# Examination of Factors Contributing to the Decline of the Yellow Perch Population and Fishery in Les Cheneaux Islands, Lake Huron, with Emphasis on the Role of Double-Crested Cormo...

**Article** *in* Journal of Great Lakes Research · September 2008

DOI: 10.3394/0380-1330(2008)34[506:EOFCTT]2.0.CO;2



**1 author:**

David Fielder
State of Michigan

J. Great Lakes Res. 34:506–523
Internat. Assoc. Great Lakes Res., 2008

# Examination of Factors Contributing to the Decline of the Yellow Perch Population and Fishery in Les Cheneaux Islands, Lake Huron, with Emphasis on the Role of Double-crested Cormorants

**David G. Fielder***

*Michigan Department of Natural Resources*
*Alpena Fisheries Research Station*
*160 E. Fletcher*
*Alpena, Michigan 49707*

***ABSTRACT.*** *Double-crested cormorants increased exponentially in the Les Cheneaux Islands area during the 1980s and 1990s. The yellow perch fishery and population declined by the late 1990s and finally collapsed in 2000. Previous research confirmed that cormorants fed seasonally on perch. This analysis sought to use creel survey data and data from an annual gillnet collection to characterize the perch fishery and population during this time so as to explore if declines were a result of declining recruitment or increased mortality or both. Regression analysis explored six possible independent variables to account for yellow perch trends. Yellow perch abundance and its fishery declined throughout the Les Cheneaux Islands. Mean age declined which was consistent with a high mortality rate explanation. Yellow perch recruitment, as indicated by gillnet catch rate of age-2 perch, continued during this time including one very strong year class. Total annual mortality rates determined by the cohort method were as high as 85% during much of this time and increased over the time series. Cormorant abundance accounted for a total of five significant relationships with the yellow perch data, more than any other independent variable. From this, it is apparent that cormorant predation is at least one factor affecting the perch population and fishery and may be the most influential force, among those examined, during this time series.*

***INDEX WORDS:*** *Yellow perch, cormorants, population dynamics, predation, mortality rate, Les Cheneaux Islands.*

## INTRODUCTION

Yellow perch (*Perca flavesence*) have been the center piece of a recreational fishery in the Les Cheneaux Islands region of northern Lake Huron since the early Twentieth Century (Lucchesi 1988). The fishery, however, experienced unprecedented declines, first documented in 2000. Concurrent with the collapse of the fishery has been the proliferation of the double-crested cormorant (*Phalacrocorax auritus*; hereafter termed "cormorant") which uses the region for nesting during the spring and summer. Because cormorants are principally piscivorous, there has been considerable concern and speculation over the role of their predation as a factor causing or contributing to the decline of the yellow perch fishery and population (Wilgoren 2002). Other changes, however, have also taken place in the area during this time including declines in water levels, implementation of a neighboring walleye stocking plan, and changes in the amount of fishing effort. Of importance to fishery managers are what has caused the collapse of this fishery and what management action if any is warranted?

Before the proliferation of cormorants, the recreational harvest of yellow perch had been as great as 439,000 fish (in 1986) as documented by periodic creel surveys (Lucchesi 1988). The influence of fishing mortality on the sustainability of the population and the fishery itself was examined during the 1980s. Diana *et al.* (1987) and Lucchesi (1988) concluded that the fishery was not in genuine decline by the mid 1980s compared to the late 1970s

*Corresponding author. E-mail: fielderd@michigan.gov

or early 1980s. Instead, complaints of small average size were due to relatively intense exploitation by the recreational fishery. Overall those studies characterized the population as healthy, and exhibiting regular recruitment. To address angler's concerns, a 178 mm minimum length limit was implemented by the Michigan Department of Natural Resources (MDNR) in 1987. The only remaining commercial fishery at the time was a Native American fishery that was deemed small relative to the recreational fishery, since it took just 4% of the annual yellow perch harvest by number (Lucchesi 1988). The region was closed to commercial fishing in 2000 (Consent Decree Manual 2000).

The question of what impact, if any, cormorant predation was having on the Les Cheneaux Islands yellow perch population and fishery was the subject of a 1995 study (Diana *et al.* 1997). That study documented that cormorants fed heavily on yellow perch between mid April and mid May, but then consumed alewives almost exclusively for the remainder of that year. The study concluded that cormorants took just 1% of the yellow perch population above 178 mm, mostly consumed small perch and, although total numbers eaten were as high as 270,000 to 470,000 in 1995, that it was insignificant relative to the total population. That study also reported total annual yellow perch mortality to be just 45%. No management action was recommended.

Despite the findings of Diana *et al.* (1997), the yellow perch fishery collapsed within 5 years. Alternatives to explain the fishery collapse were hypothesized by some as declines in recruitment (Diana *et al.* 2006). In fact, yellow perch populations were in decline in a number of key Great Lakes locations and were attributed to declines in reproductive success and recruitment. These locations included much of Lake Michigan (Clapp and Dettmers 2002) and Saginaw Bay (Fielder *et al.* 2000). Recruitment declines in Percids like yellow perch are often fueled by failures in reproductive success which might be affected by environmental factors such as water levels or unusual spring water temperatures (Craig 1987). Water temperature can affect successful incubation of eggs (Hurley 1972) or lead to overall poor fry survival (Schupp 2002). Water levels can affect successful incubation of perch eggs (Henderson 1985) especially if affected by seiche events (Clady and Hutchison 1975). Other changes since the Diana *et al.* (1987) study include declines in alewives in Lake Huron, raising the question if cormorants may have consumed yellow perch for a longer period of time in the absence of alewives (Fielder 2004, Argyle 2005).

Walleye (*Sander vitreus*) were never abundant in the Les Cheneaux Islands fish community but walleye stocking by the MDNR (1986–1990) and later by the Chippewa / Ottawa Resource Authority (1990–1998, 2000, and 2003) may have generated an increase in walleye abundance beginning in 1989. Walleye abundance at these past stocking levels never became substantial; however, their increase constitutes an additional change that may have contributed to declines in yellow perch via predation.

In its simplest form, abundance of fish in a population will be a function of the number of members entering the population each year (recruitment) versus the number removed or that died (total mortality), (Ricker 1975). An examination of any fishery decline has to consider both possibilities as well as a combination effect. If effects of these two fundamental factors can be isolated, then further examination may be possible to determine factors causing poor recruitment, or sources of mortality or both.

A single approach to assessing the impacts of cormorant predation on a fish population has not fully emerged. Most common is to conduct diet studies to determine the mix of fish species consumed (Diana *et al.* 1987, Rudstam *et al.* 2004, Ludwig *et al.* 1989, Johnson and Ross 1996). When long-term data are available, others have also sought to compare various population and fishery metrics between the pre- and post-cormorant proliferation periods (Rudstam *et al.* 2004), with special emphasis on changes in mortality rates of fish (Rudstam *et al.* 2004, Burnett *et al.* 2002, O'Gorman and Burnett 2001, Lantry *et al.* 1999). Quantitative examinations attempting to place the significance of cormorant predation relative to other factors have been less common. Diana *et al.* (1997) already confirmed that cormorants in the Les Cheneaux Islands did in fact consume yellow perch, but efforts to examine the perch population over a longer period of time since proliferation or efforts to examine recruitment as a possible causative force have not been previously attempted.

This study sought to (1) describe the collapse of the yellow perch recreational fishery and changes to the population during the same time period, (2) examine various population metrics to try to isolate whether mortality or recruitment trends most accounted for changes to the population and fishery, and (3) within those factors, examine specific sources of mortality or recruitment change that may be most influential.

