Designing a Decision Support System for Harvest Management of Great Lakes Lake Whitefish in a Changing Climate

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This project was funded by the Great Lakes Integrated Sciences + Assessments Center through a 2011 Great Lakes Climate Assessment Grant.

Recommended Citation:


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Project Objectives

The goal of this project was to design a decision support system for sustainable harvest management of Lake Whitefish in the upper Laurentian Great Lakes in a changing climate. Upon completion, this project will synthesize the current state of lake whitefish ecological knowledge and provide an opportunity to assist decision makers allied with the fisheries to adaptively respond to climate change processes in the Great Lakes region (Figure 1). Our research that was funded by GLISA emphasized the development of a quantitative fishery model which will serve as the foundation for decision support tool. The full project objectives were to:

- Develop a lake whitefish production model, including influential climatic factors;
- Engage scientists, managers, and fishermen to assess decision-support needs and ensure the climate-lake whitefish production model is relevant to their management needs; and,
- Design an interactive, user-friendly interface to display the outcomes of the climate-lake whitefish production modeling outcomes.

Importance of lake whitefish

Lake whitefish (Coregonus clupeaformis) are an economically, culturally, and ecologically important species in the upper Laurentian Great Lakes (Lakes Huron, Michigan, and Superior). Ecologically, lake whitefish are primarily a benthivores and serve as a key energy transfer vector from lower, benthic food webs to the upper, pelagic food webs (Nalepa, Mohr et al. 2005), and are an important food source for humans. They are and have been a staple food source and focus of livelihoods for aboriginal people in the region (Cleland 1982). Today, populations of lake whitefish support the most robust and economically valuable commercial fishery in the upper Laurentian Great Lakes (Lakes Huron, Michigan, and Superior; annual catch value = US$1.66 million; Mohr and Ebener 2005; Madenjian, O’Connor et al. 2006; Ebener, Kinnunen et al. 2008).

Lake whitefish recruitment

Stock-recruitment relationships estimates are inherently stochastic but much of that variability can be attributed to variation in spawning stock size and environmental influences on growth and survival of young fish (Quinn and Deriso 1999). However, one of the most difficult problems in fisheries science is determining the influence of the environment upon recruitment (Myers 2001). For lake whitefish, both stock size and environmental factors have been shown to influence recruitment (Taylor, Smale et al. 1987). In particular, previous studies of Great Lakes lake whitefish indicate that key environmental drivers that will be impacted by climate change, water temperature, ice cover, and storm intensity, affect recruitment (Christie 1963; Lawler 1965; Taylor, Smale et al. 1987; Freeberg, Taylor et al. 1990).

Potential impacts of climate change

Climate change is expected to increase surface temperatures of the Great Lakes by as much as 6°C (Trumpickas, Shuter et al. 2009) while average wind speed is expected to decline (Sousounis and Grover 2002), and ice

![Figure 1. Conceptual model of the design of a decision support system for Great Lakes Lake Whitefish harvest management strategies in a changing climate.](image-url)
cover is expected to be substantially reduced (Assel, Cronk et al. 2003). In their current habitat space, increased water temperature, increased wind speed, and decreased ice cover are projected to inhibit the success of recruitment to the lake whitefish fishery (Lynch, Taylor et al. 2010). However, the warming trends associated with predicted climate change could increase suitable thermal habitat volume for lake whitefish (Magnuson, Webster et al. 1997) because the species will be able to shift northwards in the lake system as well as live deeper in the water column to maintain access to optimal thermal habitats (Regier and Meisner 1990).

