<u>Year Three Progress Report:</u>

Dynamics and Models of the Yellow Perch in Indiana Waters of Lake Michigan and Near-Shore Fish Community Characteristics

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Executive Summary

This report represents the progress results for the Federal Aid Project F- 18- R, Study 11 (2004 field sampling) entitled: Dynamics and Models of the Yellow Perch in Indiana Waters of Lake Michigan and Near-Short Fish Community Characteristics. These findings extend and enhance the work ongoing since the 1970's with emphasis on the period 1984-2004. These investigations have focused on yellow perch *Perca flavescens* and have created one of the most significant and useful long-term data sets of the Great Lakes fisheries.

Yellow perch and 15 other species were quantitatively sampled using bottom trawling and gill netting at three index zones in the Indiana waters of Lake Michigan. Two sample zones were located near the Michigan City harbor mouth: zone M was approximately 2 km east, while zone K was approximately 3 km west. The third sample zone was located 6 km west of the Burns Ditch harbor mouth near the city of Gary. Trawling was done at a depth of 5 m, while gill netting was done at 10 and 15 m depths. For 2004, total effort as each station was 6 hours of night-time trawling, and 6 gill-net nights. Fish data (number, lengths, weights, species, station, etc.) were recorded electronically and stored in the Ball State University computer database. The sampling schedule has remained unchanged since 1984 for stations M and K, and since 1989 for station G.

Growth rates were generated from 967 age ≥ 1 yellow perch taken from both trawl and gill net catches at sites M, K, and G from June to August, 2004. Females grew faster than males after age 3, and reached exploitable size (200 mm) by age 4, while

males by age 5. These growth rates are reduced from the 1993-1997 cohorts, but are more in line with the long term growth rates observed for yellow perch in Lake Michigan. These findings suggest either increased competition for resources, changes in the environmental carrying capacity, or both.

The relative abundance of age ≥ 1 yellow perch trawl CPUE in 2004 was 288/h for both sexes combined and dropped slightly from 2003. Female catch (160/h) exceeded male catch (128/h). The strong 1998 year class was barely evident, and was a change from previous years. The combined 2002 and 2003 year classes made up > 90% of the trawl catch, while the 1999 to 2001 year classes are poorly represented and made up only 4% of the catch. It appears the yellow perch CPUE continues to be dynamic, showing variable and inconsistent recruitment. Although the appearance of relatively high value of age 1 fish is positive, the overall CPUE remains well below values seen in the mid 1980's.

The alewife *Alosa pseudoharengus* population remained abundant and is being carried by a strong 1998 year class (88% of total). The 2004 trawl CPUE of 118 fish/h did show nearly a 50% decline from 2003, but it still remains above the 1984 to 2004 median. Mortality of the 1998 year class should be high in the next year or two, and may promote a decline in overall CPUE in this portion of the lake. Our hypothesis that the alewife has a strong influence on yellow perch has not changed, and thus, our interest in alewife CPUE, size and age structure remains high.

Two other species, round goby *Neogobius melanostomus* and spottail shiner *Notropis hudsonius,* were prevalent in the trawl catch. The round goby has extirpated the johnny darter *Etheostoma nigrum* and the mottled sculpin *Cottus bairdi* from the study area as neither species have been seen in our catch since 2001. It also serves as a prey species for intermediate sized yellow perch (100-174 mm TL). The spottail shiner was the most abundant fish in the trawl catch (41%), as it has been for over a decade.

The sex ratios of yellow perch were near 50:50 for fish < 130 mm total length. Fish ≥130 to 199 mm were dominated by females (71%), while fish > 200 were all females. This skewed distribution is likely do to differential mortality rates.

Our modeling effort confirmed some past associations while it also revealed several new relationships. First, the abundance of alewife continues to be a dominant factor in yellow perch recruitment. When alewife abundance is high, yellow perch recruitment suffers. This alewife/stock/recruitment relationship was first described by Shroyer and McComish (2000), but this year, some diversion from the original model was identified. The 2003 and 2004 yellow perch population abundance was greater than expected by the model. In response to this finding, we tested for several new variables that might be influencing the population abundance of yellow perch, including water temperature, water level, and lake-wide phosphorus levels. However, none of the abiotic variables were significant in the updated model. In addition, we ran two new versions of the current stock/recruitment relationship that is integrated into the model. Instead of using only population abundance, we additionally used (1) only females and (2) fecundity, hypothesizing these inputs would be more associated with recruitment factors. Our findings suggest that our best model for predicting recruitment was using the historic values of trawl caught quality sized yellow perch. Lastly, 20 year projections of yellow perch abundance suggest the alewife heavily influences population abundance of trawl caught yellow perch.

Introduction

The yellow perch *Perca flavescens* has a long history as an important sport and commercial species in Indiana waters of Lake Michigan (Francis et al. 1996). The yellow perch population has undergone wide fluctuations in the past (Wells 1977) and in Indiana, it has been at a very low density since the early 1990s following a precipitous decline from peak abundance in the mid 1980s (McComish et al. 2000). Beginning in 1995, the Indiana Department of Natural Resources (IDNR) imposed quota restrictions on commercial fishermen in an attempt to conserve and rebuild the failing stock. In 1997, commercial fishing for yellow perch was closed and a daily creel limit of 15 was imposed on sport anglers as the population continued to show no signs of recovery. These harvest restrictions remain in effect at this writing.

Since the 1970s, Ball State University has provided much of the technical data used by the IDNR in their management of yellow perch and other near-shore species in Indiana waters of Lake Michigan. Over that period, an extensive database has been generated, helping to contribute to improved understanding of dynamics of the yellow perch population including growth, recruitment, and mortality, as well as the interactions with the rest of the fish community. Yellow perch growth in southern Lake Michigan differs by sex and is inversely related to population abundance (McComish et al. 2000). Females grow faster than males, but growth rates of both sexes typically slow as population abundance increases.

Recent research findings as they relate to the decline in yellow perch abundance have focused on failed recruitment of yellow perch year classes. Shroyer and McComish (2000) demonstrated a strong negative relationship between alewife *Alosa pseudoharengus* abundance and yellow perch recruitment. They showed that trawl catch-per-unit-effort (CPUE) of alewives in the year a yellow perch cohort hatched explained over 70% of the variability of subsequent trawl CPUE of the yellow perch cohort at age 2. In addition, efforts to establish stock-recruitment relationships have been undertaken to further understand the reasons for recruitment failures of yellow perch (McComish et al. 2000). However, natural variability and sampling limitations outlined by Hilborn and Walters (1992) complicate the development of this type of relationship.

Total mortality and individual mortality sources, such as natural and harvest mortality, are essential to understanding population dynamics. McComish et al. (2000) made considerable progress in determining the total mortality of yellow perch in Indiana waters of Lake Michigan, which was readily obtained from representative age-frequency data (Ricker 1975). Recent findings indicated a relatively high mean instantaneous total mortality rate (Z; Ricker 1975) of 1.09 at age ≥ 2 for the 1982 to 1995 year classes with combined sexes. This relatively high rate may likely be attributed to the heavy commercial exploitation (McComish et al. 2000). However, subdividing total mortality into natural and harvest is much more difficult because it typically requires detailed harvest data not available for Indiana waters of Lake Michigan. Another means of computing mortality rates for exploited stocks was proposed by Pauly (1980). This method incorporated parameters associated with von Bertalanffy growth parameters and water temperature. This method is preferable because of the sex specific growth rates associated with yellow perch (McComish and Shroyer 1996). Further work is needed in this critical area for the yellow perch in Indiana waters of Lake Michigan, especially with the current ban on commercial harvest.

The goal of this study was to continue adding to the historic fish community database in southern Lake Michigan using continued standardized methods of population assessment. This information can be used to evaluate fish community structure and track changes over time, thereby providing technical support to the IDNR in their management of this fishery. The specific objectives of this project were the following:

1. Intensively trawl and gill net during the June through August 2004 period for the non-salmonine fish community at three locations in the Indiana waters of Lake Michigan, with subsequent vital data collections and computer data storage.
2. Complete a comparative age and growth analysis of yellow perch in Indiana waters of Lake Michigan.

3. Evaluate yellow perch size structure, age structure, sex composition, year class strength, recruitment, and mortality by year class in Indiana waters of Lake Michigan.
4. Evaluate catch composition and time series of relative abundance characteristics of the near-shore non-salmonine and non-yellow perch fish community in Indiana waters of Lake Michigan.
5. Develop and refine descriptive, predictive, and simulation models of the yellow perch population in Indiana waters of Lake Michigan.

Individual objectives are detailed in this report by job titles.

Acknowledgments

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Job Titles

Job 1: Intensive Trawl and Gill Net Sampling of the Near-Shore Non-Salmonine Fish Community in Indiana Waters of Lake Michigan, Including Data Collection and Computer Data Storage

Field sampling sites and methods in 2004 were described in detail by McComish et al. (2000) and remain unchanged from previous years. Weather and sea conditions, temperature profiles, and secchi depths were recorded at each index zone and depth location immediately before initiation of fish sampling. The dates of trawl and gill net sampling were performed in accordance with established sampling period protocol (Table 1-1). Total night-time trawl effort was 18 h at the 5 m depth and total gill net effort was 18 net-nights at both 10 and 15 m depths.

Trawl and gill net catches in 2004 were field processed following the BSU Animal Care and Use Committee approved protocol with fish subsequently disposed of in a landfill. Data were recorded both electronically and on data sheets as described by McComish et al. (2000). Temperature profiles and secchi readings were recorded manually on standard data sheets and later transcribed to computer files. All fish data (lengths, weights, numbers, etc.) were initially recorded using a laptop computer and then immediately backed-up on floppy disks. Field data were downloaded to the master database files upon returning to the university. These methods reduced both data entry time and human error associated with transcribing data from hard copy to the computer. As in past years, all data files were examined visually and queried by the Staff Fisheries Research Biologist to ensure data values were reasonable before use in subsequent analyses.

Table 1-1. Dates of trawl and gill net sampling at three index sites in Indiana waters of Lake Michigan in 2004. Gill nets were set at approximately 1900 hours on a given date and pulled at approximately 0700 hours the next morning. Horizontal lines separate semi-monthly sample periods.

