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Temperature Influence on Commercial Lake Whitefish Harvest in Eastern Lake Michigan

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ABSTRACT. *Lake whitefish* (Coregonus clupeaformis) *support the largest commercial fishery in Lake Michigan, yet relatively little is known of the thermal ecology of free-ranging lake whitefish. In 2000 six commercial trap nets were instrumented with self-recording temperature data loggers to examine the relationship between lake whitefish harvest, water temperature statistics, and fishing effort. Several variables including surface water temperature (SWT), bottom water temperature (BWT), difference between SWT and BWT, and fishing effort were used in both a backward and forward stepwise regression model against fishing harvest. Both the backward and forward results generated similar R^2 statistics of 0.62 and 0.58 respectively, with the backward model suggesting BWT, variance of BWT, and the difference between SWT and BWT as the best regression model. The forward regression results suggested that SWT alone was the best model. Subsequent ANOVA tests support selecting the simpler model for describing the lake whitefish dependence on temperature, which was:*

$$y = 21{,}000e^{-0.366T}$$

where y is dressed lake whitefish harvest (kg) and T is SWT (°C). This model worked well for surface water temperatures between approximately 10 and 20°C. The success in describing the fish harvest with surface water temperatures is most likely the consequence of warm surface water intrusions into the hypolimnion from coastal downwellings being the dominant factor controlling lake whitefish distribution.

INDEX WORDS: *Lake whitefish, Lake Michigan, water temperature.*

INTRODUCTION

Although lake whitefish (*Coregonus clupeaformis*) has been an important fishery for nearly 150 years, in recent decades it has become the most important commercial fishery in Lake Michigan (Copes and McComb 1992). The commercial fishery for lake whitefish operates throughout the northern half of Lake Michigan but the fishery

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along the eastern shore south of Ludington is a trap net fishery that is limited to waters less than 27 m in depth. It is well known that water temperature plays an important role in preferred fish habitat (Brandt *et al.* 1980) and there is additional evidence to suggest that some Great Lakes fish exhibit little seasonal change in their bathymetric distribution (Selgeby and Hoff 1996). However, during summer stratification the coastal region of Lake Michigan is subject to relatively frequent upwellings and downwellings (Beletsky *et al.* 1997), potentially disrupting the optimal thermal habitat of lake whitefish and, thus, their bathymetric distribution. Although much has been published on lake whitefish ecology based upon laboratory, modeling, and tagging data studies (Trudel *et al*. 2001, Edsall 1999, and Walker *et al*. 1993) relatively little is known about the thermal ecology of free-ranging lake whitefish in Lake Michigan.

In conjunction with a commercial trap net fishery we instrumented six different trap nets with self-recording temperature data loggers. Our objective was to estimate how much of the lake whitefish harvest variability can be explained as a function of temperature and fishing effort, and to identify the simplest possible model with the maximum explanatory capability.

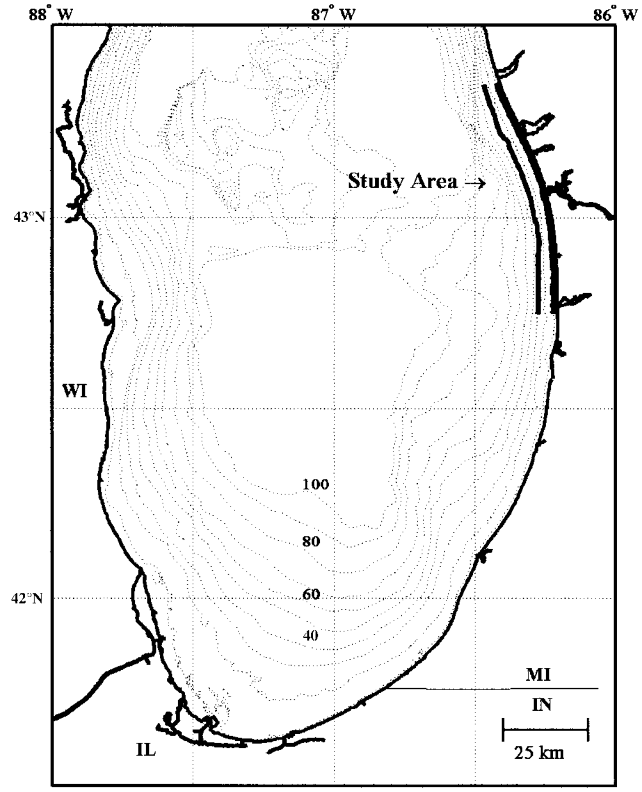

FIG. 1. Southern Lake Michigan and the study area outlined by the highlighted 30-m depth contour. Additional depth contours out to 100 m are also displayed.

