Introduction

From 2005 through 2010, the United States Geological Survey (USGS), in cooperation with state, provincial, and tribal fisheries agencies, conducted acoustic and midwater trawl surveys to estimate the population density of fall spawning congregations of cisco *Coregonus artedi*. Throughout the rest of this report, I will refer to the results of these surveys as “acoustic density estimates”. Most occurred in Lake Superior in the Black and Thunder Bay region of Ontario, along the coast of Minnesota, and in the Apostle Islands area of Wisconsin (Appendix A). Commercial fishing for cisco was occurring in these same locations and in close proximity to the surveys. Fishers were targeting spawning cisco with small-mesh gill nets. This combination of events presented a rare opportunity to directly estimate the catchability of gill nets by relating catch rates (catch per unit of effort) to a fishery-independent population density estimate from the acoustic-trawl surveys. A good, direct estimate of catchability would be very useful in future management of cisco because it would verify and quantify the extent to which gill net catch rates were related to changes in population sizes.

In addition, acoustic density estimates were made for several other stocks of spawning cisco in Michigan waters of lakes Superior, Huron, and Michigan by Chippewa-Ottawa Resource Authority (CORA) and Michigan Department of Natural Resources (MIDNR). These surveys used experimental gill nets in place of midwater trawls to obtain size and sex composition of the cisco stock. These nets were constructed with a standard range of mesh sizes. As with the commercial fishery, this survey combination provided an opportunity to directly estimate the catchability for these experimental gill nets. A catchability estimate for experimental nets would help biologists assess cisco populations in areas where commercial fisheries are absent.

The purpose of this study was to develop a data set by matching the acoustic density estimates and commercial and experimental gill net lifts as closely as possible in time and space, and then to apply statistical models to attempt to make direct estimates of catchability for gill nets.
Methods

Data Set – Both acoustic density estimates and gill net catches were organized by date and spatial grid (commercial fishing statistical grids, see Appendix A). Acoustic estimates were conducted at nighttime. Gill nets were mostly set one day and lifted the next. So for a given grid, the two were considered a match when the date of an acoustic estimate and the date of the gill net set were the same. This method seems to give the best chance for both gears to be targeting the same group of fish, which is crucial for estimating catchability.

Acoustic density estimates of spawning cisco were provided by Dan Yule of USGS, Ashland, WI. Acoustic density estimates were made by time period (1 to 3 days) and location (commercial statistical grid). Ten acoustic samples in a grid were considered as the minimum sample size for making acoustic density estimates. The estimates were calculated as the number of adult spawning cisco per hectare. These were fish of 250 mm in length or larger. The methods used for making acoustic estimates are described by Yule et al. (2006).

Commercial harvest data were provided by Bill Mattes of GLIFWC, Odanah, WI; Eric Berglund of OMNR, Thunder Bay, ON; Cory Goldsworthy of MNDNR, Duluth, MN; and Peter Stevens of WIDNR, Bayfield, WI. Data were provided on dates and locations (commercial fishing grid) of net sets and lifts, which could be matched to the acoustic density estimates. In addition, information on harvests in weight (catch), lengths of nets (effort), and mesh sizes were provided for each net lift. CPUE was calculated as the catch in kilograms of cisco per 1000 meters of nets lifted.

Experimental gill net data were provided by Mark Ebner of CORA. Data for these net lifts were similar to those of the commercial nets. CPUE was calculated in the same way.

Estimating Catchability – Starting with a simple linear model, progressively more complex nonlinear and general linear mixed models (GLMMs) were constructed and fit to the data. The most suitable model was selected based on goodness of fit and other stock assessment criteria.

In theory, catch per unit of effort (CPUE) for gill nets should be proportional to population density ($N$) in linear fashion, such that:

$$CPUE = qN,$$  \hspace{1cm} (1)

where $q$ is the catchability coefficient. This would be the simplest and most useful relationship between CPUE and $N$, and if it fits the data well, we could use the estimate of $q$ in future gill net assessments. Least squares regression methods were used to fit this Model (1).