Date	Site	Trawl	10-m Gill Net	15-m Gill Net
6/01/04	K	+	+	+
6/02/04	M	+	+	+
6/03/04	G	+	+	+
6/16/04	M	+	+	+
6/17/04	K	+	+	+
6/22/04	G	+	+	+
7/06/04	M	+	+	+
7/07/04	K	+	+	+
7/08/04	G	+	+	+
7/19/04	M	+	+	+
7/20/04	K		+	+
7/21/04	K	+		
7/26/04	G	+	+	+
8/02/04	K	+	+	+
8/03/04	M	+	+	+
8/09/04	G	+	+	+
8/16/04	M	+		
8/18/04	K	+	+	+
8/19/04	M		+	+
8/24/04	G	+	+	+

Job 2: A Comparative Age and Growth Analysis of Yellow Perch in Indiana Waters of Lake Michigan

Methods

The advancement of technology at the Aquatic Biology and Fisheries Center (ABF), including computer enhancement, a binocular microscope equipped with a digital camera, digital image capture capability, and imagery analysis software has greatly improved the efficiency of yellow perch age analysis and provided a higher degree of quality. Further advancements in 2002 with the development of a Windows™ based back calculation software package, titled FishBC© (Doll 2003), allowed replacement of the previously used DisBcal program. The Windows format of FishBC allows for better compatibility with the various software programs used during the entire fish aging process and subsequent data analysis. Additionally, this program increases efficiency and quality of the data analysis.

Yellow perch age and growth methods in 2004 were similar to those described by Allen et al. (2002). We aged fish using opercular bones based on the procedure described in Baker and McComish (1998) with images of opercles captured electronically. Annular increments were measured using SigmaScan™ software that allowed us to annotate directly on the computer the distance from the focus to each annulus and the opercle edge. Values were then uploaded into the FishBC software program. A 10-mm standard intercept for opercle back-calculations was used as proposed by Baker (1989) and validated by McComish et al. (2000). Age and growth analysis was completed using 967 age ≥ 1 fish sub-sampled from trawl and gill net catches at sites M, K, and G from June to August 2004. Within the aged sub-sample, 318 (33%) were males and 649 (67%) were females. Note this sex ratio is not representative of the total catch due to the size-selective sub-sampling procedure (refer to ***Job 3*** for overall sex ratios).

Age and Growth Results

Detailed age and growth relationships of yellow perch sub-sampled in 2004 are shown in Appendices 2-1 through 2-4. Males up to age 10 and females up to age 12 were present in the aged sub-sample, with fish older than age 9 uncommon (Appendices 2-1, 2-2, 2-3, and 2-4). There were no differences in growth between females and males for ages 1 and 2 during 2004 (Figure 2-1). Female yellow perch grew faster than males from age 3 through 9, except at age 5 where high variability in growth was observed. Few fish older than age 9 were captured making analysis of growth differences difficult beyond that age. On average both females and males reached stock size (≥ 130 mm) by age 3, while females attained quality size (≥ 200 mm) by age 4 and males by age 5.

Mean lengths at last annuli of successive age classes (Figure 2-1) should not be interpreted as absolute growth curves because younger cohorts, both female and male, are apparently following different curves when compared to recent cohorts of older fish. For example, the 1998 year class is growing slower than previous cohorts. True differences in growth rates among cohorts will be answered in the coming years by fitting the von Bertalanffy growth function to back-calculated lengths at last annuli of individual cohorts in successive years.

Mean back-calculated lengths of yellow perch males and females at last annuli from 1976 to 2004 show varied trends (Figure 2-2). Only ages 1 through 4 are used in the display because older ages were not found in abundance in all years, and when present, showed similar trends as ages 1to 4. On average, both sexes ordinarily reached stock size (≥ 130 mm) by age 2 in the 1970s and 1995 to 2000 and by age 3 in other years. Males reached quality size (≥ 200 mm) by age 3 or 4 in 1976 to 1978 and 1997 to 2000 and beyond age 4 in other years. Females were quality size by age 3 in 1976 and 1996 to 2000, by age 4 in 1977 to 1979, 1984, 1995, 2001, and 2004 and beyond age 4 in other years. Mean length at last annulus of males and females for ages 1 and 2 decreased in 2004 to lengths observed during the mid to late 1980s when the yellow perch population abundance was at its peak (Figure 2-2). Male lengths at age 3 and 4 trended slightly upwards in 2004 for the first time since 2000 but remain at lengths comparable to the mid 1980s. Female lengths at ages 3 and 4 also trended upwards in 2004 to lengths

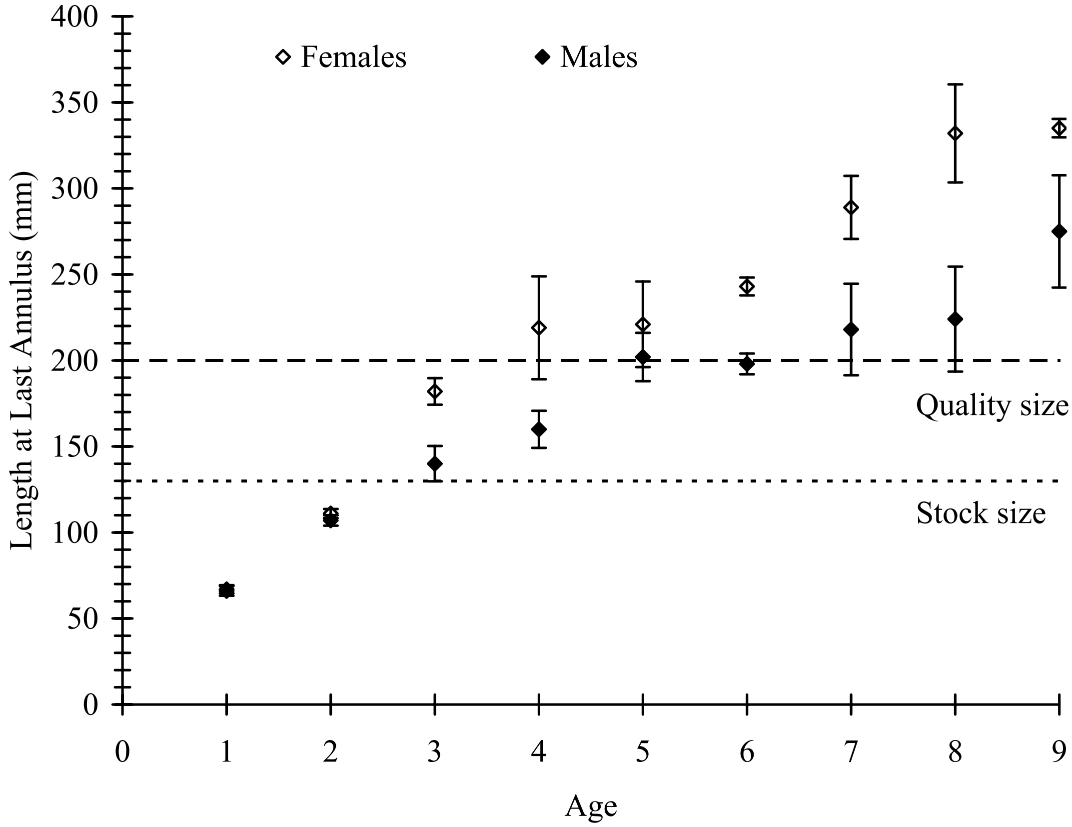

Figure 2-1. Mean back-calculated lengths at last annuli of individual age classes of male and female yellow perch collected from pooled sites in Indiana waters of Lake Michigan in 2004. Error bars represent ± 2 SE.

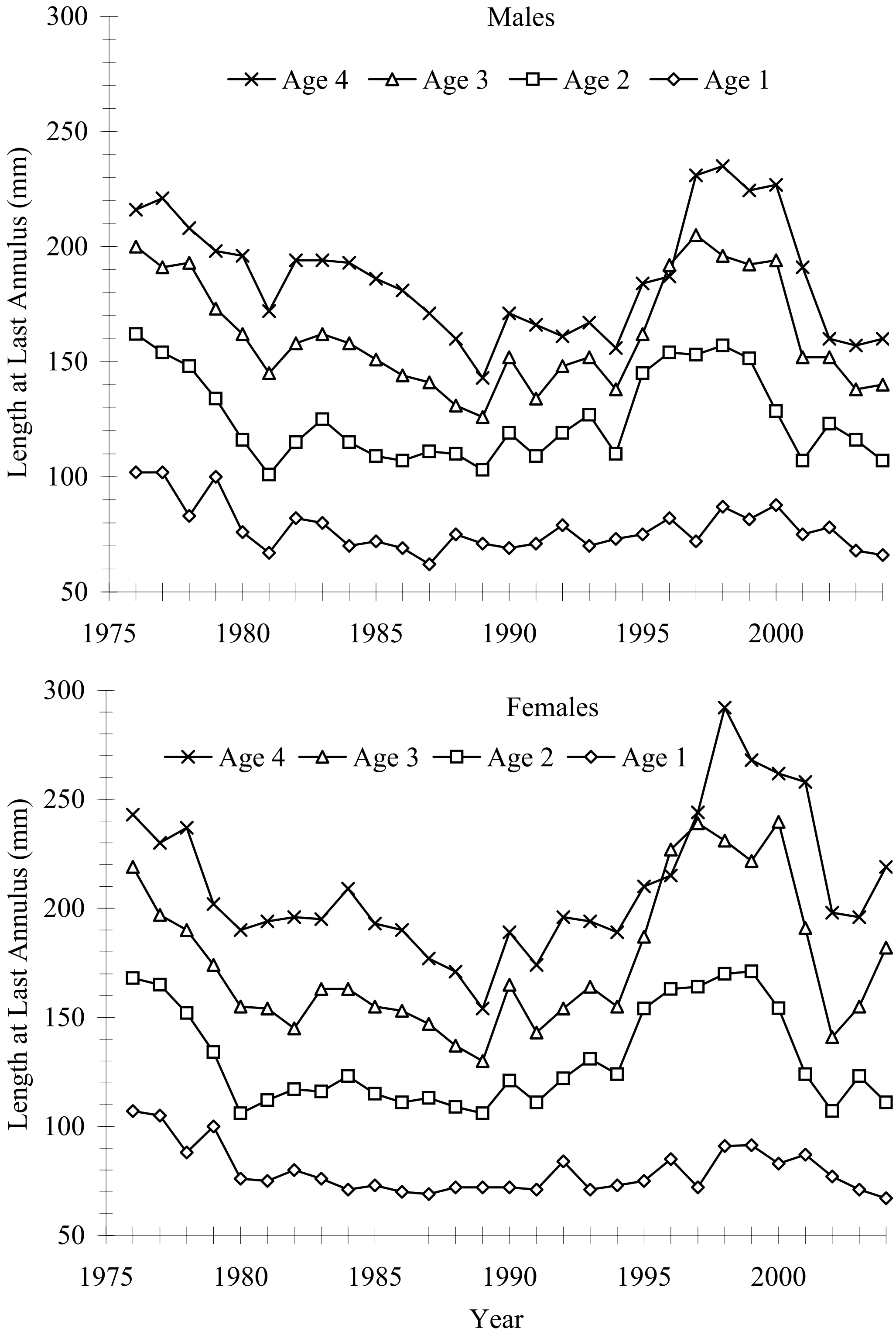

Figure 2-2. Mean back-calculated lengths at last annuli of male and female yellow perch ages 1 to 4 collected in Indiana waters of Lake Michigan from 1976 to 2004.

observed in the mid 1990s.