Modeling climate relationships with lake whitefish recruitment in the 1836 Treaty waters

The 1836 Treaty waters are regions of Lakes Huron, Michigan, and Superior that were ceded from the local tribes to the United States. The tribes, however, did not relinquish their right to fish in the ceded waters. In 1979, United States v. State of Michigan (Fox Decision) reaffirmed the rights of the tribes for commercial fishing of lake whitefish and other species. To ensure that the fishery is managed and regulated cooperatively, the 2000 Consent Decree established guidelines for management of this fishery under the purview of the Chippewa Ottawa Resource Authority (CORA) and the Michigan Department of Natural Resources when the management units are shared. Currently, a Technical Fisheries Committee and a Modeling Subcommittee conduct stock assessments, establish total allowable catches, and designate harvest regulations for the 14 lake whitefish management units in these waters. The harvest from the 1836 Treaty waters management units comprise approximately a quarter of the total harvest of lake whitefish in the entire Great Lakes (M. Ebener, CORA, personal communication). For lake whitefish in the 1836 Treaty waters, harvest objectives have not yet been formalized but the co-managers (the State of Michigan and the Chippewa-Ottawa tribes) desire high yields, low interannual variability in yield, and avoidance of low stock sizes (Deroba and Bence 2012). To achieve these goals, the Modeling subcommittee uses statistical catch-at-age models to estimate lake whitefish population metrics, including recruitment (Deroba and Bence 2009) in order to optimally regulate harvest rates.

Modeling methods

We chose the 1836 Treaty Waters of Lakes Huron, Michigan, and Superior as our study area because they have a latitudinal gradient, comprise approximately a quarter of the total lake whitefish harvest in the entire Great Lakes (M. Ebener, personal communication), and have established statistical catch-at-age models to determine total allowable catches which are used to designate harvest regulations for 13 management units (Figure 2). We used the spawning stock biomass and recruitment estimates from 1976-2011 to integrate 5 climate variables into a Ricker stock-recruitment model because lake whitefish recruitment is density dependent (Taylor, Smale et al. 1987). The Ricker model was transformed to a linear function by taking the natural log:

\[
\ln \frac{R_i}{S_i} = \ln \alpha_i - \beta_1 S_i + \epsilon_i
\]

For a given yearclass, i, \( R_i \) is recruitment, \( S_i \) is spawning stock, \( \alpha_i \) is the productivity parameter, \( \beta_1 \) is the density dependent shape parameter, and \( \epsilon_i \) is normally distributed random error. We developed 25 climate variable combination models, with the full model including three climate variables:

\[
\ln \frac{R_i}{S_i} = \alpha_i + \beta_1 S_i + \beta_2 \text{ice}_i + \gamma_1 \text{fall}_i + \gamma_2 \text{spring}_i + \epsilon_i
\]

Where:

- \( \text{ice}_i \) is the proportion of mid-December ice cover over spawning habitat for a given management unit and \( \beta_1 \) is its density dependent shape parameter,
variability in lake whitefish recruitment beyond cover and stock size. Temperature (models indicated that climate variables improved model fit between the sufficient to complete model comparison. In three other units, the standard stock-recruitment model was the best model fit. In the remaining seven units, AIC comparisons between the standard stock-recruitment model and the models indicated that climate variables improved model fit (Table 1). These results indicate that seasonal temperature, ice cover, and the interaction between ice cover and stock size improve the ability of the stock-recruitment model to represent recruitment data and that these variables are able to explain a proportion of the variability in lake whitefish recruitment beyond what is explained by stock size alone.

Results to date

In three of the 13 management units, data were not sufficient to complete model comparison. In three other units, the standard stock-recruitment model was the best model fit. In the remaining seven units, AIC comparisons between the standard stock-recruitment model and the models indicated that climate variables improved model fit (Table 1). These results indicate that seasonal temperature, ice cover, and the interaction between ice cover and stock size improve the ability of the stock-recruitment model to represent recruitment data and that these variables are able to explain a proportion of the variability in lake whitefish recruitment beyond what is explained by stock size alone.

