STUDY PERFORMANCE REPORT

State: Michigan

Project No.: F-53-R-15

Study No.: 480

Title: Development of Decision Models for the Great Lakes' fisheries

Period Covered: April 1, 1998 - September 30, 1999

Study Objective: 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 continued extensive work in data summarization and data standards. We participated in assembling lakewide information on recreational harvest on Lake Michigan. We continued to provide assistance in implementing new recommended methods of analysis to the Michigan Great Lakes creel survey. Documentation of the methods of analysis has been published. We continued 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 began efforts to update analysis of a 37 year time series of trawl data on forage fish abundance in Lake Michigan, to include the most recent years, which overlap in time with hydroacoustic estimates of forage fish abundance. We also refined earlier analyses of these data in preparation for publication. These data are central to our efforts for refining fish community models for Lake Michigan. We expanded our analysis of survey indices of lake trout abundance for Lake Superior to encompass all of Michigan waters and applied similar methods to Lake Huron. We also worked closely with other researchers to compile all data needed to calibrate stock assessment models for lake trout and whitefish for large portions of Michigan's waters of lakes Michigan, Huron, and Superior. We also refined our summaries of harvest, diets, and growth for use in modeling predators in Lake Huron. We have also continued to compile information on sea lamprey abundance, and sea lamprey wounding of lake trout and alternative prey for our work modeling the sea lamprey–lake trout interaction.

We ported our lakewide model for chinook salmon into a software tool (AD model builder) to allow more rapid estimation of parameters and facilitate implementation of a Bayesian approach to characterizing uncertainty. Our analyses of the chinook stock assessment model in this environment are consistent with earlier model fits, and further analysis is planned as the basis for a journal publication.

We continued to refine existing predator population models for the main basin of Lake Huron and use these in combination with a gross production approach to estimate predator consumption of forage fish. Our results continued to suggest that total consumption may be near or above productive capacity of the system.

We have also worked on tropho-dynamic modeling on Lake Michigan. In this area we have worked with the existing SIMPLE fish community model. We ported this model to a more recent version of Visual Basic, updated data inputs and fixed a few problems with the existing model implementation. We held two workshops in association with the Lake Michigan Technical

Committee. Currently the model is not capable of reproducing the historical dynamics of the fish community. At least some of the problems stem from incorrect parameter estimates, which can be adjusted or updated. This work with the existing SIMPLE model forms a backdrop for our more extensive work in attempting to fit a fish community model to existing predator and forage fish data in Lake Michigan. This modeling is in its early stages.

We have continued to work on building improved lake trout stock assessment models and on quantitative methods for summarizing data used by these models. We developed a prototype lake trout stock assessment model derived from our earlier stock assessment models, incorporating new refinements and ported to the AD Model Builder environment. We are now working with other researchers and biologists to apply these models to lake trout stocks throughout Michigan's water of the Great Lakes. Similar modeling work is underway with lake whitefish. We have also developed a version of lake trout models for Lake Huron that integrates a sea lamprey functional response. A side benefit of this project is that the novel generalized linear modeling approach we developed for summarizing wounding rates by sea lamprey on hosts has been useful in all the lake trout stock assessment work.

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, exploring the possibility of incorporating sea lamprey predation (functional response) models into our lake trout stock assessment models, and evaluating different quantitative stock assessment methods. We have expanded the scope of our Lake Michigan work through involvement with the SIMPLE model. 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 play a role in developing a lakewide recreational fishery database for Lake Michigan. Estimates for 1995 through 1997 were recalculated (updated with refined methods) and an estimate was generated for 1999 in a lakewide format established by the task group established by the Lake Michigan Committee. Results were provided to the Lake Michigan Technical Committee. We have also worked extensively toward implementing and error checking new methods for estimating harvest and effort (see Project 489, Study Performance Report for more detail).

We analyzed updated information from Biological Resources Division (BRD) of USGS, Michigan DNR, Chippewa Ottawa Treaty Management Authority (COTFMA), and Ontario Ministry of Natural Resources (OMNR) on harvest, age composition, and diets for the major piscivores in Lake Huron for work estimating consumption rates of forage fish (see Job 4 and Project 689, Study Performance Report).

We further reviewed the design of Lake Superior and Lake Huron lake trout assessments that provided data used in modeling work. We extended our reanalysis of data taking into account "random" site by year effects to most of Michigan's waters of Lakes Huron and Superior. This work forms an important basis for quantitative assessment of lake trout stocks. Results indicated that there are typically significant "random" site by year effects. Simulations demonstrated the need to account for these in estimates of variances for survey indices (see also Job 8).