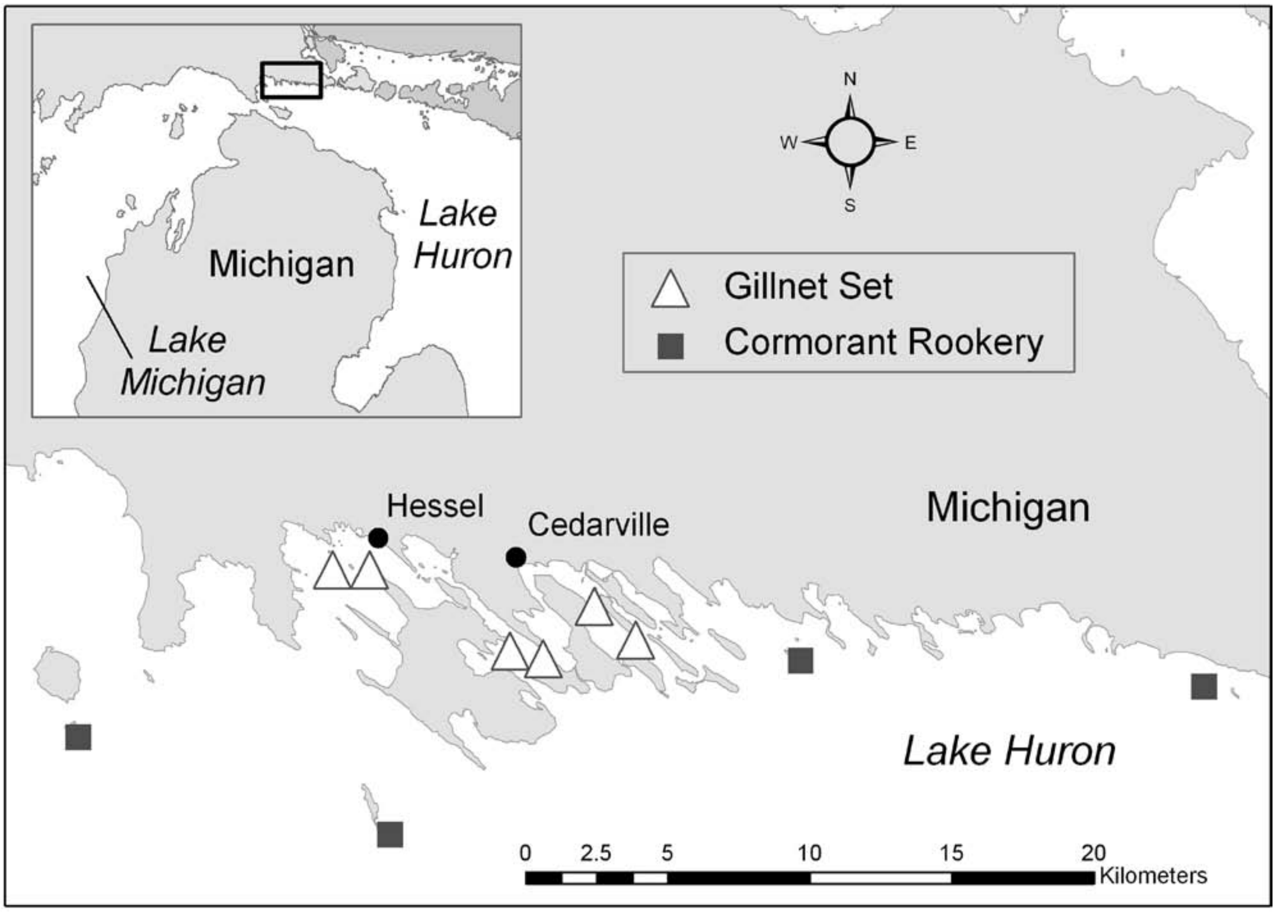


*FIG. 1. Les Cheneaux Islands archipelago of northern Lake Huron and the location of annual gillnet assessment locations and double-crested cormorant rookery locations.*

## STUDY SITE

The Les Cheneaux Islands is an archipelago of at least 23 islands in the Michigan waters of northern Lake Huron and encompasses about 11,650 ha in area (Maruca 1997, Fig. 1). The channels and embayments of the area form pristine coolwater habitat that supports a diverse fish community. Commercial fishing in the region dates to as early as 1881 (Grover 1911, Pittman 1984). The region has supported a popular sport fishery with emphasis on yellow perch since at least 1920 (Lucchesi 1988).

## METHODS

### Fishery Statistics

Fishery statistics were obtained from creel surveys conducted by the MDNR. Statistics included number of yellow perch harvested by anglers (harvest), number of angler hours exerted in the fishery (effort), and the number of yellow perch harvested per hour of fishing effort (angler CPUE). These surveys did not uniformly cover the winter ice fishery, so in order to keep years comparable to discern trends, the examination of creel survey statistics was limited to the open water period which was April–October and accounted for the majority of the fishing effort and harvest in most years. The MDNR survey design followed that of Ryckman (1981). Survey results were available from 1979, 1980, and 1986 (reported by Lucchesi 1988), from 1991 (reported by Rakoczy 1992), from 1995 (reported by Schneeberger and Scott 1997), and from 2000 to 2004 (MDNR unpublished data). Early versions of the survey used ground counts that were later found to underestimate open-water fishing effort and thus harvest estimates. Lucchesi (1988) conducted a creel survey using both ground and aerial count (over flights) methods and developed a correction factor of 2.5× for relating effort estimates from the ground method to the more accurate aerial method. Analysis and summaries in this study utilized the aerial (counts from air planes) pressure (effort) count method and applied Lucchesi's (1988) 2.5× correction factor to ground count years (1979, 1980, and 1991) to derive comparable estimates. Estimation of all fishery statistics included 2 standard errors of the mean (2SE) which approximated the 95% confidence interval (Sokal and Rohlf 1981) allowing for inspection of statistical difference at the $P = 0.05$ level.

### Yellow Perch and Walleye Population Assessment

Yellow perch were collected in an annual fish community gillnet survey conducted by the MDNR between 1969 and 2004. Data from that survey series were also utilized by Lucchesi (1988), Diana *et al.* (1987), Diana *et al.* (1997), and Diana *et al.* (2006). The gillnets were composed of experimental mesh panels of 38 mm, 51 mm, 64 mm, 76 mm, 89 mm, 102 mm, 114 mm, 127 mm, 140 mm, and 152 mm stretch measure mesh. Panels were 30.5 m each for a total gillnet length of 305 m. These mesh sizes were utilized by that survey series because they provide for a collection of a cross section of the entire fish community and most age groups of yellow perch excepting the most juvenile members. Two such nets were fished on the bottom overnight in three different embayments in early October resulting in a typical total effort of 6 net lifts per year. Gear did not change over the time series providing standardized estimates of abundance. Abundance of yellow perch was expressed as number per lift and termed gillnet catch-per-unit-of-effort or gillnet CPUE. Analyses of yellow perch abundance based on gillnet data used geometric means by year. The index of walleye abundance was the geometric mean of the gillnet CPUE (number per 305 m of gillnet) from the same annual fish community survey (1969–2004) described here.

Location of net sets within the Les Cheneaux Islands varied over the years, but nearly every year included Hessel Bay and Muskellunge Bay. Since 1985 Government Bay was also assessed. Prior to that, Sheppard Bay was netted rather than Government Bay. The transition in the mid 1980s from Sheppard Bay to Government Bay resulted in a change in gillnet CPUE as Sheppard Bay generally hosted greater densities of yellow perch than Government Bay. Of most interest to this study were the surveys since 1985 of Hessel, Muskellunge, and Government bays. The entire data series dates to 1969.

Yellow perch caught in the gillnets were counted and measured for total length, weighed, sexed, scored for maturity, and scales or spines collected for later age determination. Aging was performed according to the methods of Schneider (2000). Although different personnel preformed age determinations over the time series, the methods were standardized. Since 2000, all yellow perch collected have been aged, however, prior to that year, some subsampling of yellow perch for scale collection was performed. The exact method used to select subsamples between 1969 and 1999 was not always clear in the records and, in some cases, it appeared that the subsample was not in proportion to the size (and hence age) distribution in the full sample or the population the sample represented. Analyses using age data such as total annual mortality estimation and indexing of recruitment was limited to years where there was confidence in the handling and reporting of the age data and any subsampling procedure from those years. Trends in growth rate of yellow perch was expressed as mean length-at-capture and the growth rate of age-3 yellow perch was specifically utilized as an index of overall growth rate across years.

### Yellow Perch Recruitment

Recruitment of yellow perch is expressed as the geometric mean gillnet CPUE of age-2 fish. Age-2 yellow perch are believed to be the first age group fully vulnerable to the gillnet gear regardless of trends in growth rate in most years. This is evidenced by the age structure of all yellow perch taken from the gillnet sample where age-2 is the first age at which a declining abundance is normally evident in subsequent ages (age-3 and beyond). Increasing gillnet CPUE values in the age structure from age-0 to age-1 or from age-1 to age-2 indicated less than full vulnerability to the gear in some years. Assessment of recruitment patterns at age-2 is not ideal because annual mortality has already had 2 years with which to affect (diminish) the magnitude of the cohort, making interpretation more difficult. However, discerning recruitment at age-2 might be considered conservative, in that any cohort showing relatively strongly (large numbers) at age-2 must have been substantial at younger ages.

### Environmental Variables

Two environmental variables (mean April water levels and mean April water temperature) were examined for association with trends in the various fish population and fishery metrics to further explore alternative hypotheses to mortality forces. Environmental variables such as these would most likely exhibit themselves in the form of recruitment trends. Mean April water levels were obtained from the National Oceanic and Atmospheric Administration (NOAA) using the monthly means from the Harbor Beach gauge station (number 9075014). Although removed considerably from the Les Cheneaux Islands geographically, the Harbor Beach station serves as NOAA's principle index of Lake Huron water levels and differences with other locations around the lake are considered either negligible or at least trend proportionally (Cynthia Sellinger, Great Lakes Environmental Research Laboratory, NOAA, personal communication). Water temperature data were not available specifically from the Les Cheneaux Islands region, so estimated mean monthly water temperatures were obtained from NOAA. These values are modeled estimate values and serve as an index expressed as monthly average values (Croley and Hunter 1994, Croley 2005). Although not specific to the Les Cheneaux Islands, these values are utilized under the premise that they would reflect differences among years. Mean April values were selected on the belief that this corresponded to the annual yellow perch spawning period and would be the most influential month to utilize.

### Yellow Perch Total Annual Mortality

Total annual mortality rate was assessed by two methods. First was estimation from catch curve analysis. Specifically the Robson-Chapman method of total annual mortality rate estimation (Van Den Avyle and Hayward 1999) was used. Total annual mortality rate (A) was estimated as a percentage. The second method for estimating total annual mortality rate was the cohort method, where catch curves are again constructed but instead of using the descending progression of number of fish by age within a year, the descending progression of number of fish by age is constructed within a single year class or cohort over time. This is often a superior method because it overcomes the unlikely assumption of equal annual recruitment inherent in traditional catch-curve analysis (Hilborn and Walters 1992). Ages utilized for these methods were selected based on the criteria of a diminishing age progression in the catch as recommended by Van Den Avyle and Hayward (1999). Confidence intervals (95%) for the mortality rates are also reported.

### Cormorant Abundance

Counts of nest numbers were used as an indicator of trends in cormorant abundance. Rookeries where cormorants nest were generally well known as they were limited to small uninhabited islands. Nest counts were direct enumerations of nests on the ground and in trees and were not estimates. Nest counts were limited to those identified as belonging to cormorants; co-nesting species such as gulls were not included. The trends in nest numbers were taken from Ludwig (1984), Ludwig and Summer (1997), Scharf and Shugart (1998), MDNR (unpublished data), and by USDA Wildlife Services (unpublished data). These data span the years 1980–2004. The nest count methods of MDNR and USDA Wildlife Services were based on the advice and guidance of D. Trexel (University of Minnesota, personal communication) and are similar to the ground and tree nest inventory methods of Bregnballe and Lorentsen (2006). Nest counts were done after initiation of nesting but before nestlings fully fledged which was typically from May through early July.