### Management unit

<table>
<thead>
<tr>
<th>Management unit</th>
<th>Selected model</th>
</tr>
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<tbody>
<tr>
<td>WFM_05</td>
<td>S</td>
</tr>
<tr>
<td>WFM_01</td>
<td>S + ice + fall + S:ice</td>
</tr>
<tr>
<td>WFM_02</td>
<td>Spring</td>
</tr>
<tr>
<td>WFM_03</td>
<td>Data insufficient</td>
</tr>
<tr>
<td>WFM_04</td>
<td>S</td>
</tr>
<tr>
<td>WFM_05</td>
<td>S + ice + S:ice</td>
</tr>
<tr>
<td>WFM_06</td>
<td>Fall</td>
</tr>
<tr>
<td>WFM_08</td>
<td>Data insufficient</td>
</tr>
<tr>
<td>WFS_04</td>
<td>Data insufficient</td>
</tr>
<tr>
<td>WFS_05</td>
<td>S + ice + spring + S:ice</td>
</tr>
<tr>
<td>WFS_07</td>
<td>S + ice</td>
</tr>
<tr>
<td>WFS_08</td>
<td>S</td>
</tr>
</tbody>
</table>

Table 1. The management units and model selected through Akaike’s Information Criterion (AIC) comparisons. S = stock size; ice = the proportion of mid-December ice cover over spawning; fall = the mean fall (October – December) air temperature for land-based stations within 5 miles; spring = the mean spring (March - May) air temperature for land-based stations within 5 miles; and S:ice = the interaction between stock and ice cover.

Modeling implications

Our findings show that seasonal temperatures and ice cover improves stock-recruitment model fit and suggest that fall temperatures and ice cover are important for egg development, spring temperatures are important for larval survival, and all three are important for determining year-class strength of lake whitefish in the 1836 Treaty Waters. Great Lakes lake whitefish stocks are characterized by spatial and temporal variation (Deroba and Bence 2012) and previous site-based correlational studies have also indicated indicate seasonal temperature and ice cover influences recruitment (Christie 1963; Lawler 1965; Taylor, Smale et al. 1987; Freeberg, Taylor et al. 1990; Brown, Taylor et al. 1993). Christie (1963) found that cold autumn temperatures and warm spring temperatures correlated to strong year-classes in Lake Ontario and the reverse combination produced weak year-classes. Lawler (1965) found a similar correlation in Lake Erie and attributed the relationship to optimal spawning temperature, incubation, and development. Freeberg et al. (1990) proposed a different mechanism for correlations with spring temperatures for Lake Michigan, that temperature influences the timing and production of copepod zooplankton, prey for larval lake whitefish.

The relationship between seasonal temperatures, ice cover, and lake whitefish recruitment have significant implications for the fishery in the context of climate change. Climate change is expected to increase surface temperatures of the Great Lakes by as much as $6^\circ C$ (Trumpickas, Shutler et al. 2009). The positive relationship between spring temperatures and recruitment with climate change suggests the potential for increased lake whitefish production in the Great Lakes, if habitat is not limiting and sufficient food resources are available when the larvae hatch. However, the negative relationship between fall temperatures, ice cover, and recruitment may inhibit egg survival and, consequently, lake whitefish production. Future research will investigate the impact of water temperature and storm intensity on recruitment and use the full suite of climate variable to project our model analysis using potential climate scenarios.

Decision-maker engagement

In presenting our climate-lake whitefish production model to state, tribal, provincial, and federal managers, fishery scientists, and tribal fishermen, we are soliciting their input through in-person and online surveys on how they would recommend that this model be best integrated into a decision-support tool that could be used to inform adaptive
Anticipated outcomes

This decision-support tool developed will:

- Provide assistance for sustainable management to lake whitefish managers including: the 1836 Treaty Waters Technical Fisheries Committee, the Michigan Department of Natural Resources, and the Chippewa-Ottawa Resource Authority and other management agencies by example;
- Communicate the potential impacts of climate change on the ecology and management of Great Lakes fisheries and coastal communities to fishermen, managers, students, and the public;
- Serve as an example regional climate change case-study for Michigan Sea Grant Extension Educators, the Great Lakes Integrated Sciences and Assessments Center, and other educational users;
- Inform future proposals for National Oceanic and Atmospheric Administration climate change funding initiatives, including the Great Lakes Integrated Sciences and Assessment;
- Help build prosperous and adaptive coastal Michigan communities by encouraging adaptive strategies; and,
- Support the completion and dissemination of student research (Abigail Lynch’s dissertation).

References