METHODS

The 30-m depth contour is highlighted along eastern Lake Michigan (Fig. 1), outlining the region where six trap nets were deployed during May to October 2000. The nets were deployed at similar depths in the vicinity of the 25-m depth contour and two different sizes of net were used. Nets 1–3 were 6.1 m in height while nets 4–6 were approximately the same width as nets 1–3 but were 50% taller with a height of 9.1 m. No attempt was made to correct for differences in net height by weighting the fish catch. Each net was constructed of polypropylene and all nets remained in their original deployment locations throughout the study period. Three self-recording temperature data loggers (Stow Away Tidbit Temperature Logger made by Onset Computer Corp.) with an accuracy of ± 0.1°C were attached to each net. The bottom logger was attached near the bottom of the net, the second logger was attached to the net top, and the third logger was attached to the surface marker float. The majority of the loggers recorded temperature readings at hourly intervals throughout the deployment period while several others sampled at 10-minute time intervals. The higher sampling rate enabled us to estimate that it takes less than 30 minutes for the fishermen to raise, empty, and lower their trap nets as suggested by the rapid changes in recorded bottom temperatures. These temperature signals also correspond to the trap net servicing dates entered in the vessel logbook. The vertical placement of the temperature loggers is most useful during summer stratification when simple intercomparisons of the data make it possible to identify upwelling and downwelling episodes and determine if the trap net is within or below the thermocline region.

The fish harvest is reported in kg of dressed fish and the temperature data were reported as averages between net sampling events. The thermistor data from the top of the trap net were found to be highly correlated (ρ = 0.92) with observed temperatures from near the net bottom. Therefore, only the surface and bottom temperature data were used in the analyses. In addition to calculating the mean temperatures between net pulls, the temperature variance and difference between surface and bottom temperatures were also calculated from the time series data. The time interval for all of these calculations was variable, and began when the net was placed on the bottom and ended at the next corresponding net pull. The time duration between net pulls corresponds to the "fishing effort." We recognize that fishing effort may not be linear in time but any additional assumptions are not supported with these data. The fishing effort (days) was calculated for each sampling interval, for each net, and is included in the regression analyses described below.

Several variables were used in an attempt to identify the best model for estimating fish harvest. The variables included: surface water temperature (SWT), bottom water temperature (BWT), variance of SWT, variance of BWT, difference between SWT and BWT, and fishing effort. Both backward and forward stepwise regression models (SYSTAT) were attempted which regressed the lake whitefish quantities on the variables described above. Common transformations on the response were attempted as well such as the square root and natural log. For each model the coefficient of determination (R^2) was computed to test model adequacy. A plot of fitted values versus the corresponding residuals for each model was also used to help detect model flaws caused by non-constant error variance, nonlinearity, and the presence of outliers.