There were a total of four principle cormorant rookeries in the Les Cheneaux Islands area that were counted for these surveys. From west to east they were; St. Martins Shoal, Goose Island, Saddlebag Island, and Crow Island (Fig. 1). Green Island near the straits of Mackinaw, which is often reported as part of the Les Cheneaux Islands collection of cormorant rookeries, was omitted from this study due to its distance from the archipelago.

### Analysis

Analysis of trends was done by examining for significant differences (2SE of the mean or 95% confidence interval) among years. Means not overlapping with such error bounds were deemed significantly different. Gillnet lift data were not always recorded separately by net within each location over the time series so error bounds in those years are lacking. Geometric means were used for analysis of most gillnet CPUE expressions and are always denoted by the term geometric mean while the label of mean for any other metric always refers to the arithmetic mean. Geometric means as a measure of central tendency are common in fishery statistics (Ricker 1975, McConnaughey and Conquest 1993, Sammons and Bettoli 1998). Geometric means are believed to better represent the distribution of these gillnet CPUE data because changes in values are believed to be relative and geometric means are believed to be more stable about CPUE values representing larger population means (McConnaughey and Conquest 1993). Geometric means are the mathematical equivalent of the back-transformed mean of the natural log values of the data (Sokal and Rohlf 1981). Standard errors (SE) of the geometric mean were calculated according to the methods of Kirkwood (1979) and gillnet CPUE data were first transformed to all positive (nonzero) data by the addition of 0.1 which was 1/2 of the detection limit of the survey in most years. Expression of the geometric mean and the SE of the geometric mean always included the back transformation and the subtraction of the 0.1 constant.

Relatedness of trends across metrics was assessed by linear regression analysis with coefficients of determination ($r^2$) serving as an indicator of how much variability of one parameter (dependent variable) was explained by the other (independent variable). Separate testing was performed on six independent variables; cormorant nest counts, geometric mean CPUE of walleye, yellow perch recruitment (geometric mean gillnet CPUE of age-2 yellow perch), fishing effort, and mean April water levels and temperatures. Two alternative hypotheses were tested, these being; (1) that declines in yellow perch were caused by declines in recruitment or (2) by increases in mortality rate with cormorant, walleye abundance, and fishing effort being specifically tested as mortality sources. Fishing effort was used as a surrogate for fishing mortality which was unknown. Fishing effort, however, could not be regressed against harvest or angler CPUE as both of those metrics are a mathematical function of effort. Analysis of the environmental data (mean April water temperature and water level) lagged the data by 2 years so as to make comparisons specifically between fish population and fishery metrics with environmental conditions at the time of spawning two years prior. This is based on the premise that environmental variables would most likely impact reproductive success and most fully exhibit their effect when yellow perch first recruited to the population at age-2. To test this assumption, the lagged water temperature and level data was also regressed on the geometric mean CPUE of age-2 yellow perch abundance (recruitment metric). Testing of the dependent variable of yellow perch mortality rate was limited to that produced by the catch curve method. The mortality rate estimates using the cohort method are not annual data (year specific) as they are year class specific and could not be regressed. Table 1 summarizes the independent and dependent variables analyzed by regression as well as their data sources. Analysis was limited to the time period from 1979 to 2004 which fully captured the various changes including the collapse of the fishery. A cormorant control program was implemented by the USDA's APHIS Wildlife Services in 2004 so this end point limited analysis to the time period before cormorant management activities commenced.

Significance of the alpha (type I error rate) used to test for the significance of the Pearson Correlation Coefficient (to test if the relationship is linear, an assumption of the method) and for the F statistic in the ANOVA of the predicted and residual values resulting from the regressions equation, was adjusted according to the Bonferroni correction (Neter *et al.* 1985). The Bonferroni correction is a multiple-comparison correction used when several dependent or independent statistical tests are being performed simultaneously in order to avoid spurious positives. This correction results in a more conservative approach to assigning statistical significance. The Bonferroni correction sets the alpha for the entire set of comparisons as alpha/n where n is the number of tests for the hypotheses. The number of tests used, however, was limited to the within metric number as opposed to all tests conducted across the same independent variable. This usually resulted in the alpha of 0.05 being divided by 2 to set the test alpha level.

Because time series data were involved in the regression analysis, there was a risk of autocorrelation (serial correlation) within variables which in turn tends to compromise (underestimate) the ordinary least squares variance as well as impose other inefficiencies and pose interpretative difficulties. To test for autocorrelation, the Durbin-Watson test was used (Neter *et al.* 1985). The preferred remedial measure for correcting for autocorrelation is the inclusion of additional independent variables in the model but because I was trying to isolate the effects of the independent variables, I instead used the "first differences" transformation of the dependent variable values to allow for the regression and resolve autocorrelation issues.

Conclusions about which factors most accounted for trends in the fish population and fishery were

***TABLE 1. Independent and dependent variables and independent data sources as analyzed by regression analysis for the Les Cheneaux Islands 1979–2004.***

<table>
<tr><td rowspan="13">Dependent Variables</td><td></td><td colspan="6">Independent Variables</td></tr>
<tr><td>Fishery Statistics</td><td>Cormorant abundance</td><td>Walleye abundance</td><td>Fishing effort</td><td>Yellow perch recruitment</td><td>Spring Water levels</td><td>Spring Water temps</td></tr>
<tr><td>Harvest</td><td rowspan="11">Cormorant nest count data</td><td rowspan="11">Geometric mean of the gillnet survey CPUE</td><td rowspan="11">From creel survey series</td><td rowspan="11">Geometric mean of the gillnet survey CPUE of age-2 fish</td><td rowspan="11">Mean April Lake Huron levels from NOAA</td><td rowspan="11">April monthly mean temperature from NOAA</td></tr>
<tr><td>Angler CPUE</td></tr>
<tr><td>Pop. Abundance metrics</td></tr>
<tr><td>GNCPUE all stations</td></tr>
<tr><td>Hessel GNCPUE</td></tr>
<tr><td>Pop. Age & growth metric</td></tr>
<tr><td>MeanLN@age3</td></tr>
<tr><td>Mean age</td></tr>
<tr><td>Mortality metric</td></tr>
<tr><td>CC mortality</td></tr>
</table>

based on which independent variables had the most significant relationships with the various dependent variables and which had the strongest relationship as indicated by the coefficient of determination. The collective approach allowed for the evaluation of which independent variables accounted for the most dependent variables in the perch population and fishery. Issues with collinearity prevented multiple regression analysis.

## RESULTS

### Trends in the Fishery and Cormorant Abundance

The sport fishery harvest of yellow perch peaked in 1986 and declined from there until the collapse in 2000 (Fig. 2). Among the precollapse years however, only 1995 and 1980 differed significantly with respect to harvest from the peak of 1986. Harvest was not significantly different among years within the post collapse period (2000–2004) but was different from the precollapse period (Fig. 2). Angler CPUE, which is a better indicator of the fishery quality and abundance (because it is effort independent) also did not vary significantly between 1979 and 1995 with the exception of 1980. Those years, however, were all significantly different from the post collapsed period of 2000–2004.

Cormorant abundance, as indicated by the nest count data, grew exponentially between 1980 and 1995 (Fig. 2). Abundance leveled off between 1995 and 2004. Cormorant nest numbers declined in 2004, which was attributed to abandonment of one rookery by cormorants stemming from the invasion or introduction of raccoons (*Procyon lotor*; B. Dorr, USDA WS, personal communication).

### Walleye Abundance

Walleyes, as indicated by the gillnet CPUE, were nearly completely absent from the fish community until 1988 (Fig. 3). Abundance increased there to a high in 1998 and then declined. Despite these trends, there were no significant differences among years. The overall magnitude of walleye gillnet CPUE in this time series was relatively low.

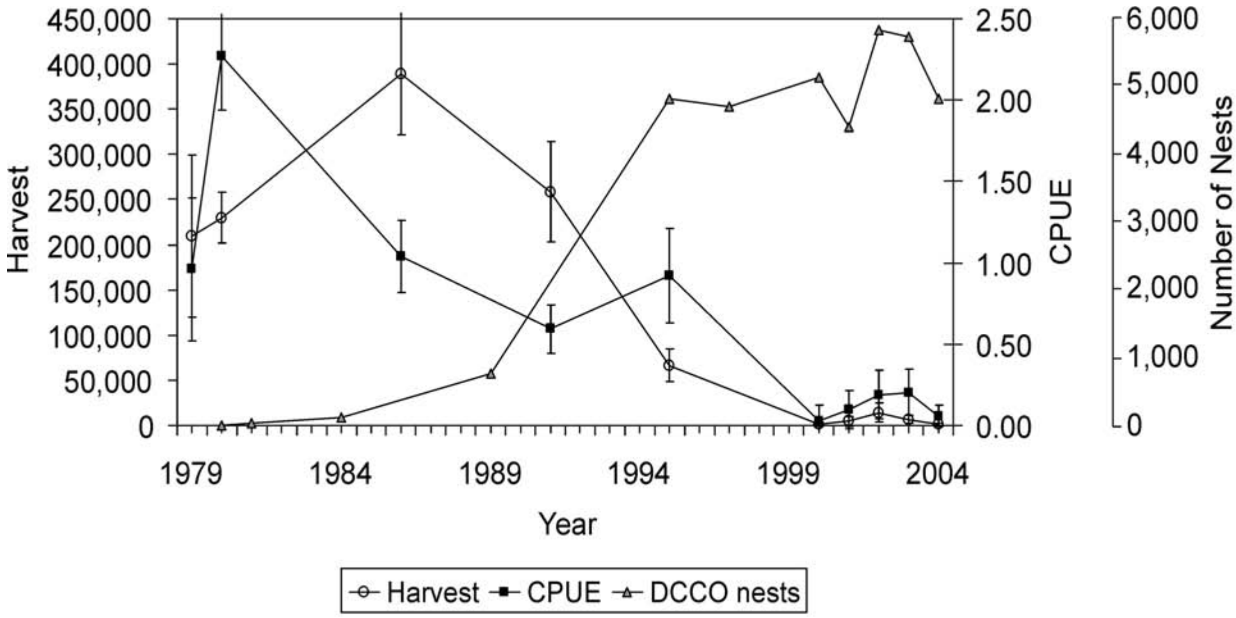


***FIG. 2. Trends in open water (April–October) yellow perch harvest and angler harvest rate (fish per hour of effort or CPUE), and double-crested cormorant (DCCO) nest numbers for the Les Cheneaux Islands, Lake Huron as determined by creel survey and nest inventory counts, 1979–2004.***

