

STUDY PERFORMANCE REPORT

State: Michigan

Project No.: F-53-R-14

Study No.: 480

Title: Development of decision models for the Great Lakes' fisheries

Period Covered: April 1, 1997 to March 31, 1998

Study Objective: To develop decision models for Great Lakes salmonine fisheries that incorporate stocking, harvest and other management actions as control variables and predict the likely outcomes such as harvest rates in different locations, and other measures of ecosystem performance relevant to achieving a valuable and sustainable fishery.

Summary: We have worked extensively in data summarization and data standards. We have further updated the lakewide salmonine stocking database for Lake Michigan and updates were supplied to the Green Bay Fisheries Resources Office, United States Fish and Wildlife Service (FRO, USFWS). We completed assembling lakewide information on recreational harvest and effort and took a leadership role in bringing a multi-agency design of a lakewide recreational fishery database for Lake Michigan to fruition. Our work providing assistance in the redesign of the Lake Michigan creel survey is complete and we continue to assist in implementing recommended methods of analysis. Our contribution toward improving creel survey estimation methods has been submitted for publication. We continue to provide oversight on a project aimed at evaluating the feasibility of using mail surveys to assess harvest and effort on the Great Lakes. We assisted in analysis of a 35 year time series of trawl data on forage fish abundance in Lake Michigan. We worked toward an improved analysis of survey indices of lake trout abundance for Lake Superior, and we also compiled extensive information on harvest, diets, and growth for our use in modeling predators in Lake Huron. We also compiled additional information on sea lamprey abundance, sea lamprey marking on lake trout and alternative prey, and lake bathymetry for our work on modeling the sea lamprey lake trout interaction.

Our continued analysis of lakewide patterns of harvest, effort and catch rates further emphasized that changes in catch rates have not been uniform lakewide, and that the "collapse" of the chinook salmon fishery during the 1980s was more severe and extended on the east side of Lake Michigan than on the west side. Additional analyses suggest that this spatial difference probably reflects a change in distribution, possibly in response to a change in prey fish spatial distributions. A lakewide model was built and calibrated that treats chinook salmon as one mixed population. This model allows estimation of lakewide changes in natural and fishing mortality over time and indicates that the decline in chinook salmon fishery during the late 1980s and early 1990s resulted from an increase in the magnitude of in-lake natural mortality during that period, and not from fishing. This temporal pattern in mortality reflects observed changes in age compositions and catch rates but does not match well qualitatively with the one long-term series of information on prevalence of bacterial kidney disease, suggesting potential complexities in the data or causes of the in-lake mortality.

We refined existing predator population models for the main basin of Lake Huron and used these in combination with a gross production approach to estimate predator consumption of forage fish. The predators we considered included three populations of lake trout (north, central, south), two distinct populations of walleye (Saginaw Bay and southern main basin), chinook salmon (entire main basin), and burbot (entire main basin). Our results suggest that total consumption may be near or above system productive capacity. Current estimates of consumption are above estimates of historical consumption by lake trout and are large relative to admittedly crude estimates of forage abundance. Model projections, however, indicate that large reductions in stocking would be required to substantially reduce predator demand for prey, due to major contributions of native self-sustaining predators and naturalized populations.

We have continued to work on building improved lake trout stock assessment models and quantitative methods. We completed a number of refinements to a lake trout model for the MI-4 area of Lake Superior. Additional data were added to Lake Huron lake trout models originally developed as part of Shawn Sitar's MS thesis (Sitar 1996) to allowed improved projections. We have also worked to refine the Lake Huron and Lake Superior lake trout models by integrating a sea lamprey functional response into the lake trout models. To this end we have applied a novel generalized linear modeling approach to fit a function relating expected marking rates by sea lamprey and lake trout size using data from individual lake trout. This approach has allowed us to synthesize large databases on marking in the form of year and area specific asymptotic (with lake trout size) wounding rates, and these results are now being used in several contexts by ourselves and others.

We have expanded our work into other areas by continuing to develop tropho-dynamic models for the Lake Huron piscivore community and detailed population models of lake trout for Lake Huron and Lake Superior, and exploring the possibility of incorporating sea lamprey predation (functional response) models into our lake trout stock assessment models. We have expanded the scope of our Lake Michigan work through involvement with the SIMPLE model (Jones et al. 1993). This expanded scope, as well as increased efforts on Lake Michigan, was possible because of cooperative arrangements with a variety of groups and agencies.