When the relationship between CPUE and $N$ is nonlinear, adding another parameter to Model (1) helps describe it, such that:

$$CPUE = qN^\beta,$$  \hspace{1cm} (2a)

where $\beta$ is a shape parameter that makes Model (2a) a power curve. When $\beta=1$, Model (2a) is linear, reducing back to Model (1). When $\beta$≠1 it means that catchability changes with abundance (Figure 1). When $\beta$<1 it means that CPUE is declining slower than $N$, and is called hyperstability (Harley et al. 2001). When $\beta$>1 it means that CPUE is declining faster than $N$, and is called hyperdepletion. To fit this relationship, Model (2a) was made linear by taking the natural log of both sides:
\[
\ln(CPUE) = \ln(q) + \beta \ln(N). \tag{2b}
\]

Then, least squares regression methods were used to fit Model (2b). Obviously, models (2a) and (2b) are the same model in different algebraic form. Henceforth, I will refer to this simply as Model (2).

![Figure 1. – Reproduced from Harley et al. (2001).](image)

General linear mixed models (GLMMs) are linear models that include factors having both fixed and random effects on the dependent variable (McCulloch and Searle 2001; Venables and Dichmont 2004). For example, it is reasonable to assume that population density has a continuous, fixed effect on CPUE, but we might treat a factor such as year as a categorical factor having random effects on CPUE due to variable weather conditions or something else varying yearly. In this case, we are not really interested in what the random year effects are, but in how their random variability might be affecting the relationship between CPUE and density. If we take these random effects into account in the model, we might be able to get a better estimate of the fixed effect parameter relating to catchability. There are many ways to construct GLMMs, but a good one to try with this data set is the following Model (3), which is basically an expansion of Model (2):

\[
\ln(CPUE) = \mu + \alpha + b + c + \text{interactions}, \tag{3}
\]

where \(\mu\) is the theoretical mean of \(\ln(CPUE)\), \(\alpha\) is the fixed effect of acoustic density \((\ln(N))\), \(b\) is a random effect of space (state/province), and \(c\) is a random effect of year. Divisions by state/province provided the best opportunity to estimate a random effect of space with this data. Potential random effects of grid would probably have been a better spatial unit, but this could not
be considered due to insufficient replication within grids. Potential random effects of year were already discussed. All data were collected during fall spawning time, so date of collection was not considered a factor. Model (3) was fitted using the maximum likelihood procedures in SAS (SAS Institute 2003).

For the commercial gill net fisheries, attempts were made to fit models (1) and (2) to each of five separate groups of data – one for each of the 3 fishing areas (ON, MN, and WI), one for the combined data for all jurisdictions, and one for the combined data for all jurisdictions except Ontario. Ontario was excluded in the last group because of a suspected mismatch in the size selectivity of the larger mesh gill nets used, which will be discussed later. Attempts were made to fit model (3) to each of the two combined data groups.

Attempts were made to fit similar models to the experimental gill net data.

**Results**

**Data Set** – Several summaries were made to help characterize the commercial gill net data. Table 1 shows the number of acoustic density estimates and density-lift matches found for the data set by jurisdiction and totals.

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Number of acoustic density estimates (grids with ( n \geq 10 ))</th>
<th>Number of acoustic density – net lift matches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>47</td>
<td>66</td>
</tr>
<tr>
<td>Minnesota</td>
<td>37</td>
<td>42</td>
</tr>
<tr>
<td>Wisconsin - State</td>
<td>31</td>
<td>13</td>
</tr>
<tr>
<td>Wisconsin - Tribes</td>
<td>31</td>
<td>8</td>
</tr>
<tr>
<td>Totals</td>
<td>146</td>
<td>129</td>
</tr>
</tbody>
</table>

The characteristics of commercial gill nets used under the four management authorities were somewhat different. I tried to get an idea about how this might affect their fishing efficiency, and hence catchability, by contrasting some of their characteristics in Table 2. Note that the smallest nets and mesh sizes are used in Minnesota waters and the largest nets and mesh sizes are used in Ontario. This difference in mesh size will prove interesting later.
Table 2. – Comparison of commercial gill net characteristics for four jurisdictions in study. Gill net statistics here are for nets matching the dates and grids of the acoustic density estimates only. Average height (meters) is based on an assumed mesh height of 35 mm for all nets.