The age when yellow perch attained quality size (≥ 200 mm) varied for males and females from 1984 through 2004, as determined by length at last annuli (Table 2-1 and 2-2). The average length of the male 1999 year class (age 5) reached quality size (≥ 200 mm), while the 1998 year class has yet not. The 1993 to 1997 cohorts reached quality size (≥ 200 mm) by age 3 or 4, the 1991, 1992 and 1999 cohorts by age 5, the 1989 and 1990 cohorts by age 6, and the 1983 to 1988 cohorts by age 7 or 8 (Table 2-1). Mean length at last annulus for the female 1999 (age 5) and 2000 (age 4) year classes reached quality size in 2004. The 1993 to 1997 cohorts reached quality size by age 3, compared to age 4 for the 1991 and 1992 cohorts and age 5 or 6 for earlier cohorts (Table 2-2).

The von Bertalanffy growth equation was used to quantify the growth characteristics of individual cohorts. The equation is:

$$l_t = L_\infty (1 - e^{-K(t-t_0)})$$

Where, l_t is length at annulus t, L_∞ is the length an average fish would reach if it lived indefinitely and continued to grow according to the equation, K is the Brody growth coefficient, and t_0 is the hypothetical age at which a fish would have been zero length if it had always grown according to the equation (Ricker 1975).

The von Bertalanffy growth parameters were estimated from the data in Tables 2-1 and 2-2. Estimates for the recent year classes are provisional because they are based on only 4-8 annuli. Nonetheless, the results seem to suggest male year classes beginning in 1996 are likely to reach similar asymptotic lengths of cohorts from the mid to late 1980s (Table 2-3). Female cohorts from 1993 to 1999 have exhibited a trend to slower growth where their asymptotic length will likely be less than previous year classes (Table 2-4). Furthermore, K for these year classes appears similar to their male counter parts and may be approaching what would be considered maximum length.

The declining trend in growth rates starting in the late 1990s for both male and female yellow perch (Figures 2-1 and 2-2) continues to be of concern. Several

Table 2-1. Mean lengths at annuli 1 to 9 for male yellow perch collected from sites M, K, and G in Indiana waters of Lake Michigan from 1984 to 2004. Each row represents the back-calculated length at last annulus for a cohort over successive years.

Year	Total length (mm) at annulus								
class	1	2	3	4	5	6	7	8	9
1983	70	109	144	171	180	189	202	233	205
1984	72	107	141	160	169	193	211	193	216
1985	69	111	131	143	186	194	195	215	216
1986	62	110	126	171	183	195	202	206	206
1987	75	103	152	166	187	192	194	215	234
1988	71	119	134	161	187	188	212	224	218
1989	69	109	148	167	167	202	214	222	236
1990	71	119	152	156	192	208	212	228	238
1991	79	127	138	184	201	222	219	246	218
1992	70	110	162	187	202	213	230	241	245
1993	73	145	192	231	226	240	236	223	270
1994	75	154	205	235	251	253	267	259	250
1995	82	153	196	224	245	236	273	243	275
1996	72	157	192	227	218	237	221	224	
1997	87	151	194	191	225	232	218		
1998	82	129	152	160	190	198			
1999	88	107	152	157	202				
2000	75	123	138	160					
2001	78	116	140						
2002	68	107							
2003	66								

Table 2-2. Mean lengths at annuli 1 to 9 for female yellow perch collected from sites M, K, and G in Indiana waters of Lake Michigan from 1984 to 2004. Each row represents the back-calculated length at last annulus for a cohort over successive years.

Year	Total length (mm) at annulus								
class	1	2	3	4	5	6	7	8	9
1983	71	115	153	177	193	206	250	270	291
1984	73	111	147	171	195	228	244	281	276
1985	70	113	137	154	213	222	274	275	284
1986	69	109	130	189	201	250	269	266	289
1987	72	106	165	174	222	249	247	275	275
1988	72	121	143	196	228	236	267	262	290
1989	72	111	154	194	212	242	247	286	305
1990	71	122	164	189	230	251	289	320	311
1991	84	131	155	210	236	283	319	301	
1992	71	124	187	215	266	306	312		
1993	73	154	227	244	295	312	314	305	234
1994	75	163	239	292	307	302	291	294	322
1995	85	164	231	268	305	305	320	313	335
1996	72	170	222	262	279	272	290	332	
1997	91	171	240	258	271	284	289		
1998	91	154	191	198	232	243			
1999	83	124	166	196	221				
2000	87	107	155	219					
2001	77	123	182						
2002	71	111							
2003	67								

Table 2-3. Von Bertalanffy growth parameters and coefficients of determination (R^2) for the 1983 to 2000 year classes of male yellow perch in Indiana waters of Lake Michigan. Values fitted to the data in Table 2-1 by the Marquardt-Levenburg method of nonlinear least squares. Estimates for the 1996 to 2000 year classes are provisional.

Year class	L_∞ (mm)	K	t_0	R^2
1975	246	0.445	-0.211	0.982
1976	342	0.158	-1.37	0.965
1977	501	0.0928	-1.08	0.957
1978	4.27E+06	7.29E-06	-1.96	0.946
1979	232	0.386	0.107	0.957
1980	227	0.495	0.359	0.980
1981	225	0.394	-0.132	0.965
1982	214	0.405	-0.0925	0.986
1983	232	0.302	-0.174	0.97
1984	231	0.271	-0.370	0.98
1985	251	0.215	-0.528	0.98
1986	221	0.342	0.062	0.99
1987	249	0.243	-0.460	0.97
1988	251	0.236	-0.475	0.99
1989	273	0.201	-0.524	0.98
1990	268	0.224	-0.466	0.99
1991	251	0.300	-0.223	0.96
1992	263	0.298	0.001	0.99
1993	248	0.584	0.418	0.95
1994	262	0.608	0.467	0.99
1995	268	0.473	0.223	0.95
1996	229	0.806	0.538	0.97
1997	228	0.604	0.211	0.94
1998	227	0.310	-0.511	0.95
1999*				
2000	171	0.686	0.229	0.98
Means	243	0.394	-0.093	0.97

* indicates parameter values could not be computed for this year class.

Table 2-4. Von Bertalanffy growth parameters and coefficients of determination (R^2) for the 1983 to 2000 year classes of female yellow perch in Indiana waters of Lake Michigan. Values fitted to the data in Table 2-2 by the Marquardt-Levenburg method o nonlinear least squares. Estimates for the 1996 to 2000 year classes are provisional.

Year class	L_∞ (mm)	K	t_0	R^2
1975	227	0.600	-0.0798	0.995
1976	2.76E+05	1.16E-04	-0.239	0.977
1977	307	0.256	-0.215	0.967
1978	259	0.310	-0.273	0.912
1979	260	0.403	0.324	0.864
1980	267	0.390	0.274	0.935
1981	298	0.271	-0.0213	0.942
1982	340	0.167	-0.607	0.983
1983	567	0.070	-1.120	0.99
1984	446	0.105	-0.718	0.99
1985	502	0.092	-0.593	0.98
1986	399	0.144	-0.212	0.98
1987	333	0.204	-0.101	0.98
1988	346	0.193	-0.175	0.99
1989	433	0.125	-0.463	0.99
1990	463	0.129	-0.308	0.99
1991	498	0.123	-0.423	0.98
1992	468	0.166	0.050	0.99
1993	297	0.596	0.579	0.89
1994	313	0.612	0.596	0.96
1995	337	0.437	0.366	0.99
1996	317	0.462	0.414	0.95
1997	295	0.576	0.377	0.99
1998	264	0.395	-0.109	0.96
1999	358	0.177	-0.475	1.00
2000*				
Means	390	0.271	-0.136	0.98

* indicates parameter values could not be computed for this year class.

hypotheses have been proposed in an attempt to explain this apparent trend, including: intraspecific competition for available food resources, biological interactions with other fishes particularly interspecific competition, selective mortality of the population, and finally, physiological factors specific to energy allocation (Allen et al. 2002). It seems unlikely that any one of the stated hypothesis is solely responsible for the decreased growth rates. However, additional evidence from our sampling effort suggests that density dependent factors and available food resources may be responsible for the changes observed in the yellow perch growth.

Density dependent factors such as food availability, cannibalism, and predation can influence a fish population in varying ways based on the density of that population (Van Den Avyle 1993). For example, under normal circumstances an increase in population abundance will likely increase the competition for food resources and cannibalism. A reduction in food resources will slow growth of individual fish at specific ages and may lead to decreased condition. Furthermore, consequences could lead to increased predation and reduced survival and reproduction, ultimately resulting in reduced population abundance. Conversely, low abundance will result in the opposite phenomenon where growth rates may increase due to a decrease in the competition for available food and cannibalism becomes minimal. Fish would then be healthier and survival and reproduction could lead to increased population abundance.