Job 1. Title: Data review.

Findings: We continued to take a leadership role in developing a lakewide recreational fishery database for Lake Michigan. Data for 1995 through 1997 were compiled in a lakewide format established by the task group established by the Lake Michigan Committee. Database design and example results were presented at the Lake Michigan Committee meeting in March 1998. For research purposes we have also constructed a database with recreational fishing information for Lake Michigan extending as far back as possible for each jurisdiction (Wisconsin 1969, Illinois 1986, Indiana 1986, Michigan 1985). During this process algorithms were refined to estimate harvest, effort and directed effort and harvest from the Michigan DNR Fisheries Division's Great Lakes Creel Survey. Currently used and recommended methods were documented and included in a research report (Lockwood, Benjamin and Bence, in review) . We also further refined the Lake Michigan stocking database and provided this to Green Bay FRO, USFWS. This database includes records on stocking from 1963 through 1996 for all salmonines except lake trout.

We collected updated information from Biological Resources Division (BRD) of United States Geological Survey, Michigan Department of Natural Resources (MDNR), Chippewa-Ottawa Treaty Management Authority (COTFMA), and Ontario Ministry of Natural Resources (OMNR)

on harvest, age composition and diets for major piscivores in Lake Huron for work on estimating consumption rates of forage fish (see Job 4).

We further reviewed the design of Lake Superior lake trout assessments that provided data used in modeling work and reanalyzed data taking into account “random” site by year effects in preparation for revising MS thesis work by Chris Weeks for publication. These results indicate that there are significant “random” site by year effects and these lead to increased variances of survey indices.

We participated in analysis of Great Lakes Science Center (BRD, USGS) forage fish survey data for Lake Michigan with Dr. Dan Hayes (Michigan State University), his graduate student Ann Krause, and BRD personnel. The result has been improved indices of abundance based on General Linear Mixed Models, that take into account station and depth effects and account for random year by station interactions. This work is based on analysis of a 35 year time-series of trawl survey data and is being done collaboratively with BRD. Our methods adjust for changes in survey design, extract more information from the data, and account for multiple sources of uncertainty. We have constructed age-specific indices of abundance for two primary prey, the alewife and bloater. Estimates of alewife recruitment to age-2 are highly variable. Furthermore, it is difficult to track individual year classes of alewives due to the combined effects of sampling variability and annual variations in survival. Nevertheless, it is evident that recruitment to age-2 and overall abundance of alewife has declined during the 1990s. Spatial patterns of alewife abundance have changed over time; for example there were notably higher abundances on the west side of the lake and especially low abundance in the southeast during the early 1990s. Bloater young-of-the-year recruitment started to increase in 1979, peaked in 1988 and has declined steadily since, with 1995 recruitment similar to the level in 1982. In contrast to alewives, annual trends in bloater recruitment change smoothly and stronger year classes can be easily tracked as they age. We examined variability between repeated trawls done at the same location. The magnitude of this variability was related to natural history characteristics; more pelagic species like the alewife were more variable than more benthic species such as bloater. These differences appear to be reflected in the variability in spatial distributions and uncertainty in abundance indices.

We brought together much of the needed data/information on sea lamprey abundance, lake bathymetry, lake trout harvest and survey catches and sea lamprey marking rates to support modeling sea lamprey-lake trout interaction modeling for Lakes Huron and Superior. Further detail on this project is described under Jobs 6 and 8.

Job 3. Title: Spatial model for chinook salmon.

Findings: We did not actively develop a spatial model further, but have done additional analyses of spatial patterns in the Lake Michigan fishery. To some extent these analyses call into question the ultimate value of a detailed spatial model that follows the fishery seasonally, at least given current information availability.

We further refined our historical description of the salmonine and chinook salmon fishery on Lake Michigan from 1986 through 1996 both by summarizing lakewide trends based on revised and improved data, and by exploring the nature of patterns for seven defined areas of the lake (south, southwest, northwest, Green Bay, north, southeast and southwest). These results are reported in detail in Darren Benjamin’s MS thesis (Benjamin 1998). Relationships to alewife

abundance are reported by Benjamin (1998) based on unpublished analyses by Ann Krause (as part of her ongoing MS work).