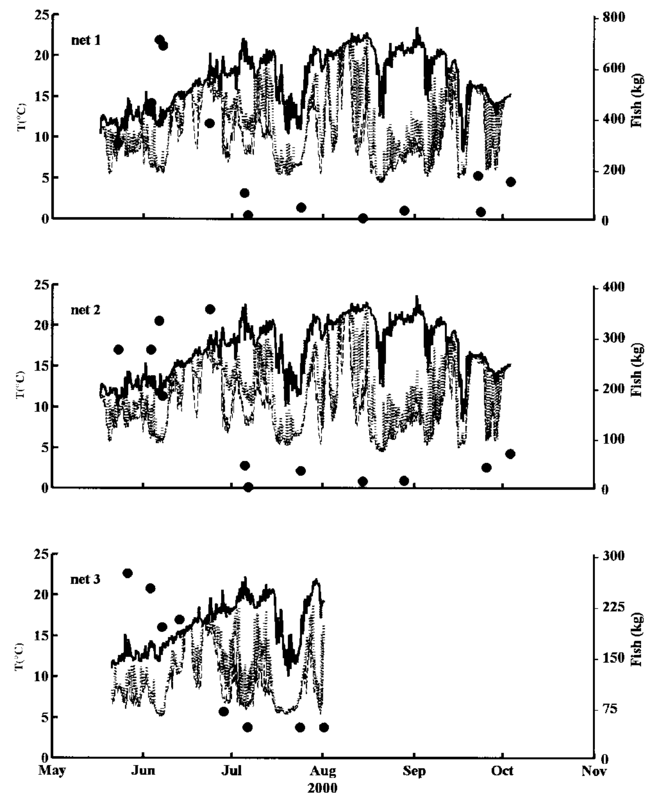

FIG. 2. Water temperature time series and fish harvest from nets 1–3. The surface temperatures are highlighted and the mid depth and bottom temperatures closely track one another. Fish harvest are displayed as •.

RESULTS AND DISCUSSION

The water temperature time series data from the six trap nets and their respective lake whitefish harvest are shown in Figures 2 and 3. Several episodes of upwelling and downwelling occur throughout the deployment period with the greatest activity being from early June through early October (Figs. 2 and 3). The variability in fishing effort is also clearly evident in the figures. The fishing effort ranged from as short as 1 day to a maximum of 35 days, with an overall median value of 10 days between net pulls.

Initial model regressions were based upon the whitefish harvest regressed on combinations of the temperature variables and fishing effort; however, in every case the residual versus fitted plot indicated heteroscedacity implying a transformation of the model response was necessary. Following the same approach the natural log transformation of the whitefish harvest was identified to be the best transformation for these data and was used in all subsequent analyses.

We initially suspected that the average difference between surface and bottom temperatures would strongly correlate with lake whitefish catch because it can indicate coastal upwelling, downwelling, and stratification and that the fish would be sensitive to these parameters. We also suspected that fishing effort would show good correlation with fish harvest. However, the results imply only a weak association with both of these variables and lake whitefish harvest. The best regression models were identified by using both backward and forward stepwise regressions with SYSTAT. Two different models were suggested with the higher R^2 (0.62) occurring with the backward stepwise regression. This model contains the predictors: BWT, variance of BWT, and difference between SWT and BWT (Model 1). The model suggested by the forward stepwise regression contained the single predictor SWT with and R^2 of 0.58 (Model 2).

In an attempt to identify which model is more appropriate Model 1 was tested against Model 2 in an

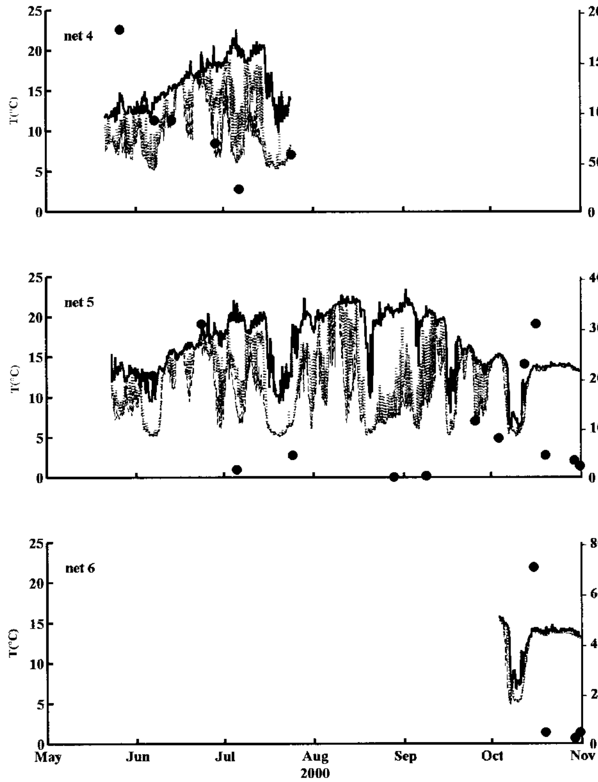

FIG. 3. Same as Figure 2 but for nets 4–6.

ANOVA (Analysis of Variance) test. The ANOVA results generated a P-value of 0.66 between Models 1 and 2 which strongly suggests the use of SWT as the sole predictor of lake whitefish harvest. The final model is described as

$$Ln\, y = -0.366T + 9.959$$
$$y = 21{,}100e^{-0.366T} \quad (1)$$

where y is the dressed lake whitefish catch in kg and T is the surface water temperature in degrees Celsius. A plot of the model versus data is shown in Figure 4.