Yellow perch population abundance has remained very low since the mid 1990s (see Job 4) and resulted in an upward shift in growth rates beginning in 1995 (Figure 2-2) and was most evident for the age 2, 3, and 4 fish. This trend changed with the 1998 year class at age 2, when a shift toward declining growth rates appeared. Density dependent growth may have influenced this reduced growth rate, as the 1998 year class was the strongest cohort since 1994. Although the 1998 year class was small by comparison to historic year classes (e.g. 1980’s), this increase was small and likely not large enough to result in slower growth. If food resources needed by the yellow perch for optimal growth were restricted, then expected growth rates would decrease with the increased intraspecific competition for available resources (Van Den Avyle 1993). Furthermore, productivity changes in the Lake Michigan food web, especially at the lower trophic levels, along with establishment and involvement of exotic species, may have a negative impact on food availability for fishes like the yellow perch (Madenjian et al. 2000).

Recent research investigating the yellow perch diet in Indiana waters of Lake Michigan has shown this species continues to exhibit opportunism by preying on the available forage (Truemper 2003). The diet of yellow perch was dominated by fish products (mainly alewife, round goby, and yellow perch), which composed 85% of the diet by volume in 2002. This is a significant increase from other yellow perch diet studies in the Indiana waters of Lake Michigan over the past three decades. This dramatic shift in diet composition was likely the result of a decline in benthic macroinvertebrates (Nalepa et al. 1998), establishment of the round goby, increased alewife abundance and an increase in yellow perch abundance (see Job 4). Nalepa et al. (1998) suggested that a decrease in the abundance of non-piscine food items may be a precursor to increased cannibalism. The 2002 diet study showed adult yellow perch had a mean volume (3.7%) of young-of-the-year yellow perch and was similar to the diet of adult yellow perch in 1984 (4.6%). At that time, however, the yellow perch population abundance was significantly higher than at present, while the other diet studies (1992 to 1993 and 1971 to 1972) showed little or no cannibalism and a lack of intraspecific competition (Truemper 2003).

Recent research on round goby diet in Indiana waters of Lake Michigan identified a possible competitive interaction between the goby and yellow perch which may be affecting yellow perch growth rates, particularly at smaller sizes. Round goby were shown to prey heavily on chironomids (Edgell 2004), a main prey item for yellow perch at younger ages (ages 1 and 2) and smaller sizes (100 to 175 mm) (Pothoven et al. 2000; Truemper 2003). Other invertebrates consumed by both fish species include gastropods, zebra mussels, ostracods, and *Bythotrephes longimanus* (Pothoven et al. 2000; Truemper 2003). Furthermore, the documented decline in *Diporeia*, another known yellow perch prey organism (Pothoven et al. 2000), may have increased the competitive interactions between yellow perch and round goby. The continued expansion of the round goby could have a negative impact on selected benthic organisms, such as chironomids (Weimer and

Sowinski 1999, Edgell 2004), and in turn could negatively affect the growth of native fish, in particular, non-piscivorous yellow perch.

Job 3: An Evaluation of Yellow Perch Size Structure, Age Structure, Sex Composition, Year Class Strength, Recruitment, and Mortality by Year Class

Year Class Strengths

Yellow perch year class strength is defined as the trawl CPUE of a cohort at age 2 because catch curve analysis (Ricker 1975) reveals younger ages are not fully vulnerable to the trawl. The 2004 collection data showed the 2002 yellow perch year class as the 14th consecutive cohort classified as extremely weak (Figure 3-1). Year classes were categorized from extremely weak to extremely strong based on previous work by McComish et al. (2000). The range of observed values since 1981 (Figure 3-1) shows the 2002 year class had a CPUE (76.8/h) which is the highest recorded since the 1988 year class. Although the 2003 year class was not fully vulnerable to the trawl in 2004, the CPUE at age 1 was 191/h and ranked as the highest abundance for age 1 fish since the 1988 year class and nearly the same as observed for the 2002 year class at age 1 (Appendix 3-1). The strength of the 2004 year class remains uncertain, but the 2004 age-0 yellow perch CPUE of 73/h was slightly more than half the catch recorded for the 2003 year class (Appendix 3-2).

Mortality Rates

Annual total mortality rates (*A*; Ricker 1975) of yellow perch cohorts were estimated using two different methods from annual data collected beginning in 1984. The first method calculated *A* from decreases in trawl CPUE of cohorts over one-year age intervals which provided information only on discrete age intervals. Mean estimated *A* ranged from 55% to 65% for ages 2-6 and 70% or higher for older ages (Table 3-1). Estimates of *A* which are not shown in the table, could not be calculated due to greater catches of a particular year class from one year to the next for ages 2 through 9. Annual total mortality rates have been higher, on average, beginning in 1994 when compared to earlier year classes.

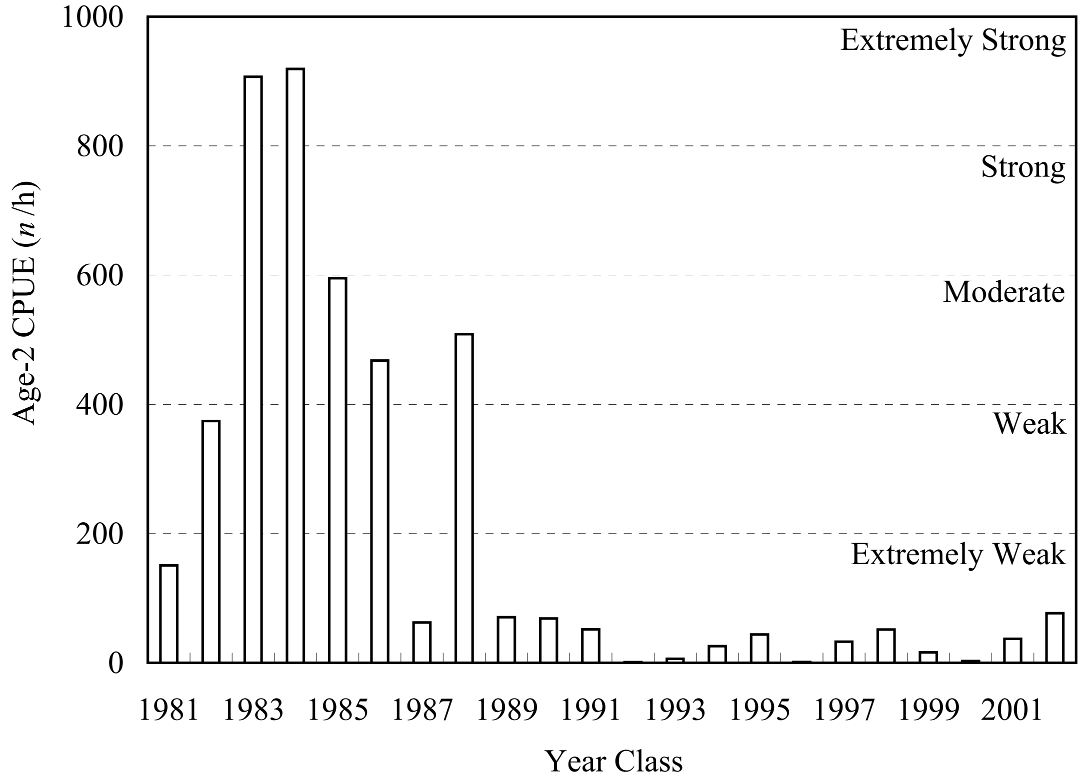

Figure 3-1. Relative strength of yellow perch year classes 1981 to 2002 based on mean annual trawl CPUE for age 2 fish, in Indiana waters of Lake Michigan.

Table 3-1. Annual total mortality rates (*A*) of yellow perch cohorts in Indiana waters of Lake Michigan from 1980 to 2001. Rates based on decreases from 1984 to 2004 trawl CPUE at successive ages. Missing data points are due to either increases in the CPUE of cohorts from one age to the next, or ages at which cohorts have not been captured. Med. = median.

	Annual total mortality of year classes (%)																							
Age	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	Mean	Med.
2-3			4	47	51	14	73		60	39		80		25	85	68		90		85		79	57	64
3-4		35	70	34		72	55	7	61		67	31		74	74	27	95		36		81		55	61
4-5	69	91	67		79	52	37	54	2	46	79		55	72		94		80		93			65	69
5-6	90	56	18	69	55	74	40	30	39	92		92	96	3	97		81		88				64	71
6-7				70	86	41	51	73	97	26	86	91				77		89					72	77
7-8				95	75	56	68	99		90	84				86		98						84	86
8-9				35	82	94	99		83	87	48			91		96							80	87
Mean	79	61	40	58	71	58	61	53	57	63	73	73	76	53	85	73	91	87	62	89	81	79	68	
Med	79	56	42	58	77	56	55	54	60	67	79	86	76	72	85	77	95	89	62	89	81	79		71

The second method was catch curve analysis of individual cohorts over successive years and has been demonstrated to be more accurate for comparing individual cohorts (Ricker 1975). Means of *A* for 1982 to 1999 cohorts at age ≥ 2 ranged from 30 to 68% and has trended downward since the 1989 year class (Table 3-2). Due to the low catches and/or variability, catch curve analysis could not be accurately estimated for the 2000 year class. Mortality rates using catch curve analysis tended to be higher than mortality rates computed using decreases in trawl CPUE for the 1982 to 1989 year classes. Conversely, for the year classes 1990 to 2000, mortality rates using the catch curve analysis tended to be lower than mortality rates computed using decreases in trawl catches. Mean *A* across all cohorts starting from 1982 using catch curve analysis was 56%, while using decreases in trawl catches had a mean of 68%. The large difference in mortality rates may be due to variability in trawl catches resulting in missing year-to-year mortality values (Table 3-1).

We additionally calculated mortality rates for separate sexes of recent cohorts for which sex-specific CPUE data were available (Tables 3-3 and 3-4). The analysis revealed major sexual differences in the various components of mortality for the 1991-1999 year classes: instantaneous rate of mortality (*Z*), instantaneous rate of fishing mortality (*F*), instantaneous rate of natural mortality (*M*), conditional rate of fishing mortality (*m*), conditional rate of natural mortality (*n*), expectation of capture by man (*u*), and expectation of natural death (*v*) (Ricker 1975). Total mortality (*Z*) showed a general decreasing trend for both male and female cohorts from 1991 to 1998 (Table 3-3). Other mortality values (*F*, *m*, and *u*) also showed a decreasing trend for males starting with the 1991 year class, while female cohorts trended downward from 1991 until 1999 (Table 3-4). Natural mortality values (*M*, *n*, and *v*) tended to be higher for males than for females due to lower L_∞ and higher *K* (Tables 2-3 and 2-4). Male instantaneous natural mortality (*M*) fluctuated upward starting with the 1991 cohort, while female *M* trended upward until the 1997 cohort and has trended downward since then (Table 3-4).