Overall patterns qualitatively match those reported elsewhere. Over the period, total effort dropped by 54% from 14.1 million angler-hours to 6.5 million angler-hours. Effort directed at salmonines declined by 63% from 8.6 million angler hours to 3.2 million angler hours by 1992 and has remained stable since that time. Harvest of all salmonines combined dropped by 53% by 1990 (from 1.8 million to 855,000 fish) and has remained roughly constant over that time. Somewhat surprising, targeted catch rate (salmonines caught per hour fishing for salmonines) has increased or remained stable from 1988 on following an initial decrease from 1986 levels. The result was catch rates in 1996 that exceeded 1986 catch rates. This pattern appears to reflect an initial decline resulting from a drop in catch rate for chinook salmon followed by a switch to other species. Lakewide, targeted catch rate for chinook salmon fell from 0.09 in 1986 to 0.03 in 1993 before increasing to 0.06 by 1996. In 1986 chinook salmon harvest comprised more than 50% of the total salmonine harvest, but by 1993 it comprised only 16%. During this same period chinook salmon harvest declined from 950,000 to 132,000 before increasing to 304,000 in 1996. The decline of chinook salmon fishery from the mid-1980s through 1993 did not reflect a decline in numbers stocked. Although there were some variations in numbers stocked over time, there was no striking trend and no tendency for year classes stocked in higher numbers to produce more harvest. Furthermore, regional patterns in harvest or targeted catch rate of chinook salmon show no positive relationship with regional numbers stocked. In fact, there seems to be a loose negative association, although the association may be coincidental. Overall the results are suggestive of a well mixed stock during much of the fishing season. This is further supported by quite similar size distributions for recreationally harvested fish from different regions of the lake.

As previously noted, there were substantial differences among regions in how the decline of the chinook salmon fishery unfolded during the late 1980s and early 1990s. Most notably, the decline in harvest and catch rate was substantially greater on the eastern shore than on the western shore. Exploration of patterns in forage fish abundance provides some suggestion that the protracted and severe decline on the east side versus west side of the lake could be related to alewife distributional changes. Sites sampled by GLSC (BRD,USGS) off Wisconsin showed pronounced increases in alewife abundance during early 1990s. At the same time there were declines elsewhere, particularly in Michigan's southern waters.

The results described above call into question assumptions we made in initial modeling efforts, that spatial distributions or the rules chinook salmon use to distribute themselves remain static over time. Sufficient data to fully estimate spatial changes in distribution over time are not available.

A lakewide model was built and calibrated that treats chinook salmon as one mixed population. Details of this modeling work are reported by Benjamin (1998). This model allows estimation of lakewide changes in natural and fishing mortality over time. It is not possible to separate regional differences in survival and distribution, but considering coded wire tagging results and size distributions, regional divergence of catch per effort or other measures of abundance from lakewide values of abundance (estimated by model) might be largely distributional changes.

Natural mortality was treated as consisting of a constant (over time) age-specific component assumed to be known (taken from literature and previous studies), a time-varying component and a pulse of mortality each year due to maturation and spawning. The time-varying component was assumed to increase logistically with age, and the temporal variation occurred in the asymptote of this logistic function. One additional mortality component was fishing, treated as a

pulse just before maturation at the beginning of August. Fishing intensity was also modeled to increase logistically with age and to vary in asymptotic intensity from year to year. Parameters determining mortality, harvest and observed data were estimated by fitting the model by maximum likelihood methods to a range of observed data including harvest amount, harvest age composition, weir age composition, age composition of mature fish in the harvest, and targeted catch rates.

The most important result, confirming less analytical evaluations, is that the decline in chinook salmon fishery during the late 1980s and early 1990s resulted from an increase in the magnitude of in-lake natural mortality during that period, and not from fishing. Our analysis indicated that this mortality component did not influence age-1 fish much and affected age-2 and older fish about equally. This estimated mortality component (as an instantaneous annual rate) increased from zero in 1985 to a peak of 1.7 in 1993 before declining to 0.29 in 1996. This pattern reflects observed changes in age compositions and catch rates but does not match well qualitatively with the one long-term series of information on prevalence of bacterial kidney disease (BKD) in chinook salmon from the Strawberry Creek Weir in Wisconsin, where a peak prevalence was seen in 1988 followed by a decline. This suggests that other factors may be influencing time-varying mortality other than BKD or that this Strawberry Creek weir series is not reflective of lakewide trends in-lake mortality from BKD.