### Yellow Perch Abundance and Trends in Age and Growth

Abundance of yellow perch, as indicated by the gillnet CPUE, varied considerably over the time series between 1969 and 2004 with the lowest catches in the early 2000s (Fig. 4). The decline in gillnet CPUE trends observed in 1985 is partly attributed to a change in sample station that year. There were significant increases in gillnet CPUE beginning in 2004.

The decline of yellow perch is more apparent when limited to the gillnet CPUE at the Hessel sampling station (Fig. 4). Hessel Bay is geographically closest to the two largest cormorant rookeries (St. Martins Shoal and Goose Island). There is a clear decline of yellow perch abundance, discernable since the early 1990s including the collapsed period. Statistical significance is difficult to discern from this pattern because error bounds were not available for all years due to data recording issues.

Yellow perch mean age and growth rate both exhibited substantial change during the collapsed period. Mean age declined precipitously indicating a lack or low abundance of older fish or a relatively large abundance of young fish (Fig. 5). Growth rate, as indicated by the mean length at age-3 in October, increased significantly during the collapsed period (Fig. 5). Mean age and growth rate were correlated ($P < 0.001$, $r^2 = 0.66$) .

### Yellow Perch Recruitment

Reliable age data from which to construct the index of yellow perch recruitment (expressed as the gillnet CPUE of age-2 fish) was limited to 23 years out of the 36 year time series (Fig. 6). The CPUE of age-2 fish reflects the year class of 2 years prior. Although variable, it is apparent that recruitment continued during the collapsed period and was not significantly different from most precollapse years. Most notable was a strong CPUE of age-2 fish in 2000 (reflecting the 1998 year class). This year class recruited to the population in the year the fishery collapsed (2000).

### Yellow Perch Total Annual Mortality Rate

Total annual mortality rate as indicated by Robson-Chapman catch curve analysis varied little between 1969 and 1990 but increased greatly in 1994 and generally exhibited a period of more variable and generally greater mortality from 1994 to 2004 (Fig. 7). Total annual mortality rate calculated using the cohort method was also high in all but one year class since the mid 1990s (Fig. 8). The greatest rate measured was 85% for the 2000 year class for the years 2001–2004. Total annual mortality rate was 72% or higher for five year classes of yellow perch represented by data since 2000, which corresponds

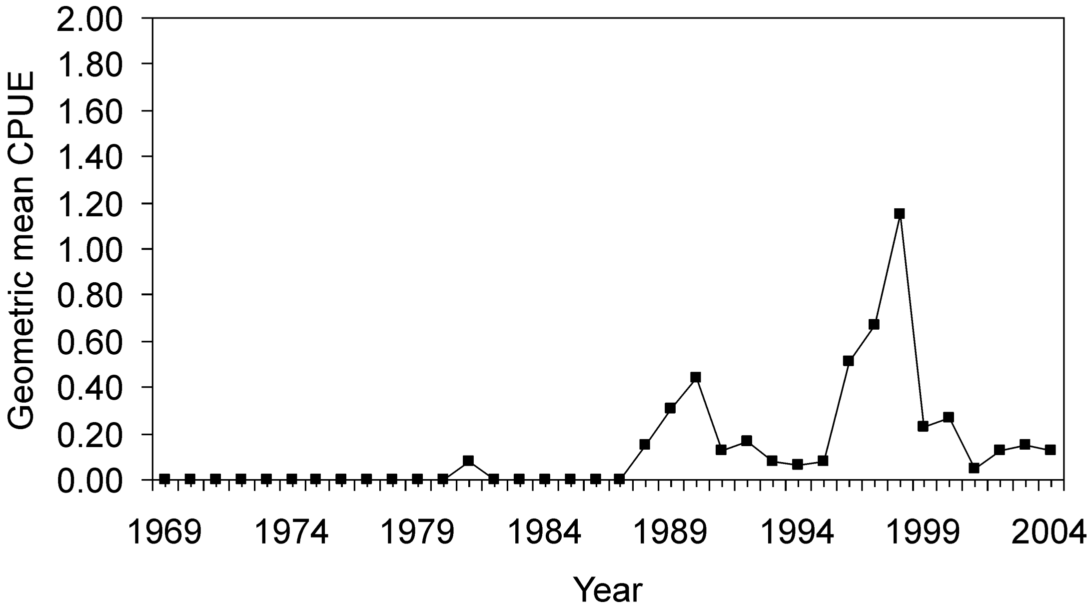


***FIG. 3. Geometric mean gillnet catch of walleye per 305 m of net (CPUE) for the Les Cheneaux Islands, 1969–2005. Error bars for ± 2 standard errors of the geometric mean are not shown to allow for scale. There were no means significantly different among years.***

to the collapsed period when fishing effort was very low in the Les Cheneaux Islands. Most notable was the fate of the strong 1998 year class. These fish recruited to the population and the fishery in the fall of 2000, during the fishery collapse. Despite the very low level of fishing effort over the following 4 years, the 1998 year class quickly depleted, exhibiting a 76% total annual mortality rate (Fig. 8).

### Spring Water Levels and Temperatures

Mean April water levels in Lake Huron and mean April surface water temperature varied over the time series since 1979 (Fig. 9). Spring water temperature rose as much as 3°C in the late 1990s compared to the long-term average. Spring water levels declined by as much as 1 meter during this same

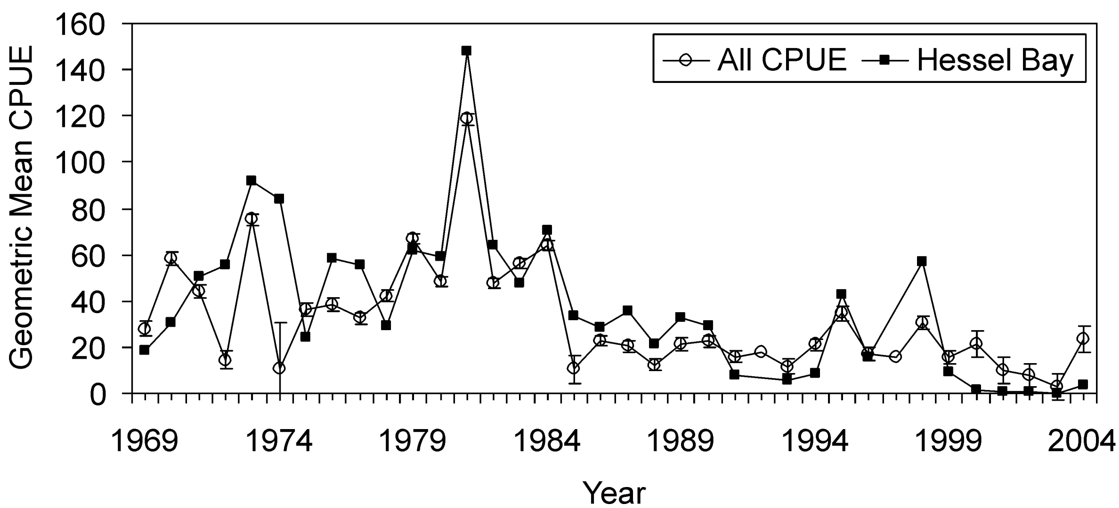


***FIG. 4. Geometric mean gillnet catch of yellow perch per 305 m of net (CPUE) for the all Les Cheneaux Islands sets combined and that for just Hessel Bay, 1969–2004. Error bars represent ± 2 standard errors of the geometric mean.***