Table 3-2. Total mortality and survival rates of yellow perch cohorts (combined sexes) in Indiana waters of Lake Michigan from 1982 to 2000. Rates based on catch curve analysis of individual cohorts at ages 2 to 9 from 1984 to 2004 trawl catches. The value of N is the number of data points (years) in the catch curve. Means of Z, S, A, and R^2 were weighted by N.

Cohort	Z	S	A	N	R^2
1982	0.95	0.39	0.61	6	0.96
1983	0.99	0.37	0.63	8	0.87
1984	1.13	0.32	0.68	8	0.93
1985	1.03	0.36	0.64	8	0.95
1986	1.07	0.34	0.66	8	0.84
1987	0.90	0.41	0.59	8	0.71
1988	0.97	0.38	0.62	8	0.91
1989	1.10	0.33	0.67	8	0.86
1990	1.06	0.34	0.66	8	0.94
1991	0.94	0.39	0.61	7	0.82
1992	0.43	0.65		6	0.34
1993	0.83	0.44	0.56	7	0.94
1994	0.73	0.48	0.52	8	0.66
1995	0.85	0.43	0.57	8	0.81
1996	0.36	0.70	0.30	7	0.21
1997	0.67	0.51	0.49	6	0.69
1998	0.37	0.69	0.31	5	0.39
1999	0.55	0.58	0.42	4	0.27
2000[a]	0.03	0.97	0.03	3	0.00
Mean	0.86	0.44	0.55	7	0.76
Median	0.92	0.40	0.61	8	0.83

[a] Low catch or variability (see R^2) precludes inclusion of data for Z, S, and A.

Table 3-3. Total mortality and survival rates of male and female yellow perch cohorts in Indiana waters of Lake Michigan from 1991 to 2000. Rates based on catch curve analysis of individual cohorts at ages 2 to 9 from 1993 to 2004 trawl catches. The value of n is the number of data points (years) in the catch curve. Means of Z, S, A, and R^2 were weighted by N.

	Males					Females				
Cohort	Z	S	A	N	R^2	Z	S	A	N	R^2
1991	0.79	0.45	0.55	7	0.71	1.03	0.36	0.64	7	0.74
1992	0.53	0.59	0.41	6	0.28	0.48	0.62	0.38	6	0.56
1993	0.96	0.38	0.62	5	0.91	0.93	0.39	0.61	8	0.92
1994	0.66	0.52	0.48	7	0.45	0.66	0.52	0.48	8	0.69
1995	0.68	0.51	0.49	6	0.42	0.79	0.45	0.55	8	0.84
1996[a]	0.37	0.69	0.31	7	0.18	0.33	0.72	0.28	7	0.21
1997[a]	0.52	0.59	0.41	6	0.55	0.71	0.49	0.51	6	0.53
1998[a]	0.23	0.79	0.21	5	0.18	0.44	0.64	0.36	5	0.44
1999[a]	-0.08	1.08	-0.08	4	0.01	1.01	0.36	0.64	4	0.54
2000[a]	-1.48	4.39	-3.39	3	0.48	0.29	0.75	0.25	3	0.08
Mean	0.72	0.49	0.51	6	0.54	0.78	0.47	0.53	7	0.74
Median	0.68	0.51	0.49	6	0.45	0.79	0.45	0.55	8	0.74

[a] Low catch or variability (see R^2) precludes inclusion of data for Z, S, and A.

Table 3-4. Estimated fishing and natural mortality rates of male and female yellow perch cohorts in Indiana waters of Lake Michigan from 1991 to 2000. Symbols follow Ricker (1975). Instantaneous natural mortality rates (M) were calculated using Equation 11 of Pauly (1980), parameters in Tables 2-3 and 2-4, and mean annual water temperature 10.48°C (Cwalinski 1996). Other statistics were calculated using equations in Ricker (1975) and values in Table 3-3.

	Males						Females					
Cohort	F	M	m	n	u	v	F	M	m	n	u	v
1991	0.25	0.54	0.22	0.42	0.17	0.37	0.78	0.25	0.54	0.22	0.49	0.16
1992	0.00	0.53	0.00	0.41	0.00	0.41	0.17	0.31	0.16	0.27	0.14	0.25
1993	0.12	0.84	0.11	0.57	0.07	0.54	0.12	0.81	0.11	0.55	0.08	0.53
1994	-0.19	0.85	-0.21	0.57	-0.14	0.62	-0.15	0.81	-0.16	0.56	-0.11	0.59
1995	-0.04	0.72	-0.99	0.51	-0.03	0.52	0.15	0.64	0.14	0.47	0.11	0.44
1996[a]	-0.69	1.06	-0.43	0.65	-0.58	0.89	-0.34	0.67	-0.41	0.49	-0.29	0.57
1997[a]	-0.36	0.88	-0.43	0.58	-0.28	0.69	-0.08	0.79	-0.09	0.55	-0.06	0.57
1998[a]	-0.34	0.57	-0.40	0.43	-0.30	0.51	-0.20	0.64	-0.22	0.47	-0.16	0.52
1999[a]							0.66	0.35	0.48	0.29	0.42	0.22
2000[a]	-2.52	1.04	-11.37	0.64	-5.77	2.37						
Mean	0.03	0.70	-0.18	0.50	0.02	0.49	0.21	0.56	0.16	0.41	0.14	0.39
Median	0.00	0.72	0.00	0.51	0.00	0.52	0.15	0.64	0.14	0.47	0.11	0.44

[a] Low catch or variability (see R^2, Table 3-3) precludes inclusion of data for F, m, u, and v.

<u>Length Frequencies, Sex Ratios, and Age Frequencies</u>

Length frequencies, sex ratios, and age frequencies were calculated as described by McComish et al. (2000). Yellow perch were enumerated for each sex and 10-mm length class for each nightly catch of six pooled 10-minute trawl tows (1-h effort) as well as each gill net catch. Age composition was calculated using month- and sex-specific age-length keys. The overall June-August age-length values for each gear and sex were then obtained by averaging the values in the age-length tables for individual catches.

Trawl Catch

Lengths of age ≥ 1 trawl-captured yellow perch ranged from 50 to 339 mm in 2004 (Appendix 3-3). Males ranged from 50 to 199 mm (Appendix 3-4), and females from 50 to 339 mm (Appendix 3-5). Two major modes were prevalent in length frequency; one at 60 to 69 mm and the second ranging from 110 to 129 mm (Figure 3-2). Sub-stock (< 130 mm) CPUE increased from 199/h in 2003 to a mean of 249/h in 2004 and was comprised mainly of age 1 fish (Figures 3-3 and 3-4; Appendix 3-2). Trawl CPUE of stock-size (≥ 130 mm) fish decreased to 40/h in 2004 and more than 50% of the catch was from the 2002 year class (age 2) (Figures 3-5 and 3-6; Appendix 3-2). Quality-size fish (≥ 200 mm) decreased to 3/h in 2004, with age 6 (1998 year class) fish making up 77% of the catch (Figure 3-7 and 3-8; Appendix 3-2). Although the 2004 yellow perch population abundance remains well below the levels observed in the 1980s, its stock structure has exhibited a trend towards greater stability as a majority of the population is present as sub-stock (Figure 3-9). Further stock stability will depend on the 1998 year class to produce similar or potentially stronger cohorts than observed for the 2002 and 2003 year classes (Figure 3-9).

Proportional stock density (PSD; the percentage of stock-size fish ≥ 200 mm) for 2004 decreased to 3% and fell below the median value for the years 1975 through 2003 (Figure 3-10). However, Figure 3-10 must be interpreted cautiously because PSD in recent years for this population has been volatile and highly influenced by changes in recruitment, growth, and sex ratios. Thus, the result may lack a significant correlation

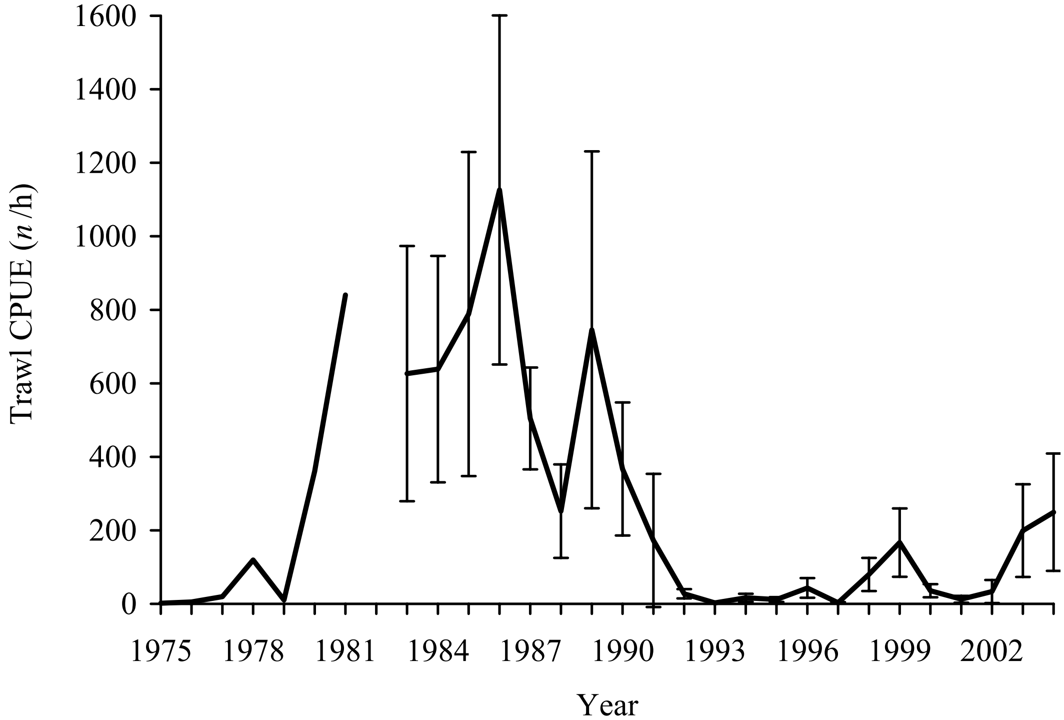

Figure 3-3. Trawl CPUE of sub-stock size (< 130 mm and age ≥ 1) yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2004. No trawling was conducted in 1982. Error bars for 1983 to 2004 represent ± 2 SE.