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Mean length (meters)</th>
<th>Mean height (meters)</th>
<th>Mean total net size (sq. meters)</th>
<th>Mean height (number of meshes)</th>
<th>Mean total number of meshes per net</th>
<th>Mesh width (mm stretched)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>1,990</td>
<td>3.5</td>
<td>6,965</td>
<td>100</td>
<td>2,407,900</td>
<td>83</td>
</tr>
<tr>
<td>Minnesota</td>
<td>133</td>
<td>3.5</td>
<td>466</td>
<td>100</td>
<td>190,190</td>
<td>68</td>
</tr>
<tr>
<td>Wisconsin - State</td>
<td>1,419</td>
<td>2.1</td>
<td>2,980</td>
<td>60</td>
<td>1,115,334</td>
<td>76</td>
</tr>
<tr>
<td>Wisconsin - Tribes</td>
<td>1,129</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>na</td>
<td>79</td>
</tr>
</tbody>
</table>

I calculated mean and maximum CPUEs for the four jurisdictions to compare and help get an idea of what is happening in each of the commercial fisheries (Table 3).

Table 3. – Comparison of mean commercial gill net CPUE for the four jurisdictions in study. Means include only net lifts that match acoustic density estimates. Harvests are given as kilograms of round weight. Wisconsin Tribal harvests were converted from dressed weights as follows: round weight = dressed weight/0.727. (Note: This formula could be giving low estimates of round weight.)

<table>
<thead>
<tr>
<th>Jurisdiction</th>
<th>Mean CPUE (kgs/1000m)</th>
<th>Maximum CPUE (kgs/1000m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>1.063</td>
<td>4.550</td>
</tr>
<tr>
<td>Minnesota</td>
<td>0.749</td>
<td>2.878</td>
</tr>
<tr>
<td>Wisconsin - State</td>
<td>1.015</td>
<td>1.583</td>
</tr>
<tr>
<td>Wisconsin - Tribes</td>
<td>0.572</td>
<td>0.957</td>
</tr>
</tbody>
</table>

The number of matches of acoustic density estimates and experimental gill net lifts were insufficient to conduct a reasonable model analysis.

**Estimating Catchability** – Results of fitting Model (1) to the acoustic density estimates and the commercial gill net data are presented in Table 4. The slopes of these regressions would be estimates of the catchability coefficient $q$ for each data group. The data for Wisconsin provided the best fit with an $R^2$ of 0.44 and a significance level of 0.01. The data for Ontario provided the worst fit with an $R^2$ of 0.01 and a significance level of 0.56. Also, excluding Ontario data from the combined data set improved the fit. With Ontario included, the $R^2$ and significance were 0.03 and 0.05, respectively. Without Ontario excluded, the $R^2$ and significance were 0.12 and <0.01, respectively.
Table 4. – LSR statistics for the fit of Model 1 to each of the fisheries separately, for all data combined, and for Minnesota and Wisconsin data combined.

<table>
<thead>
<tr>
<th>Fishery</th>
<th>Intercept</th>
<th>Slope (q)</th>
<th>R²</th>
<th>Significance F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>914</td>
<td>-0.92</td>
<td>0.01</td>
<td>0.56</td>
</tr>
<tr>
<td>Minnesota</td>
<td>364</td>
<td>14.06</td>
<td>0.12</td>
<td>0.03</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>467</td>
<td>2.54</td>
<td>0.44</td>
<td>0.01</td>
</tr>
<tr>
<td>All combined</td>
<td>677</td>
<td>1.38</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>MN + WI - combined</td>
<td>634</td>
<td>2.16</td>
<td>0.12</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Results of fitting Model (2) to the acoustic density estimates and the commercial gill net data are presented in Table 5. The slopes of these regressions would be estimates of the shape parameters β for each of the data groups. As with Model (1), the Wisconsin data fit the best (R² = 0.70 and significance level = <0.01) and the Ontario data fit the worst (R² = 0.05 and significance level = 0.67). Once again, excluding Ontario data from the combined data set improved the fit. With Ontario included, the R² and significance were 0.09 and <0.01, respectively. Without Ontario, the R² and significance were 0.18 and <0.01, respectively.

The two best fitting regressions were for Model (2) using Wisconsin data alone and for Model (2) using MN + WI data combined (Tables 4 and 5).