We have begun extending our earlier work (with the Great Lakes Science Center (BRD, USGS)) on forage fish survey data for Lake Michigan to provide age-specific indices of abundance after

1994. This work is based on analysis of a 37 year time-series of trawl survey data and is being done collaboratively with BRD. It is critical to extend these analyses to the most recent years when hydroacoustic data on forage fish are also available. The result of our previous work 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. Our methods adjust for changes in survey design, extract more information from the data, and account for multiple sources of uncertainty. To date we have obtained and organized the trawl survey data, and revised SAS programs in preparation for the extended analysis. We are also working on two manuscripts based on our earlier work on these data in preparation for journal publication. These data form a critical basis for our work on fish community modeling on Lake Michigan.

We have worked with other investigators to bring together much of the needed data/information for age structured stock assessments of lake trout and lake whitefish in much of Michigan's waters of the Great Lakes. These data include harvest and harvest age composition, fishing effort, survey or assessment fishery indices of abundance (and survey age compositions), life history information, weight and length at age, and sea lamprey wounding statistics and effort. We have also continued to bring together information on sea lamprey abundance as part of our work on modeling the sea lamprey-lake trout interaction. Further detail on some of the work in summarizing data for lake trout and whitefish stock assessments is described under Jobs 6 and 8.

Job 3. Title: Spatial model for chinook salmon.

Findings: We did not further develop a spatial model for chinook salmon in Lake Michigan. We refined some analyses (in preparation for publishing results). These analyses (reported last year) called into question the ultimate value of a detailed spatial model that follows the fishery seasonally, at least given current information availability. A lakewide assessment model that was previously built and calibrated treats chinook salmon as one mixed population. We have ported this model into a software environment (AD Model Builder) that facilitates rapid parameter estimation (allowing a wider variety of variants to be explored) and use of Bayesian approaches for characterizing uncertainty. Details of the basic model are reported by Benjamin (1998) and were summarized in last year's report. This model allows estimation of lakewide changes in natural and fishing mortality over time.

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, and resulting population and fishery dynamics 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.

After porting to AD model builder the most important result remains unchanged. 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.

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

Findings: We continued to refine 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. We presented results to Michigan DNR Lake Huron advisors and results have been used as basis for reductions in chinook salmon stocking. 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). Details of model structure were described in last years report. Refinements have emphasized changes in inputs rather than structural changes. We have adjusted numbers of chinook stocked to account for coded wire tagging returns. We have also adjusted diet information and gross conversion efficiency values (used to convert growth to prey consumption) based on recent analyses. More detail on this work is reported with the Project 689, Study Performance Report.

Overall, our results continue to 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 self-sustaining native and naturalized predator populations.

As described above (Job 3) we also developed a lakewide chinook model for Lake Michigan. Last year we worked with Ed Rutherford (University of Michigan) (stemming from work completed in Project 650 in 1997) and others to help develop population models for all salmonine predators on Lake Michigan. These models (the CONNECT model) were developed within a spreadsheet environment and did not use formal statistical procedures for parameter estimation. We have worked with Ed Rutherford to port the coho salmon model into the AD Model builder environment as a preliminary step toward statistical parameter estimation. We will work with him to port the other predator species (rainbow trout, brown trout, lake trout) into the same environment.

We worked to update the existing SIMPLE model that links predators and prey fish on Lake Michigan, together with Dr. Mike Jones at Michigan State University. We have ported the model to the most recent version of Visual Basic. In this process we have updated data inputs on predator stocking, prey fish dynamics, and harvest of predators. We also reviewed the model code, fixed some problem areas, and improved the user interface. We held two workshops with a task group of the Lake Michigan Technical Committee. The first workshop reintroduced the group to the SIMPLE model and its underlying assumptions. The second explored the fit of the model predictions to available data. Unfortunately, current parameterization of the SIMPLE model cannot recreate historical dynamics of forage fish, the fishery, or predator diets. At least some of these problems may stem from accuracy of input information on prey and predator dynamics. Thus this work on the SIMPLE model ties in closely with other work on forage fish data and on predators. We have initiated a parameter estimation model to estimate the stock recruitment dynamics of key forage fish species, while accounting for mortality due to predator consumption. In effect we are fitting a model of the fish community where predator abundances are a forcing function (estimated externally in separate analyses), and key parameters being estimated determine the stock-recruitment relationship for forage fish and the functional response linking predators to prey. Because this work uses age-specific abundances of forage fish as data to fit the model to and estimates of predator abundance as a “forcing function,” it links tightly with our work on forage fish data summarization and stock assessment modeling for predator populations. Our work with parameterization of the forage fish dynamics is still in its early stages although a very preliminary model has been built in the AD Model builder environment and fit to available data.