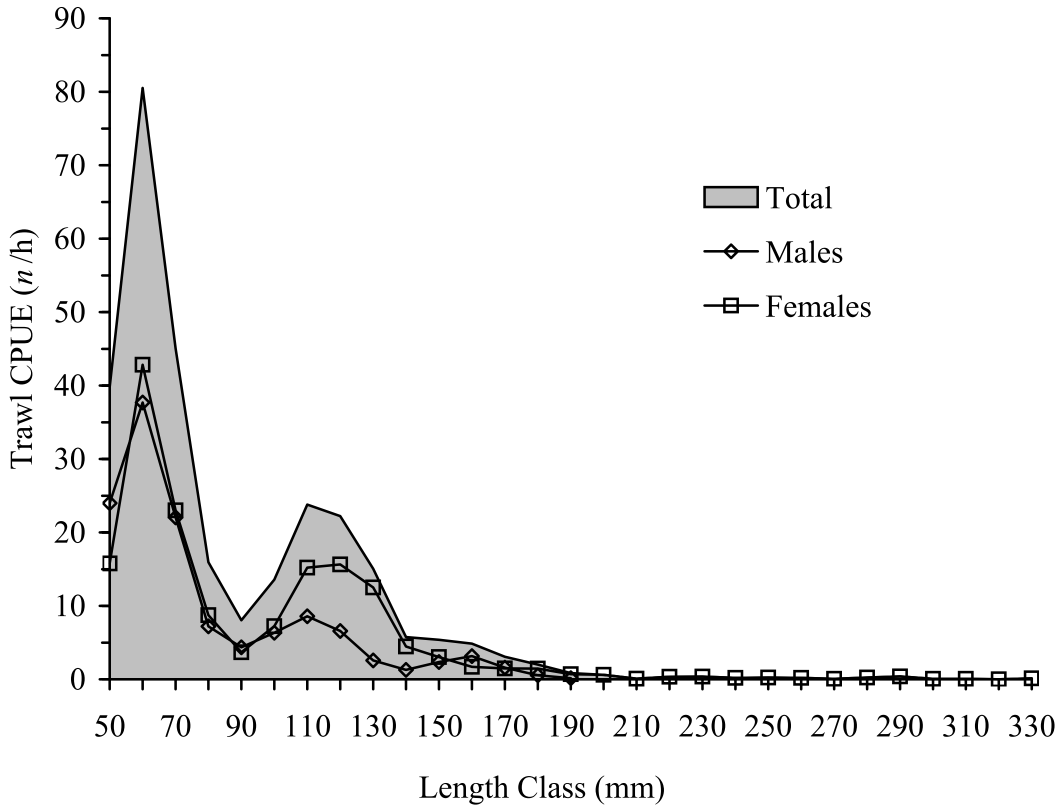

Figure 3-2. Length composition of the trawl caught yellow perch age ≥ 1 at pooled sites in Indiana waters of Lake Michigan in 2004.

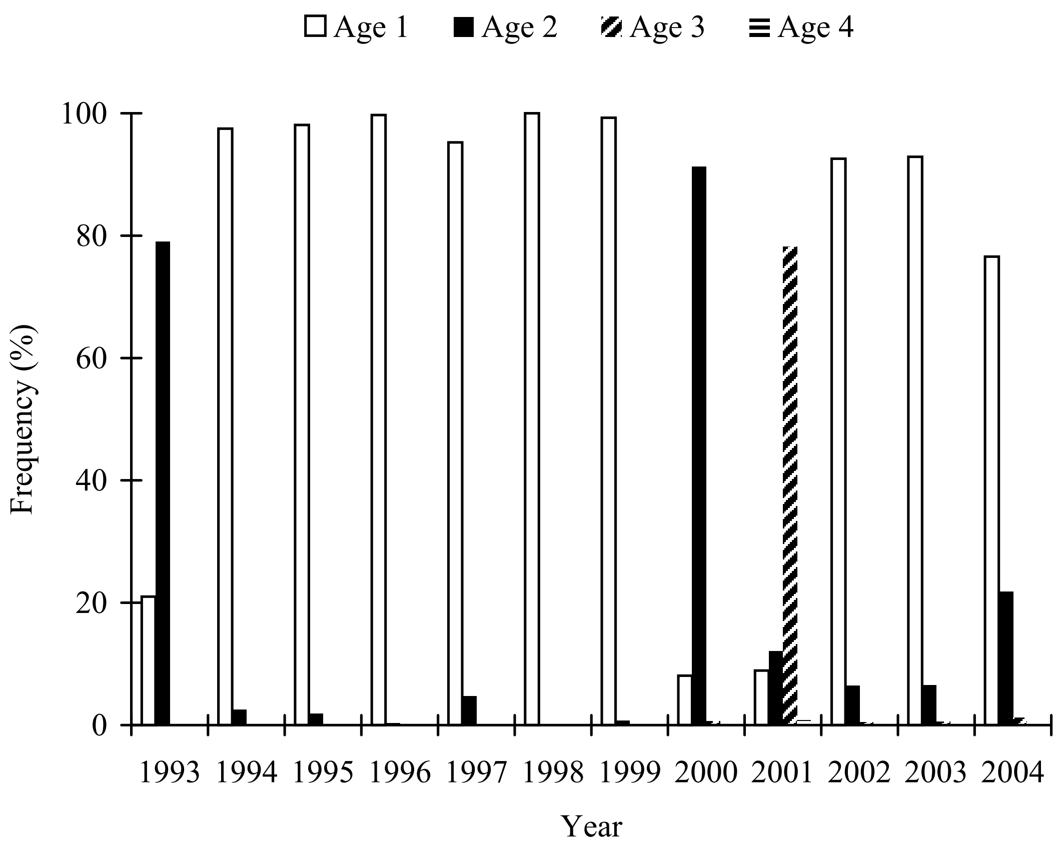

Figure 3-4. Age frequency of trawl caught sub-stock (< 130 mm and age ≥ 1) yellow perch at pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

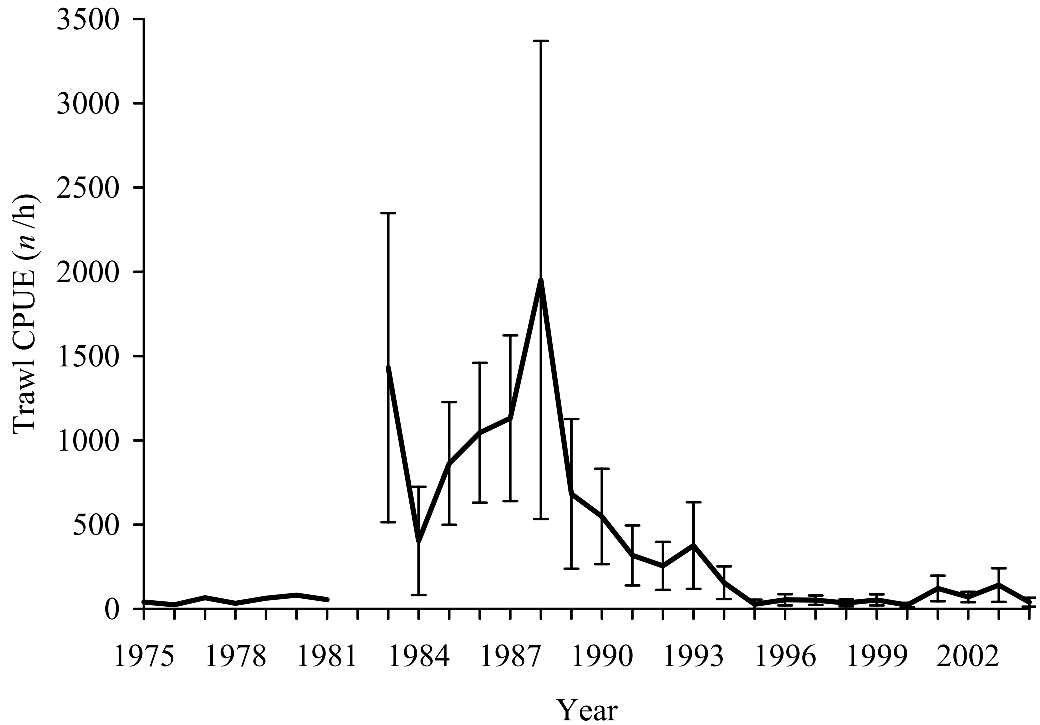

Figure 3-5. Trawl CPUE of stock size (≥ 130 mm) yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2004. No trawling was conducted in 1982. Error bars for 1983-2004 represent ± 2 SE.