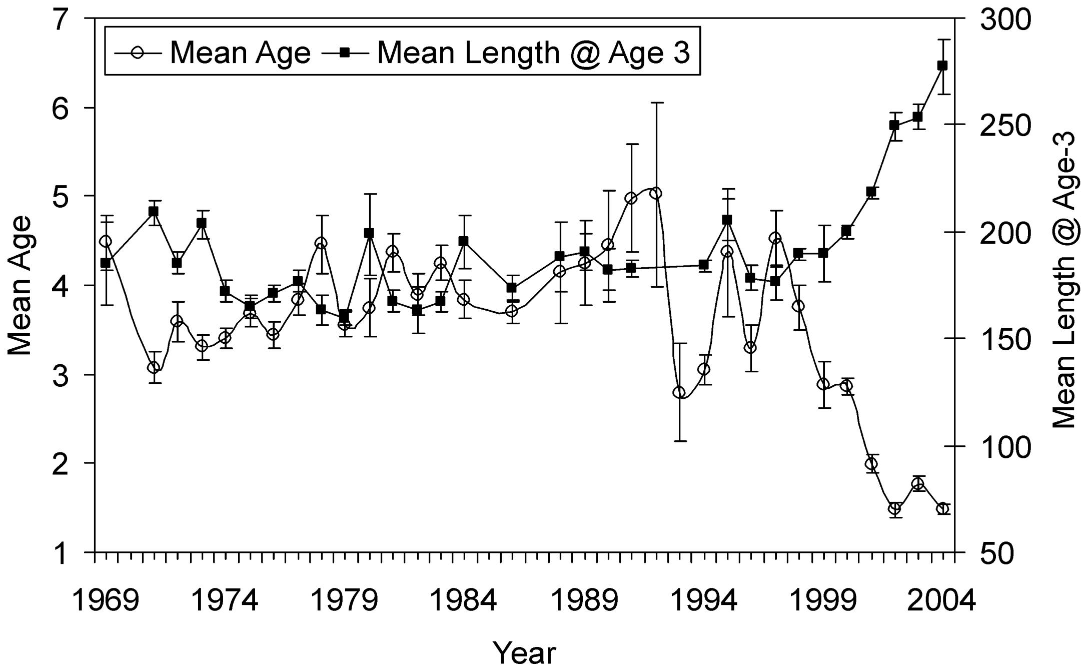


***FIG. 5. Mean age(years) and Growth rate (mean length in mm at age 3) of yellow perch collected by gillnetting in the Les Cheneaux Islands from 1969–2004. Error bars represent ± 2 standard errors of the mean.***

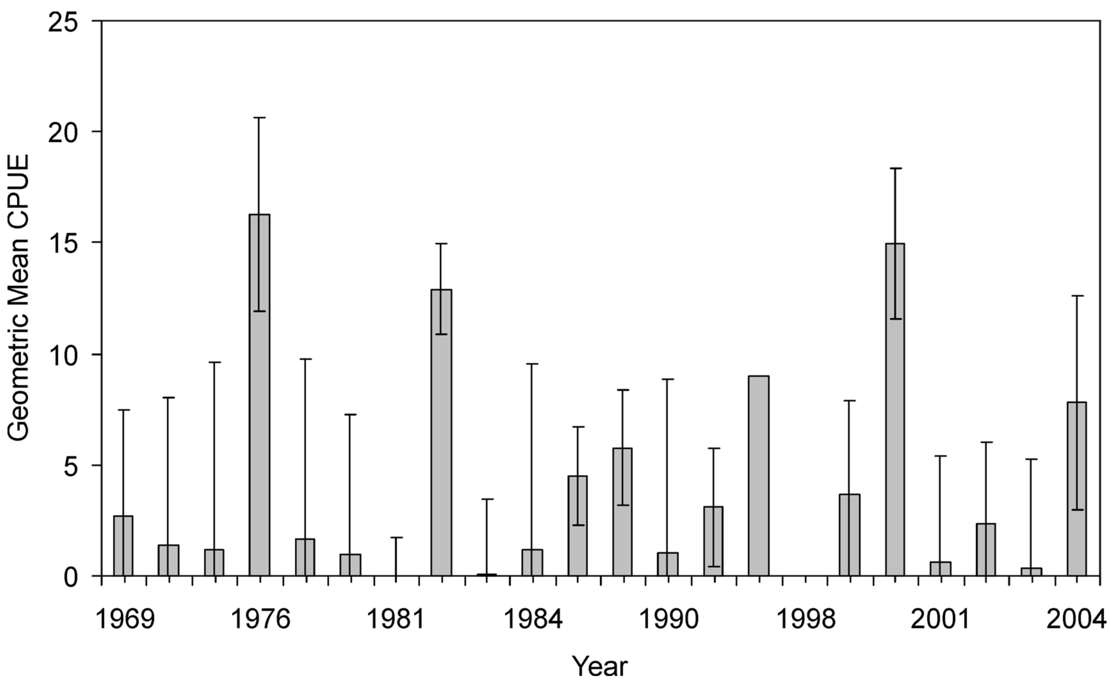


***FIG. 6. Geometric mean gillnet catch of age-2 yellow perch per 305 m of net (CPUE) in the Les Cheneaux Islands as an expression of recruitment trends, for select years (when unbiased age data existed) between 1969–2004. Error bars represent ± 2 standard errors of the geometric mean.***

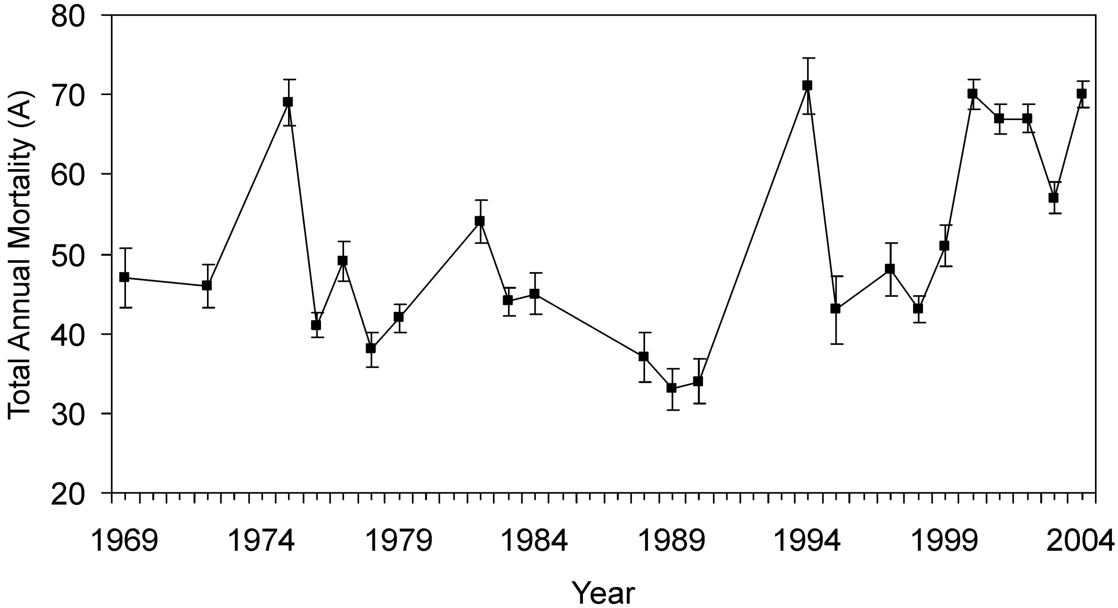


***FIG. 7. Total annual mortality rate (A) of yellow perch in the Les Cheneaux Islands as indicated by the catch-curve method, for select years (when unbiased age data existed) between 1969–2004.***

time period. Data sources did not include expressions of variance so confidence intervals were not possible. Testing of these environmental variables is premised on the belief that they may influence yellow perch recruitment. When regressed as 2 year lagged data on the geometric mean CPUE of age-2 yellow perch from the gillnet collections, no significant relationship was found (water temperature P = 0.899 and water level P = 0.432).

**Regression Analysis of Yellow Perch Metrics**

Analysis by linear regression of the seven yellow perch metrics (potential dependent variables) as a function of the six candidate independent variables indicated a total of nine significant relationships (Table 2). Of those, only three independent variables held any explanatory power for the dependent variables: cormorant abundance (nest count num-

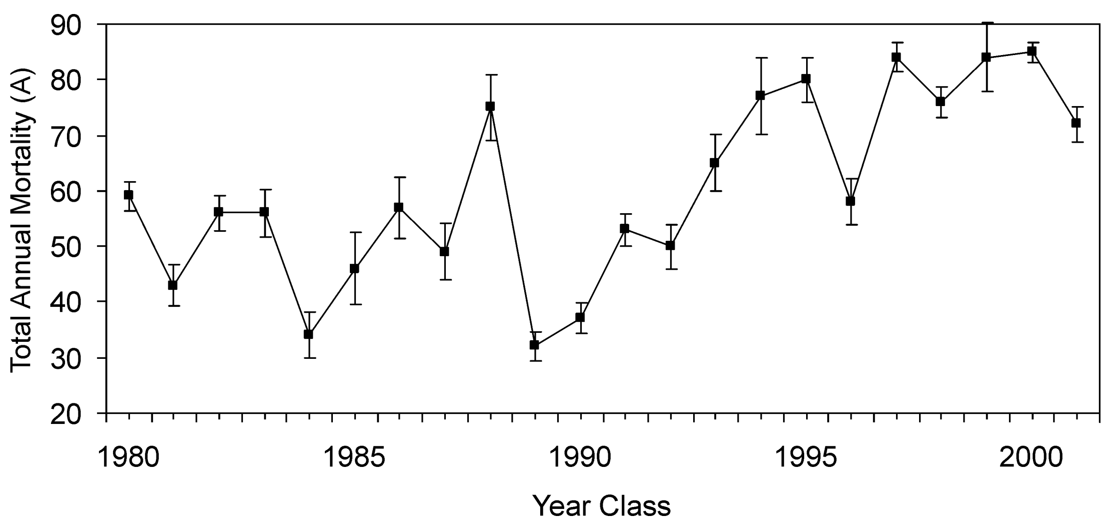


***FIG. 8. Total annual mortality rate (A) of yellow perch in the Les Cheneaux Islands as indicated by the cohort method, for year classes between 1980–2001.***