Job 4. Title: Tropho-dynamic and predator models.

Findings: We refined existing predator population models for the main basin of Lake Huron and used these in combination with a gross production approach to estimate predator consumption of forage fish. A workshop was held in conjunction with the Lake Huron Technical Committee meeting in January 1998 to obtain input and feedback on model development. Results of the modeling work were presented at the Lake Huron Committee meeting (March 1998). The predators we considered were determined through consultation with the Lake Huron Technical Committee and included, three populations of lake trout (north, central, south), two distinct populations of walleye (Saginaw Bay and southern main basin), chinook salmon (entire main basin), and burbot (entire main basin).

The models for lake trout, walleye and chinook salmon were all age-structured models. The lake trout models were based on the existing catch-at-age models developed and fit to available data by maximum likelihood methods as part of Shawn Sitar's MS thesis (Sitar 1996). We kept the existing parameter values for the historical period for these lake trout models, but updated recent years and projections by using recent projections for changes in sea lamprey abundance, stocking and harvest data and estimating recent mortality rates. Projections of sea lamprey mortality used early 1990s estimates as a baseline and adjusted them in proportion to projected changes in sea lamprey abundance based upon treatment of the St. Mary's River. Age-specific vulnerability to sea lamprey was based upon predictions for the mean size at each age using a function relating sea lamprey attacks to lake trout size (see Job 8). A new population model was developed in an attempt to assess likely historical (pre-collapse) abundance and consumption of lake trout in Lake Huron. This model used estimates of age-specific vulnerability to commercial fishing and natural mortality used in the other lake trout models, and fishing mortality was set at rates thought to allow the sustained fishery observed prior to the 1940s. A constant rate of recruitment was assumed (essentially leading to an equilibrium analysis) and this recruitment rate was set so that the model matched the observed fishery yield during the historical period. In these calculations we used a single model for the entire main basin and assumed that average weight-at-age was the simple average over regions used in the other lake trout models.

The model for walleye in the southern main basin was based on a modification of a cohort analysis originally performed by Lloyd Mohr of OMNR. During the past year we updated this analysis to include recent data on harvest age composition. The walleye model for Saginaw Bay assumed a knife-edge selectivity pattern and used tagging study-based estimates of mortality. Numbers of immigrants from Lake Erie populations were based on estimates generated by Robert Haas (MDNR, St. Claire Fishery Station) and inputs from hatcheries were also included. Although this model was fit to data by maximum likelihood methods, only a few parameters were estimated and a limited set of data were used. The key estimated parameters were recruitment from additional sources (not immigrants or stocked) for several key years, and this recruitment for other years was determined by linear interpolation between these years. The only data source the model was fit to was total annual harvest. During the past year the most significant modification to this model was to use tagging based mortality rates for each year and to explore different assumptions regarding early survival. The Saginaw Bay walleye model still indicates that the observed level of harvest cannot be supported by the numbers of walleye stocked into the system. Other indications are that most young fish caught nearshore are from hatcheries. This topic was reviewed during our January workshop: the conclusion was that for stocking to be the primary source of walleye to the fishery would require unreasonably low mortality during early life. Clearly more information on immigration, movements and sources of fish caught in the fishery is needed.

Structurally, the model for chinook salmon was not changed much during the past year. This model assumed known levels of recruitment based on numbers stocked and estimates of the number of wild recruits. These fish then were subjected to continuous natural mortality over the year, a pulse fishery centered on August 1, and a pulse of maturation/spawning related mortality.

The fishery was modeled as a pulse before maturation because this better matched the seasonal pattern than the usual treatment as a constant instantaneous rate over the year. Parameters estimated during model fitting included age specific selectivity of the fishery, year specific fishing intensity, fishery catchability, maturation schedule, and year specific survival to age-1. Data used to fit the model included recreational harvest, age composition of mature fish in the recreational harvest, and percent of year classes returning to the Swan Creek weir. Primary changes included using data on the percent return of a year class to the Swan Creek weir, and estimation of survival to age-1. Although the model was not changed in a fundamental way, these changes made large changes in estimated population size and fishing mortality. The model now estimates a substantially lower population size and much higher fishing intensity (sometimes approaching removal of half the fish of fully vulnerable ages). The change stems from the fact that population size is now required to be consistent with absolute numbers returning to the weir, which are far less than the model had been predicting would survive to maturity.