We have also developed some simplified models (one predator and one prey) of the piscivore-forage fish interaction with the aim of exploring more general aspects of different stocking strategies when operating within a system where overstocking can lead to fishery collapses. Four levels of increasingly complex models have been developed, extending from a deterministic unstructured model in the form of a differential equation through stochastic age structured models for predator and prey. Working computer simulation model were created in a Mathematica software environment but their behavior has not been explored yet.

Job 6. Title: Expand research into other areas.

Findings: Research was expanded through funding obtained from other agencies and by partnership with other Projects. Additional support 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 and GLFC supported graduate students and staff who participated in modeling and data analysis of predator and forage fish in Lake Michigan. Currently a Ph.D. student (Emily Smith) is working in this area. Details on this work are described in other Jobs. GLFC funding has supported work by a Ph.D. student (Mike Rutter) on sea lamprey-lake trout interactions (see Job 8). GLFC funding supported the initial work on predator modeling on Lake Huron (see Job 4), which has now been continued as Project 689 through the work of a Ph.D. student (Norine Dobiesz), and oversight is being provided on this project. Oversight was provided on Project 489 for evaluating the use of mail surveys to estimate recreational harvest and effort. Support has been provided by the GLFC to sponsor workshops on improving quantitative stock assessments in the Great Lakes.

Basic research on methods for analyzing spatial and temporal data was further refined in preparation for resubmission as an Ecological Monograph (Stewart-Oaten and Bence).

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

Findings: This annual report was prepared.

Three manuscripts were accepted for publication.

Lockwood, R.N., D.M. Benjamin, and J.R. Bence. 1999. 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.E. Johnson, M.P. Ebener, and W.W. Taylor. 1999. Lake trout mortality and abundance in Southern Lake Huron. North American Journal of Fisheries Management 19:881-900.

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

Ongoing work was discussed and presented as part of workshops at Lake Michigan and Lake Superior Technical Committee meetings:

- Co-ran workshop with Mike Jones on transfer updating and use of SIMPLE model (fish community model) for Lake Michigan (Jan. 14 1999).
- Participated in workshop on lake trout population modeling for Lake Superior. Made presentations on past and ongoing approaches (Jan 11-12 1999).

Results were presented through seven platform presentations at scientific meetings or seminars:

Bence, J.R., C. Bronte, M. Ebener, G. Fleischer, M. Hansen, M. Holey, J. Jonas, J. Peck, S. Sitar, and A. Woldt. Collapse and Partial Recovery of Lake Trout in the Upper Great Lakes: Success, Failure and Uncertainty. American Fisheries Society Annual Meeting, August 30, 1999.

Rutter, M.A., and J.R. Bence. Incorporating a sea lamprey/lake trout functional response model into a lake trout population model for the upper Great Lakes. American Fisheries Society Annual Meeting, August 31, 1999.

Bence, J.R. A comparison of fishery and environmental assessments. Invited Seminar. Department of Fisheries and Wildlife GSO. March 4, 1999.

Weeks, C.T., and J.R. Bence. Estimation of Growth, Mortality, and Abundance of Wild Lake Trout in Michigan Waters of Lake Superior, 1971-1995. American Fisheries Society Annual Meeting, August 25, 1998.

Bence, J.R., A.E. Krause, M.A. Rutter, and C.T. Weeks. Sampling designs uncertainty and implications for fishery management. International Association for Great Lakes Research. May 18-22, 1998.

Krause, A.E., D.B. Hayes, J.R. Bence, and C. Madenjian. Uncertainty in Lake Michigan alewife and bloater population abundance indices and mortality rates. International Association for Great Lakes Research. May 18-22, 1998.

Rutter, M.A., and J.R. Bence. Estimating uncertainty in a sea lamprey wounding model. International Association for Great Lakes Research. May 18-22, 1998.

Job 8. Title: Lake trout model development.

