participants of USDA Regional Research Project w133.

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Submitted: 21 December 2000

Accepted: 17 March 2003

Editorial handling: Roger A. Bergstedt