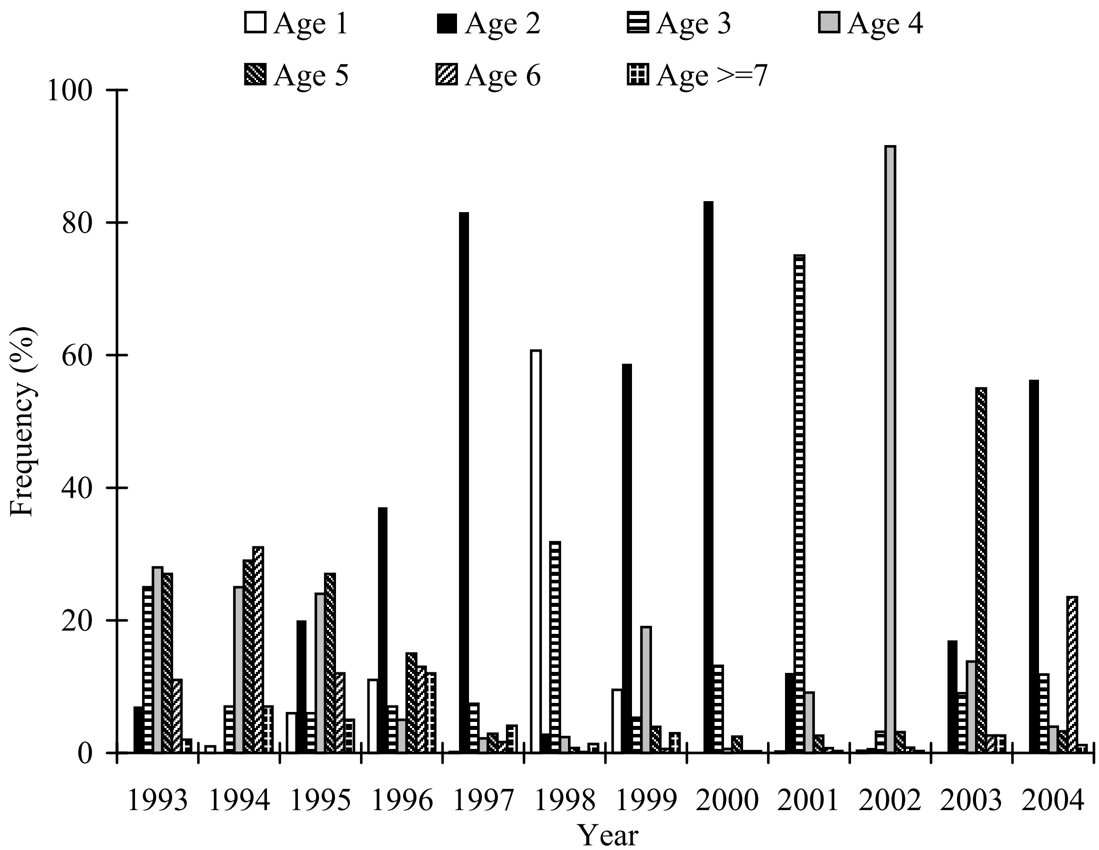

Figure 3-6. Age frequency of trawl caught stock (≥ 130 mm) yellow perch at pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

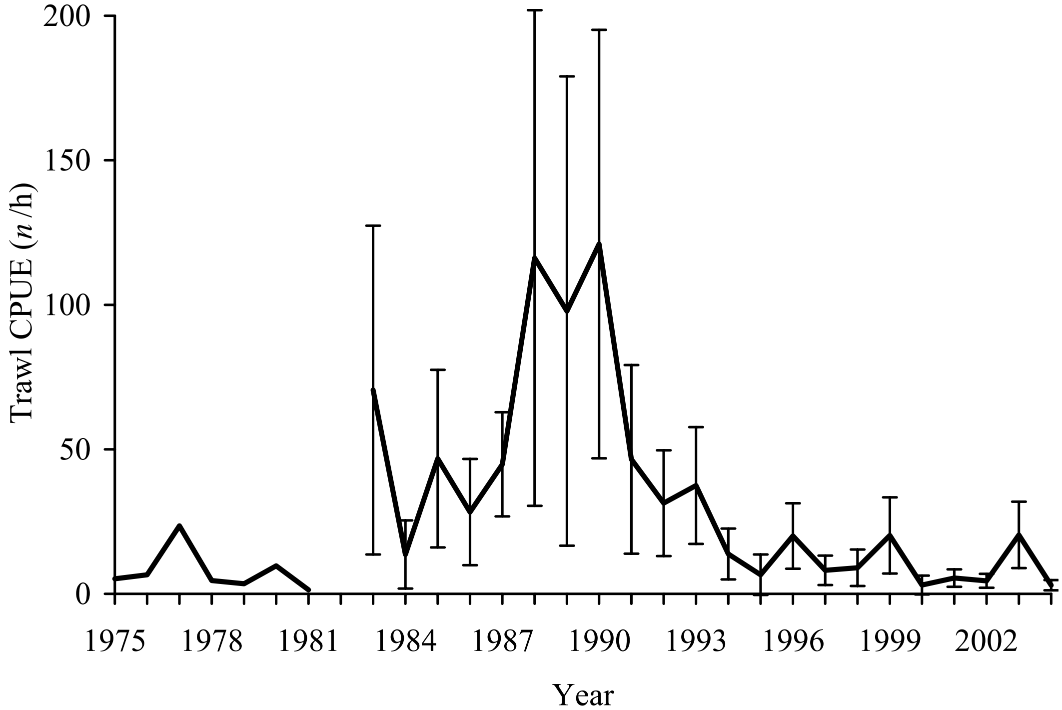

Figure 3-7. Trawl CPUE of quality size (≥ 200 mm) yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2004. No trawling was conducted in 1982. Error bars for 1983-2004 represent ± 2 SE.

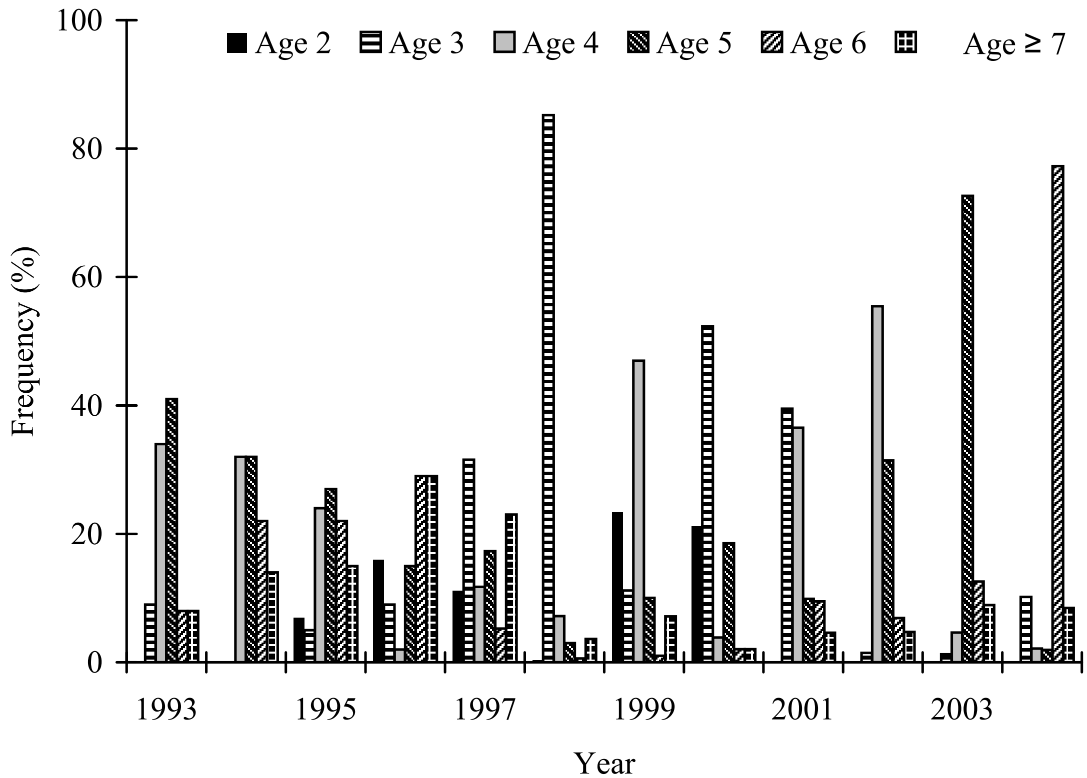

Figure 3-8. Age frequency of trawl caught quality size (≥ 200 mm) yellow perch at pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

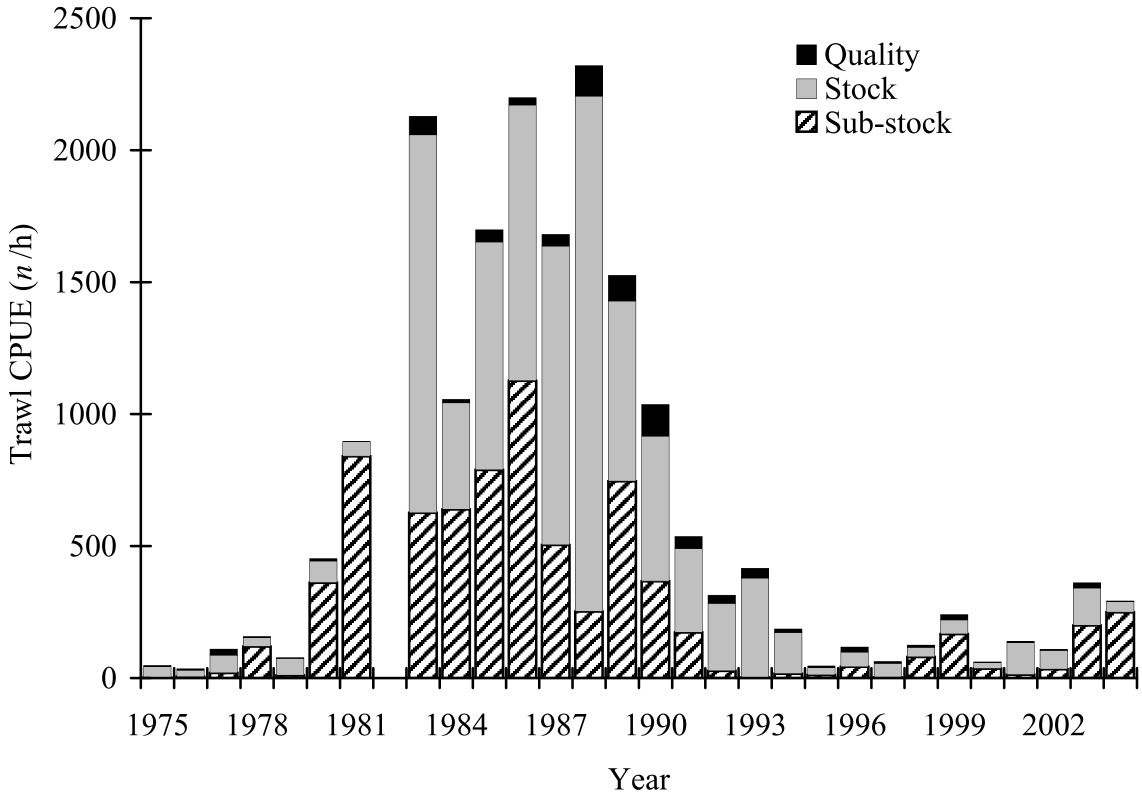

Figure 3-9. Trawl CPUE of sub-stock, stock, and quality size yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2004. No index trawling was conducted in 1982.