Although surface water temperature was found to be the most significant predictor it should not be assumed that the other variables are inconsequential. Equation 1 should not be used to extrapolate outside of the temperature ranges of the dataset. Outside of the temperature ranges in this study there may be an entirely different outcome (recall surface temperatures ranged from 10.3 to 20.5°C while bottom temperatures ranged from 6 to 15.7°C). While Figure 4 shows a negative relationship between catch and temperature it also shows decreasing

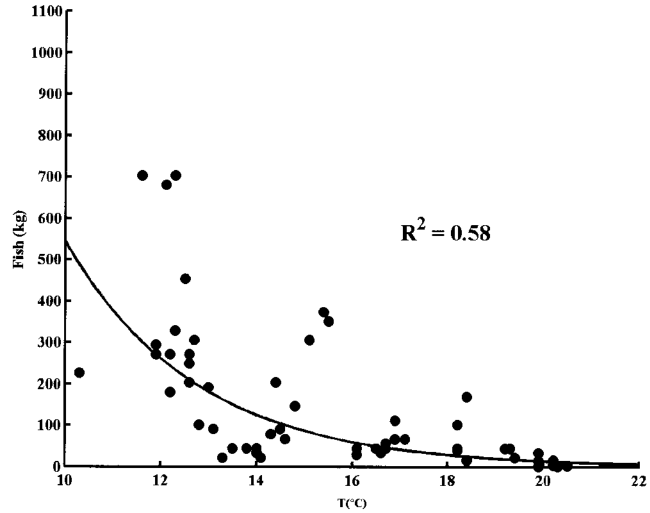

FIG. 4. Scatter plot of fish harvest versus averaged surface water temperature from all nets. Water temperatures were averaged between net pulls. The exponential model describing their interrelationship and its R^2 statistic is also shown.

variation in catch with increasing surface temperatures. The total variation in lake whitefish harvest cannot be explained by the temperature data alone, however, the improved correlations between catch and temperature at higher surface temperatures suggests fish avoidance of warm waters is a major controlling influence.

The two surprising results were that fishing effort is an unimportant predictor of fish catch and surface water temperature is the best single predictor of a cold-water fish harvest. Both of these results may be explained from physical considerations of fish habitat, and its implications on fish distribution. For example, if lake whitefish were uniformly distributed then the longer a net remained in the water the greater the expected catch. These results suggest that the lake whitefish population is patchy in distribution. The longest fishing effort was 35 days in duration yet it resulted in one of the lowest catches throughout any net deployment. Conversely, some of the largest catches occurred on time scales of less than 5 days. This suggests that ignorance of preferred lake whitefish habitat cannot be compensated for by increased fishing effort through longer net deployments.

The other surprising result, that surface water temperature is a better predictor of fish harvest than bottom temperature or any other temperature statistic, is possibly the consequence of the coastal dynamics controlling the lake whitefish habitat in this region. The temperature data suggest several large-scale temperature excursions at depth resulting from downwelled surface waters. The data further suggest that it is not the rate of change in bottom temperatures that causes the lake whitefish to avoid a certain region, but rather it is the absolute magnitude of the temperature excursions that most strongly influences their geographic distribution. Coastal downwellings are suggested to occur throughout the data set and they do not appear to influence lake whitefish harvest until surface water temperatures are maintained at approximately 18°C and warmer. Once surface waters reach these and higher temperatures followed by subsequent downwellings it suggests that the lake whitefish are displaced to deeper waters, outside these coastal influences, for a considerable length of time.

The governing process controlling lake whitefish harvest in this area of Lake Michigan may well be that the nets were deployed along an open coastline subjected to large-scale coastal downwellings. It is the combination of over-lake meteorology, the nets' proximity to shore, and whitefish abundance that dictates the lake whitefish harvest. Surface waters can be downwelled along the east coast of the lake and extend to considerable distances offshore depending upon the strength and persistence of southerly winds. Thus, caution must be applied in extending these results to not only environments with similar temperature ranges, but also to regions and depths not subject to coastal downwelling. The extension of a study like this to deeper offshore waters, free from the effects of surface downwelling, may yield totally different results as the fish respond to new and changing stressors that may require more comprehensive models and new measurements to satisfactorily resolve their behavior.

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