Findings: During the performance period, lake trout stock assessment model development (and stock assessment modeling in general) has moved forward on three fronts. First–provision of training workshops in modern stock assessment methods, general advice and specific supporting analyses, and development of prototype models has greatly facilitated implementation of statistical catch-age models for lake trout in waters subject to the 1836 treaty consent decree within Michigan waters of the Great Lakes. Prototype stock assessment models were developed for hatchery-derived populations and for self-sustaining populations. A number of significant advances and modifications were implemented. Modeling has all been ported to the AD Model builder environment. Since derivatives used in numerical fitting of models are calculated automatically using a reverse chain rule algorithm and template code is compiled as C++ programs, the resulting speed of parameter estimation has been increase several orders of magnitude and the robustness of estimation has at the same time been increased. In addition, some key features of the complex model developed for the MI4 stock have been retained within much simpler and less parameter-rich formulation. Specific changes include making the model solely age-based and not including a growth model. A key feature of the growth model was retained, namely age-specific vulnerability (selectivity) to fishing and sampling gear is still able to change over time. This was done by modeling selectivity as a four-parameter double logistic function of allow a key parameter of the function to vary following a polynomial in time. The basic prototype model for self-sustaining populations has also been applied to lake whitefish.

Support in data analysis included estimation of indices of abundance from lake trout survey data through much of the treaty waters by using mixed models. These statistical models account for systematic spatial effects and correlations among nearby observations (represented by random location by year interactions). Analyses revealed that both systematic spatial effects and correlations exist. Simulations were used to generate data with similar characteristics and simulation experiments demonstrated that ignoring the systematic effects and correlations caused substantial errors in inference that did not occur when the mixed models were applied. However, using mixed models in the absence of these complications had little impact on inferences or efficiency. Additional supporting analyses were done to summarize sea lamprey wounds (see below).

Education and training was done in the form of a series of workshops. This included a stock assessment meeting for 1836 treaty waters (August 19-20, 1999), a meeting on stock assessment methods for state, federal and tribal representatives involved in 1836 treaty waters fishery management (April 14, 1999), a workshop on quantitative fishery stock assessment methods for Michigan DNR and Tribal Biologists involved in assessments in 1836 Treaty Ceded waters (December 29, 1998), and a presentation on methods to the same group (November 24, 1998).

Second–a fundamental shift in the philosophy of modeling has occurred, with a shift to a state-space approach and characterization of uncertainty through Bayesian posterior distributions. Adoption of the state-space approach allowed the inclusion of process error. One example was to allow the effective number of lake trout stocked to vary about the actual number stocked to account for varying success of plants. Another was to model recruitment as expected recruitment about a stock-recruit relationship plus a process error. Most stock assessment assumes that natural mortality is known. We have explored the effect of this assumption through a series of refinements to the lake trout model we developed earlier for southern Lake Huron. We began with a model that assumed that both background natural mortality and sea lamprey mortality was known and that recruitment followed exactly the numbers of yearling lake trout stocked. We then recognized that there was uncertainty in background natural mortality. A log normal prior distribution for natural mortality has been derived with median predicted by life history parameters and the variance parameter determined by residual variability about the relationship for a set of lake trout estimates of natural mortality. After adding uncertainty in background natural mortality we next added process error in success of planted lake trout and finally uncertainty in sea lamprey mortality by specifying a prior for that factor. The results demonstrated that admitting uncertainty in natural mortality greatly increased the spread of the posterior distribution for estimates and sometimes shifted their modes. Process error in success of planted lake trout had little influence on the results. The overall lesson is that inclusion of an honest appraisal of uncertainty in the stock assessments is important.

The final area of lake trout stock assessment modeling has been an attempt to integrate a sea lamprey functional response into the lake trout models. We have further refined our methods for summarizing wounding information to support this modeling. We have applied a novel generalized linear modeling approach to fit a logistic 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 that it avoids biases associated with changes in relative numbers of fish of different sizes within the relatively large size classes used in previous summarizations of wounding rates. Recent refinements have included incorporation of random spatial-temporal interactions and allowing shape parameters of the logistic function to vary spatially and temporally. We have incorporated a sea lamprey functional response into a combined model for lake trout in northern and southern main basin Lake Huron. Initial efforts to fit this model using the results of the wounding analyses, lake trout harvest and assessment data, and information on sea lamprey abundance were reported at the August 1999 American Fisheries Society meeting.

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