Validation of Lake Whitefish Catch-Per-Unit-Effort Data with Time Series Analysis

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Abstract. —Catch-per-unit-effort (CPUE) data for lake whitefish *Coregonus clupeaformis* in Michigan waters of Lake Huron were examined with time analysis to test if they can describe the abundance of lake whitefish. Relations between lake whitefish CPUE and environmental and biological data were investigated with cross-correlation analysis. A 4-year time lag, corresponding to the age at maturity, was found for lake whitefish CPUE. Cross-correlation analysis indicated that lake whitefish CPUE was negatively correlated with monthly air temperatures and abundance of sea lamprey *Petromyzon marinus* in previous years, and CPUE was positively correlated with fishing effort 1 year later. The results indicated that fishermen track lake whitefish abundance and that CPUE can describe fluctuations of the lake whitefish population.

Fisheries for lake whitefish *Coregonus clupeaformis* on the Great Lakes often have been assessed with catch statistics rather than with catch-per-unit-effort (CPUE) statistics (e.g., Berst and Spangler 1973; Christie 1973; Hartman 1973; Lawrie and Rahrer 1973; Wells and McLain 1973). Extensive effort data are available for the Great Lakes and CPUE data should be a better index of abundance than catch data because changes in effort and catchability produce different catches even when abundance does not change (e.g., Ricker 1975). However, CPUE data for the lake whitefish fisheries have been suspected of error because CPUE often increases as yield increases, whereas it should decrease if the fish are being fished up (e.g., Christie 1973). If changes in CPUE represent changes in lake whitefish abundance, then fishing effort tracks abundance of lake whitefish, and both yield and effort increase when abundance increases and decrease when abundance decreases. This would mean that the large fluctuations in catch and CPUE result from changes in abundance and not from fishing, and that conventional methods of stock assessment that are based on assumptions of constant recruitment or a carrying capacity are of no value for assessment of lake whitefish fisheries.

Abundance data on lake whitefish are not available, so it cannot be determined with certainty whether or not CPUE data reflect changes in abundance. We approached this problem indi-

rectly, seeking biologically meaningful patterns in the CPUE data that would reflect expected patterns in lake whitefish abundance.

We used time series and cross-correlation analyses for this purpose.

Time series analysis has been applied to several fisheries (Jensen 1976; Van Winkle et al. 1979; Saila et al. 1980; Stocker and Hilborn 1981; Roff 1983; Jensen 1985; Stone and Cohen 1990), and biologically meaningful time lags have been found for marine species (Jensen 1985). The two general approaches to time series analysis are based on frequency domain or time domain. The frequency domain (spectral analysis) model decomposes a data series into sine and cosine functions. Spectral analysis is particularly useful when a series is thought to arise from a relatively small set of cyclical functions. Time domain (autoregressive and moving-average) models treat a series as a function of previous values in the same series; these models seem more appropriate for population analyses because they require few assumptions about the underlying model and they can fit complex time series with few parameters (Moran 1953). Outputs from autoregressive models can be explained in terms of biological phenomena such as reproductive time lags, but moving-average terms are not easily interpreted and a moving-average process can always be written as an autoregressive process. Therefore, only autoregressive terms are used in this study.

Data Sources

The catch and effort data for lake whitefish were from Jensen and Buettner (1976), Anonymous (1989a), and U.S. Fish and Wildlife Service (un-