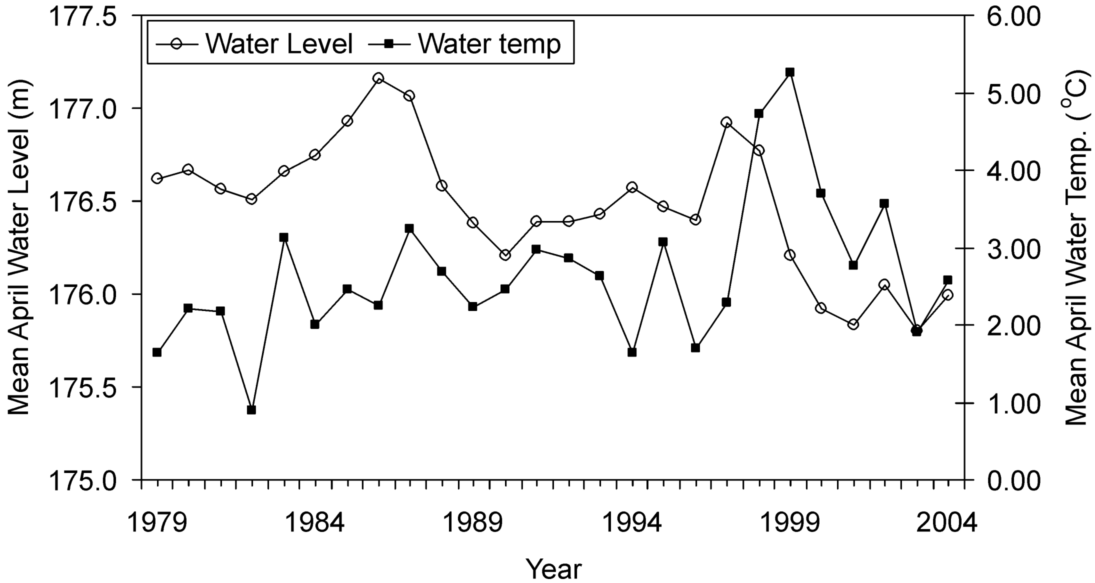


***FIG. 9. Trends in mean April water level and surface temperature for the Les Cheneaux Islands vicinity 1979–2004.***

bers) and the two environmental variables (spring water levels and temperatures when lagged by 2 years in the analysis). Autocorrelation was problematic in some analyses but in each case could be eliminated by the data transformation.

Cormorant abundance exhibited five significant regression relationships with yellow perch metrics, including harvest, angler CPUE, yellow perch abundance (as indicated by the gillnet CPUE) across all stations and when examined specifically for Hessel Bay, and lastly with total annual mortality rate of yellow perch. Spring water temperature (mean April water temperature lagged by 2 years in the analysis) had statistically significant relationships with yellow perch angler CPUE, mean age of yellow perch, and yellow perch total annual mortality rate. Spring water levels exhibited a significant relationship with yellow perch total annual mortality rate only (Table 2). There were no statistically significant relationships between yellow perch recruitment, walleye abundance, or fishing effort with any of the seven potential dependent variables.

## DISCUSSION

Based on the regression analysis, trends in cormorant abundance best explain the trends in the yellow perch fishery and population including the collapse. There were a total of five significant regression equations for cormorant abundance and none for trends in yellow perch recruitment, walleye abundance, or fishing effort. The lack of relationship between yellow perch recruitment and trends in the various dependent variables indicates that recruitment (at least as it was measured in this study) does not account for the collapse in the perch population or fishery. Curiously, however, there were some significant relationships between the environmental data (water temperature and levels) and some perch dependent variables. The absence of a significant relationship between these environmental variables and the recruitment variable itself suggests that these environmental variables are not strong predictors of the yellow perch metrics by them selves. The environmental variables were examined to test for possible mechanisms for a significance in recruitment as an independent variable, but in the absence of that significance, it is difficult to know how much weight to assign to these relationships with the environmental variables. Generally the environmental correlations coefficients ($r^2$) was much less than those explained by cormorant trends.

The significance of the two environmental variables on mortality rate of yellow perch 2 years later defies most biological mechanistic explanation except that spring water temperatures, which exhibited a positive relationship with total annual mortality, may indicate that increased recruitment from warmer years, elevated the abundance of age-

*TABLE 2. Liner regression results for those relationships that tested significant between seven dependent yellow perch variables versus six independent variables from years 1979–2004 for the Les Cheneaux Islands. "GN" denotes gillnet, "CPUE" denotes Catch-per-unit-of-effort and "CC" denotes catch curve.*

| Dependent variable | Pearson Correlation stat. | Pearson correlation sig level | Direction | $r^2$ | degrees of freedom | ANOVA sig (F stat) | constant | slope |
|---|---|---|---|---|---|---|---|---|
| **Cormorant Abundance** | | | | | | | | |
| **Fishery metric** | | | | | | | | |
| Harvest | –0.961 | <0.0001 | neg | 0.924 | 7 | <0.0001 | 214739.2 | –42.026945 |
| Angler CPUE | –0.807 | 0.0008 | neg | 0.651 | 7 | 0.0150 | 1.5860 | –0.000282 |
| **Pop. Abundance metric** | | | | | | | | |
| GNCPUE all stations | –0.770 | 0.0020 | neg | 0.593 | 11 | 0.0030 | 66.6997 | –0.010988 |
| Hessel GNCPUE | –0.782 | 0.0020 | neg | 0.612 | 10 | 0.0040 | 76.6668 | –0.014949 |
| **Mortality metric** | | | | | | | | |
| CC mortality | 0.712 | 0.0100 | Pos | 0.507 | 9 | 0.021 | 38.2710 | 0.004720 |
| **Yellow Perch Recruitment** | | | | | | | | |
| No significant relationships | | | | | | | | |
| **Walleye Abundance** | | | | | | | | |
| No significant relationships | | | | | | | | |
| **Fishing Effort** | | | | | | | | |
| No significant relationships | | | | | | | | |
| **Spring Water Levels** | | | | | | | | |
| **Mortality metric** | | | | | | | | |
| CC mortality | –0.578 | 0.0080 | Neg | 0.335 | 16 | 0.015 | 3816.052 | –21.329054 |
| **Spring Water Temperature** | | | | | | | | |
| **Fishery metric** | | | | | | | | |
| Angler CPUE | –0.772 | 0.0120 | Neg | 0.596 | 7 | 0.025 | 1.2854 | –0.266496 |
| **Pop. Age & growth metric** | | | | | | | | |
| Mean Age | –0.524 | 0.0060 | Neg | 0.275 | 21 | 0.012 | 5.0284 | –0.569016 |
| **Mortality metric** | | | | | | | | |
| CC mortality | 0.520 | 0.0160 | Pos | 0.271 | 16 | 0.032 | 33.291 | 6.472977 |

2 yellow perch, which in turn would have steepened the slope of the catch curve resulting in an increased estimate of total annual mortality rate. Spring water temperatures in year-2 were negatively correlated with angler catch rate and mean age. Again, the temperature-age correlation may be reflecting the positive relationship between temperature and recruitment. From this analysis, I cannot fully discount the possibility of a recruitment influence as a concurrent or contributory factor, but I conclude that cormorant abundance is the most influential force on the yellow perch fishery and population over the time span examined here.

This conclusion is supported by several metrics which deviated from their long-term trends coincident with the increase of cormorants in the area. Past work in the Les Cheneaux Islands asserted that the fishery was in decline before cormorants became abundant (Diana *et al.* 2006). My analysis, however, indicates angler CPUE had not varied significantly from the long-term trend until 1995 and perhaps not until 2000. This is consistent with the findings of Lucchesi (1988) who also concluded that complaints of declines in the fishery up through the mid 1980s were not genuine. Harvest declines in the presence of a stable angler CPUE means declining fishing effort had driven the declines in harvest. That appears to have been the case in 1995 (Fig. 2). It wasn't until the collapsed period that significant declines in the fishery occurred which included declines in angler CPUE. The first creel survey to describe the collapsed period was 2000 but anecdotal evidence from the local fishing community suggests that the collapse was fully evident by 1998. Unfortunately, there was no creel survey in the late 1990s, nor were quantitative creel surveys conducted in the Les Cheneaux Islands prior to 1979. Records kept by conservation officers since the 1930s (MDNR, unpublished data), however, indicate that the modern-day collapse was unprecedented.

Trends in the gillnet survey CPUE largely mirrored those of the fishery (Fig. 4) except that the gillnet CPUE did not decline until 2001, a year after the collapse in fishery harvest. The gillnet survey takes place in October each year near the end of the open water fishing season and thus is not perfectly synchronized in time with fishery harvest. The gillnet CPUE in 2000 was driven by the strong 1998 year class (Fig. 6) which, while nearly fully recruited to the gillnets was just beginning to recruit to the fishery (Fig. 4) by October. Still, these data indicate that yellow perch were never totally absent in the Les Cheneaux Islands during the collapsed period. Some of the declines in fishing effort may have stemmed from anglers quitting the fishery because of declines in quality (average size of the perch and catch rate). Negative press highlighting the abundance of cormorants may have further eroded angler expectations.

Several key yellow perch metrics further document a substantial decline in yellow perch abundance in the Les Cheneaux Islands beginning in 2000. Angler CPUE declined nearly 31 fold from the previous survey (1995) meaning that even those anglers still fishing experienced a scarcity of perch. Growth rate and mean age (Fig. 5) are consistent with a low abundance of yellow perch of harvestable size. Yellow perch growth, if density dependent, will increase in response to declines in abundance (Eshenroder 1977) presumably because of declining intraspecific competition. A declining mean age is consistent with a lack of older individuals stemming from the high mortality rate. Thus, increase in growth rate and declines in mean age are typical yellow perch population responses to a high mortality rate and lower abundance (Eshenroder 1977). The evidence clearly suggests that the collapse in the fishery was the result of decline in abundance of older perch.