Table 5. – LSR statistics for the fit of Model 2 to each of the fisheries separately, for all data combined, and for Minnesota and Wisconsin data combined.

<table>
<thead>
<tr>
<th>Fishery</th>
<th>Intercept</th>
<th>Slope (β)</th>
<th>R²</th>
<th>Significance F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontario</td>
<td>6.265</td>
<td>0.05</td>
<td>&lt;0.01</td>
<td>0.67</td>
</tr>
<tr>
<td>Minnesota</td>
<td>5.537</td>
<td>0.23</td>
<td>0.03</td>
<td>0.27</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>3.855</td>
<td>0.57</td>
<td>0.70</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>All combined</td>
<td>5.564</td>
<td>0.21</td>
<td>0.09</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>MN + WI - combined</td>
<td>5.244</td>
<td>0.32</td>
<td>0.18</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

No fit could be obtained for Model (3) for either of the combined groups of acoustic density estimates and commercial gill net data. Apparently, there were too few replicate observations for the random effects chosen or the variable effects just could not be estimated by the fitting techniques used.

Discussion

I think there are two problems that could prevent useful catchability estimates from being developed for these cisco fisheries. First, I think there is a mismatch in the size selectivity of gears in this data set, both between acoustic sampling and gill nets and between gill nets in different jurisdictions. Second, I think gill nets are probably subject to hyperstability problems (i.e. gill net CPUE is not proportional to density). Neither of these problems can be fully resolved with the current data set, but there is a possibility that some additional work could help solve them.

Size selectivity of gears – The models and data groups used in this analysis showed that the poorest relationship between the acoustic density and gill net CPUE was for the Ontario data, and the Ontario fishery uses the largest mesh size in their gill nets (Table 2). The data I received did not include the length frequencies of fish, but these have been published previously (Yule et
al. 2008a). Also, it is well known that gill nets of different mesh sizes are selective for different sizes of fish, so I will not go into that here. The bigger problem could be the difference in size structure between the acoustics density estimates and the gill net harvests, especially in the Ontario fishery.

Figure 2 is a reproduction of Figure 7 in Yule et al. (2008a). I added the blue line over the Thunder Bay panels at approximately 250 mm. Acoustic sampling is set to estimate targets at -35.6 decibels, which would give the density of all fish 250 mm and larger (Yule et al. 2006). As you can see from the figure, in some years (like 2007 in Thunder Bay) there are many fish in the 250 to 330 mm range which would be included in the acoustic density estimate, but would not be harvested by gill nets. Yule et al. (2008a) recognized and reported this fact and suggested that these 250-to-330-mm fish in 2007 represented a large 2003 year class. They also suggested that this mismatch in size selectivity was the reason there was a lack of correspondence in the acoustic estimates and gill net CPUE for Thunder Bay in 2005 and 2007 (Figure 3). Basically, the acoustic density estimates for Thunder Bay doubled from about 75 to 140 fish/ha while CPUE remained about the same at 0.5 to 0.7 kg/m.
Reproduced from Yule et al. (2008),
I found additional evidence to support this mismatch in selectivity and the presence of a large 2003 year class in the commercial netting data. The maximum acoustic density estimate occurred in 2007, but the maximum CPUE for gill nets occurred later – 2009 and 2010 (Table 6). The maximum CPUE was in 2009 for the smaller meshed nets in Minnesota. The maximum CPUE was split between 2009 and 2010 for the mid-sized meshes in Wisconsin. The maximum CPUE was in 2010 for the larger meshed nets in Ontario. This corresponds to what one would expect based on the growth of a large 2003 year class from an average length of about 280 mm in 2007 (when it would be detected by acoustics sampling but not nets) to an average length of about 380 mm in 2010 (when it would be detected by larger-mesh gill nets).

Table 6. - Acoustic density and CPUE by year. Mean acoustic density is for all jurisdictions combined. Mean CPUEs by year and jurisdiction are for all gill net lifts, including those not matching acoustic density. Shaded cells are the maximum values in each column.