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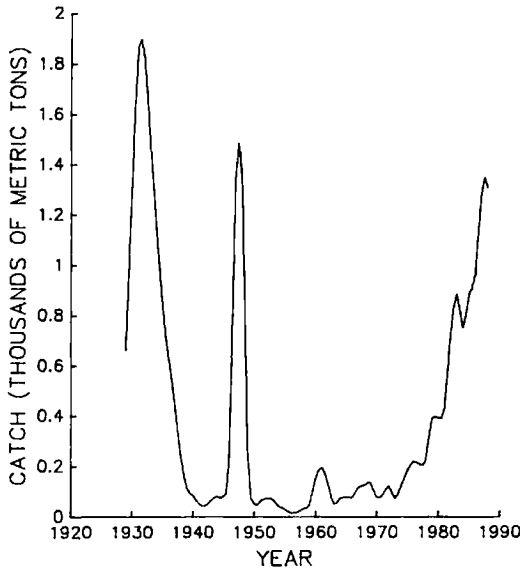
FIGURE 1.—Observed catch series (1929–1988) for lake whitefish in Michigan waters of Lake Huron.
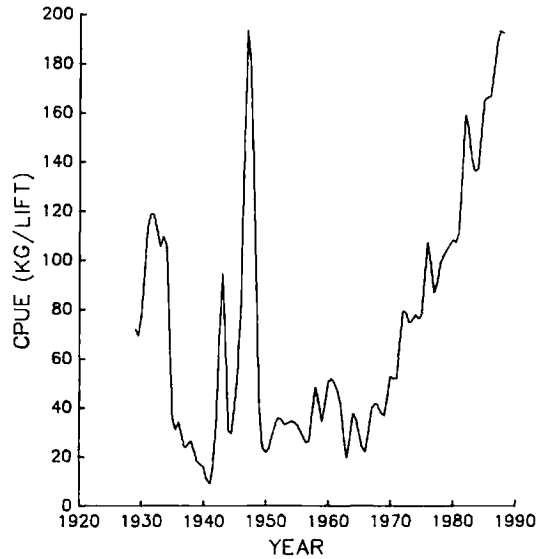
published data); the data were consistent for 60 years (1929–1988). Catch data were changed from pounds into kilograms, and kilograms per trap-net lift was used as the standard CPUE. The CPUE was calculated as (Gulland 1969)

$$\text{CPUE} = (C_g + C_t)/\{E_t + [C_g/(C_t/E_t)]\};$$

C_t = trap-net catch of lake whitefish (kg);
C_g = gill-net catch of lake whitefish (kg);
E_t = trap-net effort (lift).

Monthly air temperature data were provided by the National Oceanic and Atmospheric Administration (NOAA) Great Lakes Environmental Research Laboratory in Ann Arbor and were available from 1929 to 1988. Data (1947–1988) for sea lamprey *Petromyzon marinus* were from Smith and Tibbles (1980) and Anonymous (1989b). Model parameters were estimated with the SERIES procedure in the statistical package SYSTAT (Wilkinson 1988).

Results and Discussion

Commercial production of lake whitefish in Michigan waters of Lake Huron varied from 1,877 tonnes in the early 1930s to less than 20 tonnes in the 1950s, and it recovered to 1,300 tonnes in 1988 (Figure 1). Before 1978, the bulk of the lake whitefish landings came from state-licensed trap-net and large-mesh gill-net fisheries (Rakoczy 1984). Thereafter, a tribal gill-net fishery shared the resource and tribal catch rapidly increased from

FIGURE 2.—Observed catch-per-unit-effort (CPUE) series (1929–1988) for lake whitefish.

7% of lake whitefish landings in 1980 to 58% in 1988. The remainder of the lake whitefish catch was from a state-licensed trap-net fishery. The lake whitefish CPUE series follows a pattern similar to that of catch ($r = 0.72$, Figure 2), and catch is related to effort ($r = 0.67$). The CPUE data were subjected to autocorrelation analysis to determine if biologically meaningful time lags could be detected. The CPUE series of lake whitefish was not stationary (Figure 2), but the twice-differenced series appeared to be nearly stationary with a constant mean but with a somewhat higher variance between 1942 and 1952 (Figure 3). Further differencing did not improve consistency of the series. The partial autocorrelation function for the
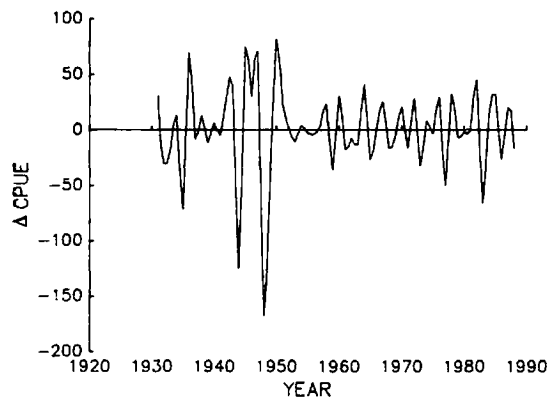