We developed a new population model for burbot. Previously we had only estimated total numbers of burbot based upon ratios of burbot to lake trout in assessment and fishery catches and the estimated abundance of lake trout from models. We refined these estimates and still use them to calibrate our model. The model, however, is needed to describe how we believe burbot populations will respond as sea lamprey mortality rates change over time, and this requires explicit description of recruitment and mortality. This model starts in 1983 and assumes a constant recruitment level. This recruitment level was calibrated so that the model correctly predicted the same population size (ages 1+) as we estimated for 1997 based on sampled ratios of burbot to lake trout (above). We explicitly included mortality components for sea lamprey, other natural mortality, and fishing. Fishing mortality was assumed to occur at a background instantaneous annual rate of 0.05 on fully selected ages from by-catch. Other natural mortality was set equal to rates estimated for lake trout. Sea lamprey induced mortality rates were

assumed to vary in proportion to projected changes in sea lamprey abundance, as was the case for lake trout. Baseline values for sea lamprey induced mortality older fish were set by subtracting natural and fishing mortality from a catch curve-based estimate of total mortality provided by BRD. Age-specific vulnerability to sea lamprey was calculated based on the assumption that it would be the same as for lake trout of the same size. Fishery selectivity was assumed to increase with increasing burbot age, and the pattern was based on estimates of selectivity for lake trout of similar size.

As noted above, consumption was based upon a gross production approach, taking into account estimates of growth, mortality and gross conversion efficiency. Estimates of gross conversion efficiency were taken from the literature. Growth estimates were based upon combinations of survey and fishery mean weight-at-age from data provided by our cooperators. Mortality was provided or estimated within the population models described above. Total consumption was allocated among forage species based upon a summarization of diet data from all available sources, largely unpublished data held by our cooperators.

Overall, our results suggest that total consumption may be near or above system productive capacity. Current estimates of consumption are above estimates of historical consumption by lake trout and are large relative to admittedly crude estimates of forage abundance provided by BRD. Model projections, however, indicate that large reductions in stocking would be required to substantially reduce predator demand for prey, due to major contributions of native self-sustaining predators and naturalized populations. Surprisingly, our preliminary results also indicate that the large reduction in sea lamprey populations that are projected to result from treatment of the St. Mary's River have only modest impact on the overall consumption. This seems to be because the model's assume the major impact of sea lamprey are on burbot and on the northern main basin stock of lake trout. Combined, these two groups contribute a relatively small portion of the total consumption. Movement of lake trout stocking to the north actually decreases consumption because these fish are being moved to an area where growth is slower and overall mortality is higher than where they are stocked now, even during the projection period.

These estimates of consumption could be improved through further work on predator models (e.g., better estimates of natural reproduction by chinook salmon or a more refined walleye model for Saginaw Bay that makes use of age composition information and better information regarding immigrants), and through application of bioenergetics models to better estimate gross conversion efficiency. To this latter end, samples of major prey and predator species have been analyzed for energy density and resulting data will be used in bioenergetics models. To date we have processed 624 samples (96 chinook salmon, 61 burbot, 151 lake trout, 38 walleye, 171 alewife, 30 bloater, 73 rainbow smelt, and 4 sticklebacks) to determine the ratio of dry to wet weight (a good predictor of energy density), and expect to process an additional 125 samples. We have done bomb calorimetry on a total of 180 samples (49 chinook salmon, 25 burbot, 23 lake trout, 25 walleye, 26 alewife, 6 bloaters, 3 sticklebacks, 23 rainbow smelt) to calibrate the relationship between energy density and dry/wet weight ratios, and expect to process an additional 25 samples. Preliminary results suggest relatively low energy density for chinook salmon in Lake Huron. Combined with recent evidence of low growth rates for this species, this is an additional reason to be cautious about current levels of predator demand.

As described above (Job 3) we also developed a lakewide chinook model for Lake Michigan. We worked with Ed Rutherford (UM) (stemming from work completed in Study 650 in 1997) and others to help develop population models for all salmonine predators on Lake Michigan.

We initiated work to update the existing SIMPLE model (Jones et al. 1993) that links predators and prey fish on Lake Michigan, together with Drs. William W. Taylor, Mike Jones, and Mary Bremigan at MSU. Our work on this project has just started, with the recent hiring of a programmer for this project. It is already clear, however, that the existing computer code will need extensive revisions to account for advances in the language it is programmed in (Visual BASIC) and to correct problems that were introduced when it was originally imported into Visual BASIC (apparently it was based on the Lake Ontario version and not all changes for Lake Michigan were implemented).