Diana *et al.* (1997) and Diana *et al.* (2006) discounted cormorant predation (and the sport fishery) as having any appreciable effect on perch abundance. Although those studies did not attempt to quantify trends in recruitment, they implied that declines in recruitment most likely account for yellow perch trends in the population and fishery. In my analysis, yellow perch recruitment was not lacking during or leading up to the collapsed period (Fig. 6) and in fact experienced a substantial year class (1998) that initially recruited during the collapsed period. A central conclusion of Diana *et al.* (1997) was that cormorants fed principally on small perch (less than 150 mm) in the Les Cheneaux Islands. It is therefore probable that the abundance of age-2 yellow perch, as measured in October, has declined since cormorants became abundant. In the absence of cormorant predation, the magnitude of yellow perch recruitment, as measured at age 2 (three growing seasons), may have been even greater. O'Gorman and Burnett (2001) documented this effect on yellow perch by cormorants in northeastern Lake Ontario. Lantry *et al.* (1999) described a similar phenomenon for smallmouth bass (*Micropterus dolomieui*) in eastern Lake Ontario as a result of cormorant predation and termed it a "mortality bottleneck prior to recruitment." Thus it appears that one effect of cormorant predation is to reduce the abundance of young members of a fish population and either create the appearance of reduced recruitment or make it difficult to distinguish between effects of mortality and recruitment.

Further evidence of continued recruitment was the declining trend in mean age (Fig. 5). A declining mean age is a classic response of an over harvested fish population (Eshenroder 1977) while increasing mean age would be indicative of recruitment declines. Declining mean age in fish populations is documented elsewhere as a response to cormorant predation (Lantry *et al.* 1999). The emergence of the strong 1998 year class within this time period illustrates that recruitment was by no means lacking in the Les Cheneaux Islands. Variable and even cyclic patterns of recruitment are common in yellow perch populations (Sanderson *et al.* 1999), and while recruitment in the Les Cheneaux Islands population was not steady, it exhibited a fairly overall consistent level.

Excessive mortality, rather than declining recruitment, appears to explain the yellow perch collapse after 1999. Total annual mortality rate increased to a very high level in the presence of rising numbers of cormorants (Figs. 7 and 8). Interestingly, some of the years of highest mortality (as great as 85%) occurred during the collapsed period when fishing activity was very low. Clearly the fishery didn't contribute substantially to the rise in mortality, suggesting instead that losses were due to some form of natural mortality.

Rising walleye abundance may result in greater yellow perch mortality but my analysis found no relationship between walleye abundance and any yellow perch metric. This was likely due to the relatively low abundance walleye achieved in the Les Cheneaux Islands. Apparently the level of walleye stocking that took place during this time series was not enough to create an abundant walleye population. Survival of walleye pre-recruits may have been subject to the same factors limiting yellow perch, particularly cormorant predation. Regardless, walleye abundance can be ruled out as a substantial force shaping yellow perch abundance up to 2004, leaving only the predation of cormorants as a principal driving factor. This does not, however, rule out the potential of walleye predation on yellow perch to become significant should walleye become more abundant.

Similarly, fishing effort also had no explanatory power in the regression analysis for trends in the yellow perch population. Despite this, it is not clear what functional relationship exists between fishing mortality and cormorant-based mortality on yellow perch. It is likely that in the early years of cormorant proliferation (say 1980 to 1995) when fishing effort was higher, that the two mortality sources were cumulative. It is then probable that the two mortality sources became compensatory once perch abundance began to decline (1996–2004). Under this scenario, it is possible that the collapse of the perch population and fishery was a function of losses to both angler harvest and cormorant predation, acting in concert to result in an unsustainable total annual mortality rate.

Was total annual mortality really as low as reported in 1995 and for 3 years after (through 1998)? Estimation of total annual mortality rate by catch-curve assumes that the sample of ages reflects a declining abundance from a trend of constant recruitment (Van Den Avyle and Hayward 1999). If the sample for analysis does not include younger (unrecruited to gear) age groups, as in my gillnet survey, and if losses are driven by a predator that will extract without selection or preference for large fish, then the result could be a flattened age frequency, which in turn would result in an underestimation of total annual mortality (lower slope of the fitted line). Because cormorants prey largely on juvenile perch (Diana *et al.* 1997), it seems plausible that the age frequency of the gillnet collections was perturbed in such a way as to cause the catch-curve method to underestimate mortality. This is especially likely when a new force of mortality is suddenly applied to a fish population, as with the exponential increase in cormorant numbers. This may partly account for the lower estimates of mortality rate between 1995 and 1999 (Fig. 7). In spite of these potential complications to mortality estimation, we see a significant relationship ($P = 0.021$) with more than half the annual variability in total mortality rate being explained by trends in cormorant abundance.

Vulnerability of catch-curve mortality estimation to variation in recruitment and size-selective mortality is overcome through the cohort-based approach used in Figure 8. The cohort-based approach suggests annual mortality of yellow perch was high since 1994. Cohort-based estimates of total mortality could not be tested by regression as they are not annual data, but instead reflect total mortality over a span of years for specific year classes.

Diana *et al.* (1997) illustrated that cormorants fed almost entirely on juvenile yellow perch. In my analysis, however, mortality rates mostly reflected ages 2 and older; the adult yellow perch. Cormorants, nevertheless, are opportunistic feeders (Ludwig *et al.* 1989) with their diet generally reflecting the size range of fish in the local community. It is possible that cormorant diet with respect to perch lengths and ages was different in 1995 (during the Diana *et al.* 1997 study) versus that in later years. This could be fueled by the decline in alewives over this time period, forcing cormorants to utilize alternate prey. As yellow perch became scarce, cormorants may also have utilized a greater size and age range. Ludwig *et al.* (1989) characterizes Great Lakes cormorants as being adaptable and reports that they will regularly switch prey items when alewives are scarce or unavailable. Adult yellow perch are fully within the size range of prey consumable by adult cormorants (Campo *et al.* 1993, USFWS 2001).

It appears that trends in total annual mortality rate are the best means to characterize impacts from cormorant predation. Yellow perch mortality rate increased in response to, or coincident with, the increase in cormorant abundance in Lake Ontario (O'Gorman and Burnett 2001, Burnett *et al.* 2002) and in Lake Oneida (Rudstam *et al.* 2004). In Lake Ontario, yellow perch total annual mortality rate nearly doubled in the presence of increasing numbers of cormorants (O'Gorman and Burnett 2001).

Establishing cause and effect relationships in large ecosystems can be challenging. The findings in this analysis suggest trends in the yellow perch population and fishery are correlated with concurrent proliferation of cormorants in the area. Diana *et al.* (1997) established that cormorants seasonally fed upon yellow perch in the Les Cheneaux Islands and consumed substantial numbers. The range of coefficients of determination ($r^2$) in Table 2 make it clear that other factors besides trends in cormorant numbers are also affecting the perch population and fishery. This analysis, however, finds abundant evidence to include cormorants among the suite of factors affecting the perch population.

One option to further isolate and define the significance of cormorant consumption on yellow perch dynamics is to manipulate the current system and measure response. Cormorant control was implemented by the USDA's Wildlife Services office in Michigan in 2004 based on new rules for cormorant management extended by the U. S. Fish and Wildlife Service (U. S. Fish and Wildlife Service 2003). Egg oiling and direct culling of a proportion of adult birds at the rookery sites is expected to produce a measurable reduction in cormorant numbers. The approach was designed as an adaptive management exercise with simultaneous evaluation of both the fish and bird populations.

Based on the findings of this analysis, I hypothesize that if cormorant predation is, in fact negatively affecting the yellow perch population and fishery, then likely responses to reduced cormorant abundance stemming from control activities would include: improvements to the fishery (increasing angler CPUE and eventually fishing effort and harvest totals); increases in mean age and a lowering growth rate; increases in abundance of perch across the area and especially in the Hessel Bay area; and, perhaps most importantly, declines in total annual mortality rate. These metrics will be used to test for the effects of declining cormorant numbers in the Les Cheneaux Islands.

## ACKNOWLEDGMENTS

The data included in this report include contributions from many others. Much of the cormorant nesting data was provided by the Michigan office of the USDA's Wildlife Services. The creel survey estimates are a product of the Statewide Angler Survey Program of the Michigan DNR. Both the creel survey and gillnet collections were funded by Sport Fish Restoration Projects F-81-R, Studies 499 and 695. Advice on statistical analysis was provided by Zhenming Su of the Michigan DNR's Institute for Fisheries Research and Shawn Sitar of the Marquette Fisheries Research Station. Several persons provided critical reviews of early versions of this manuscript that resulted in revisions and refinements. Those persons include; of the USDA's Wildlife Services, Peter Butchko and Brian Dorr; of the USFWS, Shauna Hanisch; and of the Michigan DNR; James Johnson.

## REFERENCES

Argyle, R.L. 2005. Prey fishes. In *The state of Lake Huron in 1999.* M.P. Ebener, ed., pp. 43–46. Great Lakes Fishery Commission Special Publication. 05-02.

Bregnballe, T., and Lorentsen, S.H. 2006. Great cormorant counting manual–from the Intercafe cost cormorant manual. Wetlands International Cormorant Research Group. http://web.tiscali.it/sv2001/cormo_abstract/2001-2.htm

Burnett, J.A.D., Ringler, N.H., Lantry, B.F., and Johnson, J.H. 2002. Double-crested cormorant predation on yellow perch in the eastern Basin of Lake Ontario. *J. Great Lakes Res.* 28:202–211.

Campo, J.J., Thompson, B.C., Barron, J.C., Telfair II, R.C., Durocher, P., and Gutreuter, S. 1993. Diet of double-crested cormorants wintering in Texas. *J. Field Ornithol.* 64(2):135–144.

Clady, M., and Hutchinson, B. 1975. Effect of high winds on eggs of yellow perch, Perca flavescens, in Oneida Lake, New York. *Trans. American Fish. Soc.* 104:524–525.