<table>
<thead>
<tr>
<th>Year</th>
<th>Acoustic density (fish/ha)</th>
<th>Ontario</th>
<th>Minnesota</th>
<th>Wisconsin - State</th>
<th>Wisconsin – Tribes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>40.3</td>
<td>575</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>2006</td>
<td>65.2</td>
<td>nd</td>
<td>930</td>
<td>1,015</td>
<td>392</td>
</tr>
<tr>
<td>2007</td>
<td>131.0</td>
<td>603</td>
<td>nd</td>
<td>nd</td>
<td>414</td>
</tr>
<tr>
<td>2008</td>
<td>96.2</td>
<td>786</td>
<td>nd</td>
<td>710</td>
<td>500</td>
</tr>
<tr>
<td>2009</td>
<td>48.8</td>
<td>742</td>
<td>1,300</td>
<td>1,210</td>
<td>480</td>
</tr>
<tr>
<td>2010</td>
<td>78.4</td>
<td>1,397</td>
<td>549</td>
<td>999</td>
<td>766</td>
</tr>
</tbody>
</table>
This mismatch in selectivity is pretty much a killing flaw when it comes to trying to develop a relationship between CPUE from gill nets and $N$ from acoustic surveys, especially for Ontario where gill net mesh size is the largest. Unfortunately, Ontario is also where the bulk of the data matches occur (Table 1). One thing that might help would be to redo the acoustic density estimates to increase the minimum size of fish detected from 250 mm to about 320 to 330 mm, which would provide a closer match to the sizes selected by the gill nets. Dan Yule told me that this is feasible, so this is something to consider in the future.

On a positive note, the relationship between acoustic density and gill net CPUE is better for the smaller mesh sizes which have a closer correspondence to the size selectivity of the acoustics gear (see Tables 4 and 5).

**Hyperstability** – The nonlinear Model (2) provided the best fits to some of the data groups (Tables 4 and 5). The best fits were for the Wisconsin data alone and for the WI + MN combined group. These models gave estimates of 0.57 and 0.32, respectively, for the shape parameter $\beta$, which indicates a fairly high degree of hyperstability. At least two things could be happening in these fisheries that can cause hyperstability, gear saturation and targeting of dense schools of fish (Crecco and Savoy 1985; Crecco and Overholtz 1990; Rose and Kulka 1999; Harley et al. 2001; and Olin et al. 2004).

Gill nets have limited space and meshes to capture fish, so there is no doubt that the capture rate of a net will decrease as fish accumulate in it. It is even possible that part of a net gets saturated while the rest is not, because the distribution of captures is uneven. In a fishery, if the nets are lifted well before the saturation level is reached, then there is a good chance that CPUE will be roughly proportional to $N$ (Region A – Figure 4). If the nets are lifted near or after the saturation level is reached, then CPUE will not be proportional to $N$ (Region B – Figure 4). In the latter case, abundances would be overestimated when fish density is low and underestimated when fish density is high, because saturation would cause a similar relationship between CPUE and $N$ (fish density – Figure 4). This could lead to errors in management decisions, such as allowing overharvest when abundance is low and limiting harvest unnecessarily when abundance is high (Kennedy 1951; Minns and Hurley 1988; Olin et al. 2004; Rose and Kulka 1999). I found a couple of cases in the literature where saturation did not appear to be a big problem (i.e. fishery or sampling is in Region A – Figure 4). Those cases were for lake trout in Lake Superior (Hansen et al. 1998) and northern pike in Minnesota lakes (Pierce and Tomcko 2003). However, I think there is a good chance the nets in these fisheries for spawning cisco are near the saturation level (i.e. CPUEs for 1-night-lifts are in Region B – Fig. 1).
The first argument supporting this saturation hypothesis is that the percentage of available space occupied in these cisco nets appears to be similar to values in the literature reported for saturated nets. Saturation occurs at a surprisingly low percentage of available net space and varies by species, water clarity, water temperature, and so on. von Brandt (1955) reported net saturation for herring in driftnets at 1.7% of available space in the net. Olin et al. (2004) reported net saturation in a multi-species situation at an average of 0.24% of available space occupied, with a maximum of 0.70% occupied. They concluded that visual avoidance was more important in defining the saturation level than the number of free meshes available. To get an idea about how this cisco gill net data compares to literature values, I used the Ontario data and calculated that 1-night-lifts averaged 0.2% of available meshes occupied, with a maximum of 1.5% occupied.