Job 6. Title: Expand research into other areas.

Findings: Research was expanded through funding obtained from other agencies. Additional support for research efforts was obtained from the Great Lakes Fishery Commission (GLFC) and Michigan Sea Grant to support research on salmonine stock assessment and modeling in the Great Lakes. Sea Grant funding supported graduate students who participated in modeling and data analysis of predator and forage fish in Lake Michigan. Details on this work are described in other Jobs. GLFC funding is supporting work by a Ph.D. student (Mike Rutter) on sea lamprey-lake trout interactions (see Job 8). GLFC funding has been supporting work on predator modeling on Lake Huron (see Job 4). GLFC funding has also provided funding for a project to update the SIMPLE model developed to describe predator-forage fish interactions on Lake Michigan.

Oversight was provided on Project 489. Dale Hall Post doc, Angela Mertig and Ben Peyton co-PI's.

Basic research on methods for analyzing spatial and temporal data was refined, written up and submitted for publication as an Ecological Monograph (Stewart-Oaten and Bence, pending revisions).

Job 7. Title: Publish results and prepare annual reports.

Findings: This annual report was prepared.

Four manuscripts were submitted for publication.

Lockwood, R.N., D.M. Benjamin, and J.R. Bence. (in review). Estimating angling effort and catch from Michigan roving and access site angler survey data. Michigan Department of Natural Resources, Fisheries Division, Fisheries Research Report.

Sitar, S.P., J.R. Bence, J. Johnson, M.Ebener and W.W. Taylor. Accepted pending revision. Population dynamics and estimated mortality of lake trout in southern Lake Huron 1983-1993. North American Journal of Fishery Management.

Stewart-Oaten, A., and J.R. Bence. Accepted pending revision. Temporal and spatial variation in environmental assessment. Ecological Monographs.

Ward, C., R.L. Eshenroder, and J.R. Bence. Submitted. Relative Abundance of lake trout and burbot in the main basin of Lake Michigan in the early 1930s. Transactions of the American Fishery Society.

Two MS theses were completed:

Weeks, C.T. 1997. Dynamics of lake trout (*Salvelinus namaycush*) size and age structure in Michigan waters of Lake Superior, 1971-1995. A thesis submitted to Michigan State University in partial fulfillment of the requirements for the degree of Master of Science.

Benjamin, D.M.. 1998. Chinook Salmon (*Oncorhynchus tshawytscha*) population dynamics in Lake Michigan, 1985-1996. A thesis submitted to Michigan State University in partial fulfillment of the requirements for the degree of Master of Science.

Ongoing work was discussed and presented at Lake Huron and Lake Michigan Technical Committee meetings (during July 1997 and January 1998) and at the Lake Michigan and Lake Huron Committee meetings (during March 1998).

Results were presented in three presented papers at Midwest Fish and Wildlife Conference (December 1997)

Rutter, M.A. and J.R. Bence. Modeling sea lamprey wounding rates as a function of lake trout length. 59th Midwest Fish and Wildlife Conference, Milwaukee, Wisconsin, December 7-10, 1997.

Krause, A.E., D.B. Hayes, and J.R. Bence.. Estimating forage fish abundance in Lake Michigan. 59th Midwest Fish and Wildlife Conference, Milwaukee, Wisconsin, December 7-10, 1997.

Benjamin, D.M. and J.R. Bence. Chinook population dynamics in Lake Michigan. 59th Midwest Fish and Wildlife Conference, Milwaukee, Wisconsin, December 7-10, 1997.

Job 8. Title: Lake trout model development.

Findings: We completed a number of refinements to a lake trout model for the MI-4 area of Lake Superior. This constituted the MS thesis for Chris Weeks and revisions to prepare this work for publication. Our main changes during the past year were (1) to refine the growth model, (2) revise survey indices of abundance and associated uncertainty, and (3) make several changes to assumptions to account for patterns in model residuals. The growth model had allowed changes in growth by allowing the Bertalanffy parameter of L-infinity to change from year to year. We modified this to link L-infinity and k (of the Bertalanffy growth curve) and allow both parameters to vary over time. The result was a somewhat better fit to the pattern of observed length-at-age. One interesting result is that the model's estimate of population mean length at age agreed better with the observed survey mean length at age than did the model's predictions of observed survey mean length at age. This was particularly true for younger lake trout. One of the primary causes for differences between model values for population and observed mean length at age was the assumed aging error matrices. This suggests that either aging error is less than assumed (based upon aging error data), or that length is used as a cue to alter ages by age readers.