Clapp, D.F., and Dettmers, J.M. 2002. Yellow perch research and management in Lake Michigan: evaluating progress in a cooperative effort 1997–2001. *Fisheries* 29:11–19.

Consent Decree Manual. 2000. *1836 Great Lakes Treaty Waters Consent Decree Manual.* United States of American vs. State of Michigan. U.S. District Court, Western District of Michigan, Southern Division. Case No. 2:73 CV26.

Craig, J.F. 1987. *The biology of perch and related fish.* Portland: Timber Press.

Croley, T.E. II. 2005. Recent Great Lakes evaporation model estimates. In *Proceedings of the 2005 World Water and Environmental Resources Congress: Impacts of Global Change,* Anchorage, AK, May 15–19, 2005. American Society of Civil Engineers. (http://www.glerl.noaa.gov/pubs/fulltext/2005/20050015.pdf)

——, and Hunter, T.S. 1994. *Great Lakes monthly hydrologic data.* NOAA Technical Memorandum ERL GLERL-83, Great Lakes Environmental Research Laboratory, Ann Arbor, MI (PB95-173076/XAB). (ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-083)

Diana, J.S., Jones, C.A., Lucchesi, D.O., and Schneider, J.C. 1987. *Evaluation of the yellow perch fishery and its importance to the local economy of the Les Cheneaux Islands area.* Michigan Department of Natural Resources, Coastal Management Program, Grant LRP-8c-7, Final Report. 58p. Ann Arbor.

——, Belyea, G.Y., and Clark, Jr., R.D., eds. 1997.

*History, Status, and Trends in Populations of Yellow Perch and Double-crested Cormorants in Les Cheneaux Islands, Michigan.* State of Michigan Department of Natural Resources, No. 17. Ann Arbor.

______, Maruca, S., and Lowe, B. 2006. Do increasing cormorant populations threaten sport fishes in the Great Lakes? A case study in Lake Huron. *J. Great Lakes Res.* 32:306–320.

Eshenroder, R.L. 1977. Effects of intensified fishing, species changes, and spring water temperatures on yellow perch, *Perca flavescens*, in Saginaw Bay. *J. Fish. Res. Board Can.* 34:1830–1838.

Fielder, D.G. 2004. Collapse of the yellow perch fishery in the Les Cheneaux Islands, Lake Huron, and possible causes. In *Proceedings of the Percis III; The Third International Percid Fish Symposium,* T.P. Barry and J.A. Malison, eds., pp. 129–130. University of Wisconsin Sea Grant Institute. Madison.

Fielder, D.G., Johnson, J.E., Weber, J.R., Thomas, M.V., and Haas, R.C. 2000. *Fish population survey of Saginaw Bay, Lake Huron, 1989–97.* Michigan Department of Natural Resources, Fisheries Research Report, 2052. Ann Arbor.

Grover, F.R. 1911. *A Brief History of Les Cheneaux Islands; Some New Chapters of Mackinac History.* Evanston, IL: Bowman Publishing Co.

Henderson, B.A. 1985. Factors affecting growth and recruitment of yellow perch, *Perca flavescens* Mitchill, in South Bay, Lake Huron. *J. Fish Biol.* 26:449–458.

Hilborn, R., and Walters, C.J. 1992. *Quantitative fisheries stock assessment: choices, dynamics & uncertainty.* New York: Chapman & Hall.

Hurley, D.A. 1972. Observations on incubating walleye eggs. *Prog. Fish-Cult.* 34:49–54.

Johnson, J.H., and Ross, R.M. 1996. Pellets versus feces: their relative importance in describing the food habits of double-crested cormorants. *J. Great Lakes Res.* 22:795–798.

Kirkwood, T.B.L. 1979. Geometric means and measures of dispersion. *Biometrics* 35:908–909.

Lantry, B.F., Eckert, T.H., and Schneider, C.P. 1999. *The relationship between abundance of smallmouth bass and double-crested cormorants in the eastern basin of Lake Ontario.* New York Department of Environment and Conservation. Special Report.

Lucchesi, D.O. 1988. *A biological analysis of the yellow perch population in the Les Cheneaux Islands, Lake Huron.* Michigan Department of Natural Resources, Fisheries Research Report No. 1958. Ann Arbor.

Ludwig, J.P. 1984. Decline, resurgence and population dynamics of Michigan and Great Lakes double-crested cormorants. *Jack Pine Warbler* 62:91–102.

______, and Summer, C.L. 1997. Population status and diet of cormorants in Les Cheneaux Islands area. In *History, status, and trends in populations of yellow perch and double-crested cormorants in Les Cheneaux Islands, Michigan,* J.S. Diana, G.Y. Belyea, and R.D. Clark Jr., eds., pp. 5–25. Michigan Department of Natural Resources Special Report 17. Ann Arbor.

______, Hull, C.N., Ludwig, M.E., and Auman, H.J. 1989. Food habits and feeding ecology of nesting double-crested cormorants in the upper Great Lakes, 1986–1989. *The Jack-Pine Warbler* 67:115–126.

Maruca, S.L. 1997. Description of the study area.In *History, status, and trends in populations of yellow perch and double-crested cormorants in Les Cheneaux Islands, Michigan,* J.S. Diana, G.Y. Belyea, and R.D. Clark Jr., eds., pp. 3–4. Michigan Department of Natural Resources Special Report 17. Ann Arbor.

McConnaughey, R.A., and Conquest, L.L. 1993. Trawl survey estimation using a comparative approach based on lognormal theory. *Fishery Bulletin* 91:107–118.

Neter, J., Wasserman, W., and Kutner, M.H. 1985. *Applied linear statistical models. Second edition.* Homewood, Illinois: Richard D. Irwin, Inc.

O'Gorman, R., and Burnett, J.A.D. 2001. Fish community dynamics in Northeastern Lake Ontario with emphasis on the growth and reproductive success of yellow perch (*Perca flavescens*) and white perch (*Morone americana*), 1978 to 1997. *J. Great Lakes Res.* 27:367–383.

Pittman, P.M. 1984. *Les Cheneaux Chronicles: Anatomy of a Community.* Cedarville, MI: Les Cheneaux Ventures.

Rakoczy, G.P. 1992. *Sportfishing catch and effort from the Michigan waters of Lakes Michigan, Huron, Erie, and Superior, and their important tributary streams, April 1, 1991–March 31, 1992.* Michigan Department of Natural Resources Technical Report No. 92-11. Ann Arbor.

Ricker, W.E. 1975. *Computation and interpretation of biological statistics of fish populations.* Bulletin of the Fisheries Research Board of Canada. Bulletin 191. Ottawa.

Rudstam, L.G., VanDeValk, A.J., Adams, C.M., Coleman, J.T.H., Forney, J.L.. and Richmond, M.E. 2004. Cormorant predation and the population dynamics of walleye and yellow perch in Oneida Lake. *Ecological Applications* 14:149–163.

Ryckman, J.R. 1981. Creel census methods in general. Appendix VI-A-9. In *Manual of fisheries survey methods,* J. W. Merna *et al.*, eds. Michigan Department of Natural Resources, Fisheries Management Report 9. Ann Arbor.

Sammons, S.M., and Bettoli, P.W. 1998. Larval sampling as a fisheries management tool: early detection of year-class strength. *North American J. Fish. Manage.* 18:137–143.

Sanderson, B.L., Hrabik, T.R., Magnuson, J.J., and Post, D.M. 1999. Cyclic dynamics of a yellow perch (Perca flavescens) population in an oligotrophic lake: evidence for the role of intraspecific interactions. *Can. J. Fish. Aquat. Sci.* 56:1534–1542.

Scharf, W.C., and Shugart, G.W. 1998. *Distribution and abundance of gull, tern, and cormorant nesting colonies of the Great Lakes, 1989 and 1990.* Publication No. 1, Gale Gleason Environmental Institute, Lake Superior State University, Sault Ste. Marie, Michigan.

Schneeberger, P.J., and Scott, S.J. 1997. Population dynamics and fishery statistics for yellow perch in Les Cheneaux Islands area. In *History, status, and trends in populations of yellow perch and double-crested cormorants in Les Cheneaux Islands, Michigan,* J.S. Diana, G.Y. Belyea, and R.D. Clark Jr., eds., pp. 26–46. Michigan Department of Natural Resources Special Report 17. Ann Arbor.

Schneider, J.C., ed. 2000. *Manual of fisheries survey methods II: with periodic updates.* Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

Schupp, D.H. 2002. What does Mt. Pinatubo have to do with walleyes? *North Am. J. Fish. Manage.* 22: 1014–1020.

Sokal, R.R., and Rohlf, F.J. 1981. *Biometry,* Second edition. San Francisco: W. H. Freeman and Company.

U.S. Fish and Wildlife Service. 2001. *Draft environmental impact statement: Double-crested cormorant management.* Department of the Interior, U.S. Fish and Wildlife Service. Washington D.C.

______. 2003. *Migratory Bird Permits; Regulations for Double-Crested Cormorant Management (Final Rule).* 50 CFR Part 21, RIN 1018–AI39. U.S. Department of the Interior, Washington D.C.

Van Den Avyle, M.V., and Hayward, R.S. 1999. Dynamics of exploited fish populations. In *Inland fisheries management in North America, 2nd edition,* C.C. Kohler and W. A. Hubert, eds., pp. 127–166. American Fisheries Society, Bethesda, Maryland.

Wilgoren, J. 2002. A bird that's on a lot of hit lists. New York Times. Section A, Page 12, Column 1.

*Submitted: 29 May 2007*
*Accepted: 2 May 2008*
*Editorial handling: Thomas R. Hrabic*