Second, these cisco nets appear to be saturated, or close to saturated, within one net night. The Ontario data and the Wisconsin Tribal data included some multi-night sets, so I plotted average CPUEs versus number of net nights to create graphs similar to the hypothetical graph in Figure 4. The results are shown in Figures 5 and 6 for Ontario and Wisconsin Tribal data (in-spawning season lifts only), respectively.
Figure 5. - CPUE (kgs/1000m) versus net nights fished for Ontario data (2006-2010). The squares are means calculated from the netting data. The line was drawn by eye.

![CPUE versus Nights Set - Ontario](image)

Figure 6. - CPUE (kgs/1000m) versus net nights fished for Wisconsin Tribal data (2006-2011, spawning season data only). The squares are means calculated from the netting data. The line was drawn by eye.

![CPUE versus Nights Set - Wisconsin Tribal](image)

And finally, gill net saturation could be another factor causing the results in Figure 3 (Figure 8 of Yule et al. (2008a)). For example, if saturation occurs at about 1.5 fish/m, it would explain why the extremely high acoustic densities of 375 fish/ha at Sand Island showed no higher CPUEs than acoustic densities of 75 fish/ha or 140 fish/ha at Thunder Bay. Yes, there are a few CPUEs above 1.5 fish/m at Knife River, but acoustic densities there are only 25 to 50
fish/ha. Maybe these exceptionally high CPUEs were caused by weather conditions, or maybe some large lake trout cruised through the area and chased the schools of cisco into nets that they would have normally avoided.

One thing that is somewhat inconsistent with gill net saturation is the fact that the mean CPUEs all appeared to increase pretty substantially in 2009 and 2010 (Table 6). Thus, while gill net saturation seems well supported, it would still be a good idea to study it further. The first and easiest thing to do would be to examine more of the commercial gill net data already in agency files. This study only used a limited set of netting data for a 5-year period. The is probably much more data available with multiple-night sets. If so, then I recommend using it to further examine the nature of the relationship between CPUE and nights set as in Figures 5 and 6. Alternatively or in addition, you could devise a research study to deliberately make multiple night sets to develop the relationship.

**Conclusions and Recommendations**

Attempts to make direct estimates of the catchability of gill nets on spawning cisco achieved mixed success. Nonlinear models fit better than linear models when relating CPUE and acoustic spawning density. For the nonlinear models, estimates of the shape parameter $\beta$ were always less than 1.0, indicating hyperstability. This suggests that CPUE declines slower than population density in these fisheries. More work is needed to help improve the fits and to better understand catchability of gill nets.

First, acoustic densities should be recalculated to exclude fish between 250 and 320 mm. This would better align the size selectivity of acoustic surveys and gill net harvests. It would make the Ontario gill net data more useful and possibly improve the fit of all catchability models.

Second, the gill net saturation hypothesis should be studied in more detail. Until this issue is resolved, I advise against developing monitoring programs for cisco populations based solely on gill net harvest or CPUE. The management agencies have more data in their files that might help verify or reject this hypothesis as described above in the Discussion section.

Finally, I recommend developing a new cisco population dynamics model to help analyze management decisions and identify research needs and priorities. I think the netting and acoustic data combined with the whole body of research that has been done on cisco in the last 10 years (e.g. Ebner et al. 2008; Yule et al. 2008b; Stockwell et al. 2009) would allow development of a pretty useful age- and size-structured management model. Some of the things managers could do with such a model include: (1) update historical perspectives and restoration plans for cisco using the newer growth and mortality estimates made from otolith aging methods (Yule et al. 2008b); (2) test the effects of different fishing regulations, such as increasing or decreasing fishing effort or changing gill net mesh sizes, on future restoration efforts; and (3) identify gaps in knowledge of cisco biology and evaluate their importance to future management.
References


Appendix A.

Maps of Lake Superior study areas with acoustic transects superimpose on commercial fishing grids.

(Maps provided as a courtesy of Dan Yule and staff of USGS, Great Lakes Science Center, Ashland, WI)
2004 Spawning Cisco Acoustics

2005 Spawning Cisco Acoustics at Madeline Island Area