FIGURE 3.—Second difference of the catch-per-unit-effort (CPUE) series for lake whitefish.
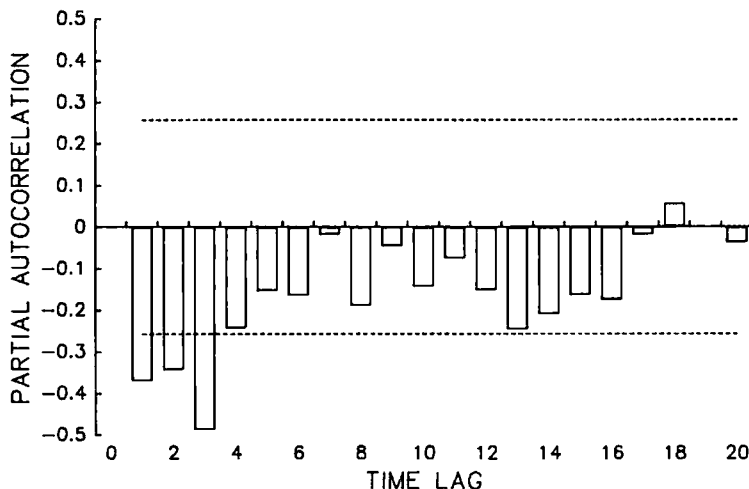
FIGURE 4.—Partial autocorrelations for twice-differenced catch-per-unit-effort (CPUE) series for lake whitefish. Time lag is in years. Dashed lines delimit 95% confidence intervals.

twice-differenced CPUE series indicated negative relations at lags of 1, 2, and 3 years, suggesting a 4-year time lag in CPUE (Figure 4). This result is important, because lake whitefish mature at age 4. A 4-year time lag corresponds to a delayed density dependence for age at maturity, and it indicates that abundance of lake whitefish was negatively correlated with abundance 4 years earlier. Abundant lake whitefish cohorts tended to produce smaller cohorts.

To evaluate the fit of the autoregressive model

$$U_t = 1.332U_{t-1} - 0.251U_{t-2} + 0.506U_{t-3} - 0.587U_{t-4},$$

we used the model for year-ahead forecasts of lake whitefish CPUE, U_t being the forecast of year-ahead CPUE. The 1-year-ahead forecast of CPUE explains 42% of the total variance for CPUE and there were no significant time lags in the residuals (Figure 5).

To describe the relation between CPUE and environmental variables, cross-correlation analysis was applied to the CPUE and monthly average air temperature data. Climatic factors affect growth of lake whitefish (Reckahn 1986; Taylor et al. 1986), and many authors have proposed that year-class strength of lake whitefish is influenced by climatic influences on egg and fry stages (Van Oos-
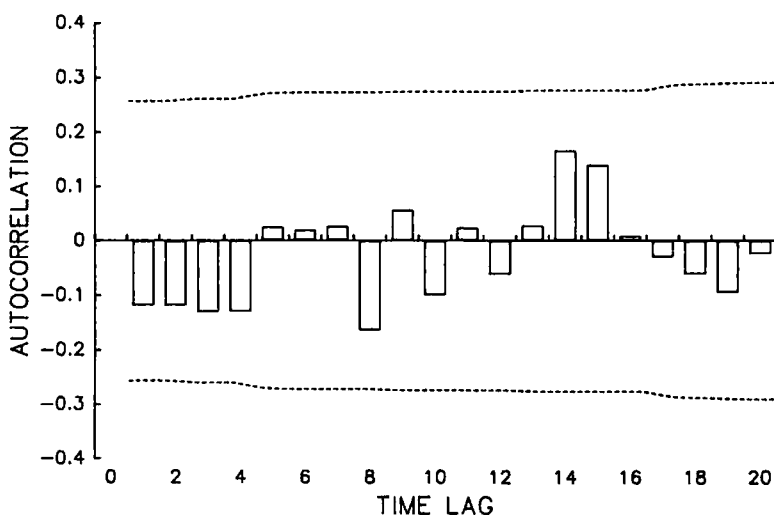

FIGURE 5.—Autocorrelations of residuals of the forecasting equation of the catch-per-unit-effort (CPUE) series for lake whitefish. Time lag is in years. Dashed lines delimit 95% confidence intervals.