We explored further the design under which lake trout survey data were collected and this suggested that the nature of sample collection, where several gill net sets were collected at each site in a given year, could introduce "cluster" effects. We reanalyzed data using a Mixed model ANOVA that included site and year effects and site by year effects as a random factor. The

random site by year effects were highly significant, and accounting for this variation increased estimated standard errors for year specific indices by about four fold. These new results were used in refitting the model to better acknowledge the relative information of the survey indices and other data sources.

A final set of changes was adopted to address lack of fit as evidenced by patterns in age composition residuals. One pattern was a very pronounced shift in commercial fishery age compositions to include more young (age-5) fish starting in the late 1980s. This same pattern was not seen in survey data and was not matched by the model. This issue was addressed by implementing two time periods (before 1989 and 1989 and later) for commercial fishery selectivity. There was also a general tendency to underestimate the proportion of age-8 fish observed. We attempted to address this problem by refining the matrix used to translate actual ages to coded (observed) ages by the model. Previously we had related mean observed (based on scales or otoliths) age to “true” age (based on fin clips) and assumed that the mean observed age for a given true age (except for older ages with small sample sizes) applied. We now use the mean established from a regression of observed on true age to smooth irregularities caused by small sample sizes. This only provided very modest improvement in residual patterns. We currently suspect that this is a problem reflecting a tendency to over classify fish to age-8 by readers that is not reflected in our aging error matrix (perhaps simply “digit” bias) rather than a problem with the model’s structure. An alternative that does not seem likely is that readers are much better at assigning fish to age-8 (but not other ages) than is assumed. In spite of the numerous changes in the lake trout model, the final results in terms of estimated fishing mortality rates have not changed much. Total mortality rates are still estimated to be about 45% on age-7 lake trout in the mid-1990s. Our previous stock-recruitment analysis and yield calculations suggested that if fishing mortality were 25% less than mid-1990s levels, spawning stock would eventually increase substantially and long-term yields would approach maximum sustainable levels. We suspect this result still holds, but need to repeat this analysis.

In work associated with Job 4, data were added to Lake Huron lake trout models originally developed as part of Shawn Sitar’s MS thesis for short-term updates in projections.

During the past year we have worked to refine the Lake Huron and Lake Superior lake trout models by integrating a sea lamprey functional response into the lake trout models and refining the lake trout models. Most of our work so far has been on Lake Huron. To date we have compiled lake trout data and model estimates of abundance, estimates of sea lamprey abundance, and information on alternative prey for sea lamprey and lake bathymetry. We have evaluated the relationship between sea lamprey marking rates on lake trout from spring survey data and lake trout size. To this end we have applied a novel generalized linear modeling approach to fit a function relating expected wounding and lake trout size using data from individual lake trout. This approach has allowed us to synthesize large databases on marking in the form of year and area specific asymptotic (with lake trout size) wounding rates. Two substantial advantage of this approach are that it allows estimates of marking and mortality even when not all size classes are present, and it avoids biases associated with changes in the relative numbers of fish of different sizes within the relatively large size classes used in previous summarizations of wounding rates. We have already used these results in our updates to lake trout models and the burbot model described in Job 4. In addition, these results are now being used by the St. Mary’s River Assessment Task force to evaluate baseline marking and variability to help determine ability to detect changes resulting from treatment of the St. Mary’s River to control sea lamprey. We are now exploring relationships between observed sea lamprey marking on lake trout and current estimates of lake trout and sea lamprey abundance in the framework of a functional response. We are also working on computer programs to incorporate a functional response directly into the

lake trout assessment models. On Lake Superior we are working collaboratively with Shawn Sitar (new Study 495) in this regard.

Literature Cited:

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- Sitar, S. P. 1996. Estimation of lake trout (*Salvelinus namaycush*) abundance and mortality due to sea lampreys (*Petromyzon marinus*) and fishing in the main basin of Lake Huron 1984-93. Michigan Department of Natural Resources, Fisheries Research Report 2030. Ann Arbor, MI.

Prepared by: James Bence
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