TABLE 1.—Significant ($P \leq 0.05$) coefficients of cross-correlation models for lake whitefish catch per unit effort and catch, effort, monthly air temperatures (January and March), and sea lamprey abundance. Coefficients for all other months are not significant.

Lag (years)	Coefficient of cross-correlation				
	Catch	Effort	January	March	Sea lamprey
−7			−0.34		
−6			−0.37		
−5			−0.35		−0.29
−4			−0.33		−0.30
−3			−0.31		−0.32
−2			−0.29	−0.30	−0.34
−1				−0.32	−0.29
0	0.71				
1	0.37	0.47			

ten 1942; Miller 1952; Christie 1963; Lawler 1965; Freeberg et al. 1990). Miller (1952) concluded that year-class strength might be inversely correlated with strength of winds. Lawler (1965) suggested that temperature is more important than other climatic factors in determining the year-class strength of lake whitefish in Lake Erie. Lawler found that embryonic development of lake whitefish is restricted to a narrow range of temperatures, the optimum for development being close to 0.5°C, and that lake whitefish are limited to waters where temperatures stay close to the freezing point during development and hatching. Taylor et al. (1986) proposed that severity of winter (indexed by ice cover) and spring temperature influence year-class strength more than the stock–recruitment relation. Freeberg et al. (1990) concluded that year-class strength is determined by the timing of ice cover, an early cold winter producing the highest survival, and by the highest food availability during the first 7 weeks of life.

We found significant cross-correlations between CPUE and monthly average air temperatures (January and March) in past years (Table 1). These cross-correlations suggest a negative relation between CPUE for lake whitefish and January temperatures in the past 1–5 years, and a negative relation between CPUE and March temperatures in previous years. These analyses indicate that abundance of lake whitefish cohorts was associated with cold January and March temperatures during the early years of cohort life. This result is consistent with the results of others, especially of Taylor et al. (1986), who proposed that severity of winter and spring temperatures are the strongest determinants of year-class strength.

The relation between CPUE and the sea lam-prey index of abundance also was examined with cross-correlation analysis. The sea lamprey was an important factor in the decline of lake whitefish populations (Spangler 1970; Walter and Hoagman 1971). The lake whitefish fishery declined to its lowest level after the sea lamprey appeared in Lake Huron in the 1950s; after the sea lamprey was controlled in the 1960s, the lake whitefish population gradually recovered (Figure 1). Significant negative cross-correlations were found between lake whitefish CPUE and sea lamprey abundance at lags of 1, 2, 3, 4, and 5 years, suggesting that the abundance of lake whitefish was associated with the abundance of sea lamprey 1–5 years earlier. This indicates that the effect of sea lamprey abundance was both through direct mortality and through a reduced recruitment that may have resulted from a smaller stock size of lake whitefish.

Finally, the relations between the catch and effort series, the catch and CPUE series, and the effort and CPUE series were examined with cross-correlation analysis. Significant positive cross-correlations between catch and effort were found at forward lags of 0 and 1 year, indicating that catch of lake whitefish was associated with effort in the present year and 1 year later. Significant positive cross-correlations between catch and CPUE and between effort and CPUE were also found at forward lags of 0 and 1 year and 1 year, respectively (Table 1). These results, combined with the results showing that lake whitefish abundance fluctuated with environmental factors and with sea lamprey abundance, indicate that fishermen track the abundance of lake whitefish and that effort increased when abundance increased. We conclude that CPUE describes fluctuations of the lake whitefish abundance, although fishing patterns, weather, catchability, and other factors might affect CPUE.

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