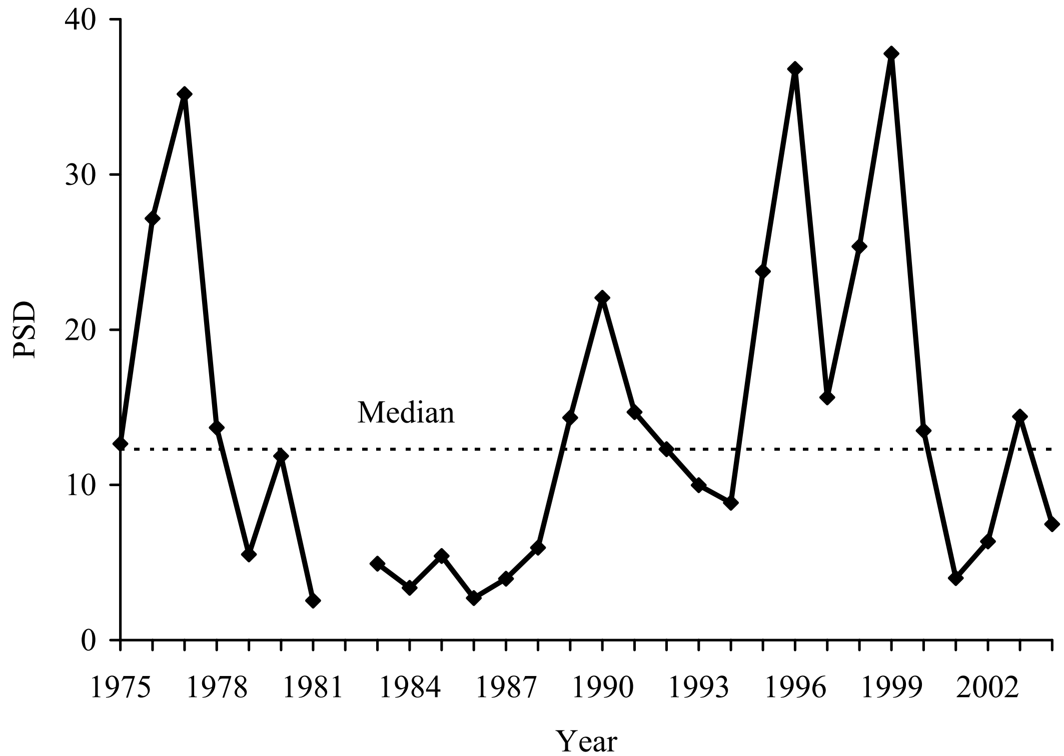

Figure 3-10. Proportional stock density (PSD) of yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2004. No index trawling was conducted in 1982.

between PSD and abundance of either stock or quality fishes (McComish and Shroyer 1996).

Sex ratios have varied substantially since 1993 (Figures 3-11, 3-12, 3-13, and 3-14). The overall sex ratio of fish age ≥1 was 45%:55% male:female in 2004 (Figure 3-11). The sub-stock composed 86% the total catch (Appendix 3-3) with a sex ratio of 47%:53% male:female (Figure 3-12). Fish of stock size (≥ 130 mm) made up 14% of the catch (Appendix 3-3) with a sex ratio of 29%:71% male:female (Figure 3-13). Quality-size (≥ 200 mm) fish comprised 1% of the total catch (Appendix 3-3) with a sex ratio of 0%:100% male:female (Figure 3-14).

Trends in typical ages and lengths of the trawl catch of each sex since 1993 are summarized in Figure 3-15. Median ages of males and females remained at age 1 for the second straight year in 2004. Median length classes of both males and females decreased in 2004 to 70 mm. The shift in trawl median length, from 2003 to 2004, for both male and female yellow perch is due the prominence of the 2004 year class in the population.

Gill Net Catch

Gill nets captured yellow perch ranging in lengths from 160 to 369 mm; males from 160 to 319 mm, and females from 170 to 369 mm in 2004 (Appendices 3-6, 3-7, and 3-8). The length frequency had a tri-modal distribution with the modes centered at 210 to 219 mm, 260 to 269 mm and 290 to 299 mm and mimicked the female length frequency due to their comprising 94% of the total catch (Figure 3-16 and 3-17). The 1998 year class (age 6) dominated the catch at 78%, while the 2001 year class (age 3) comprised 9% of the gill net catch (Appendix 3-6). Furthermore, males from the 1998 year class comprised 68% of the male gill net catch, while females from that year class made up 78% of the female catch (Appendix 3-7 and 3-8). Median age of both sexes was 6, while median length classes of males decreased 20 mm to 210 mm from 2003 to 2004, while females increased 30 mm to 250 mm during this same period (Figure 3-18).

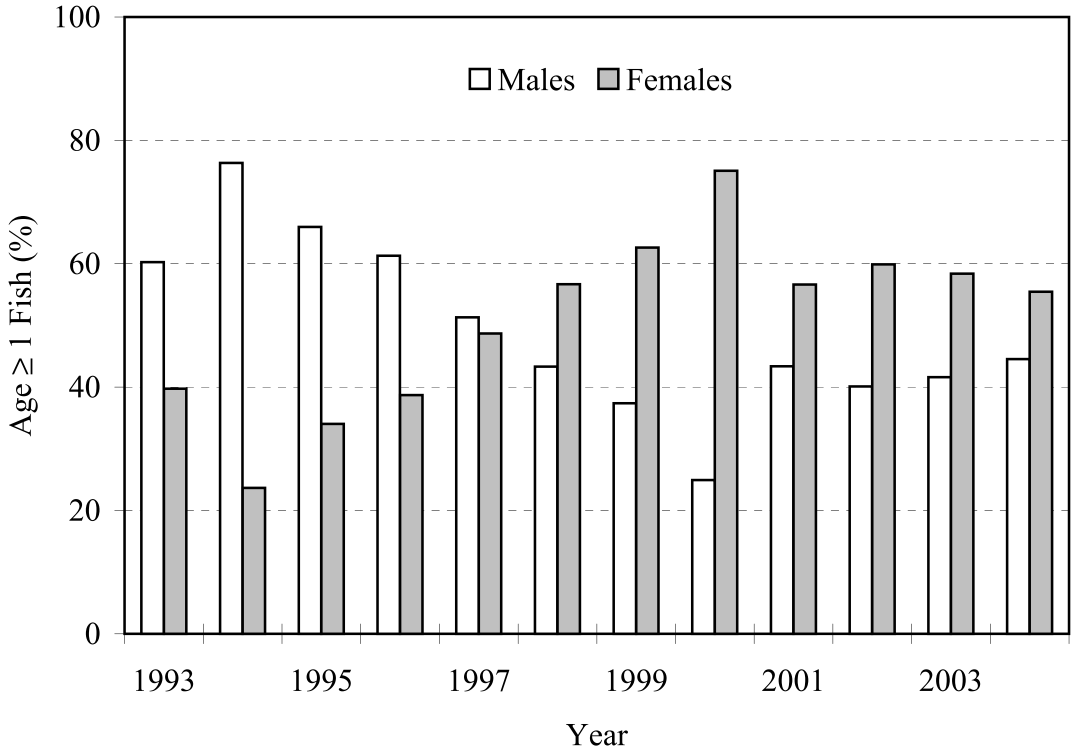

Figure 3-11. Sex ratios of age ≥ 1 yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

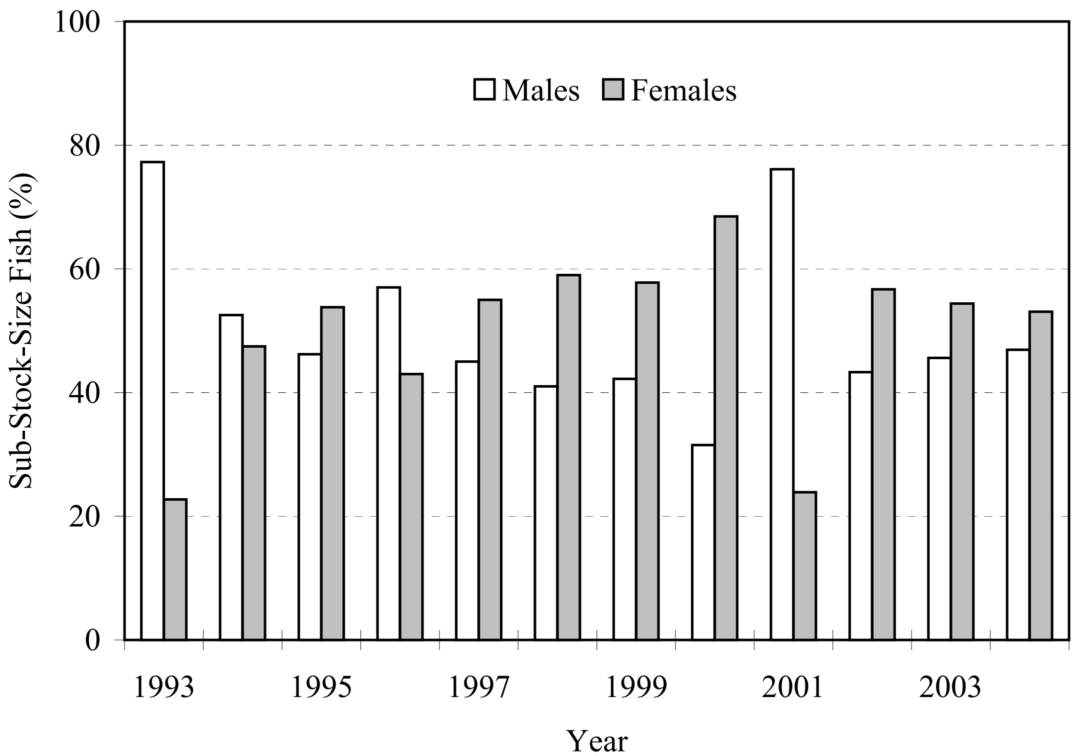

Figure 3-12. Sex ratios of sub-stock-size (age ≥ 1 and < 130 mm) yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

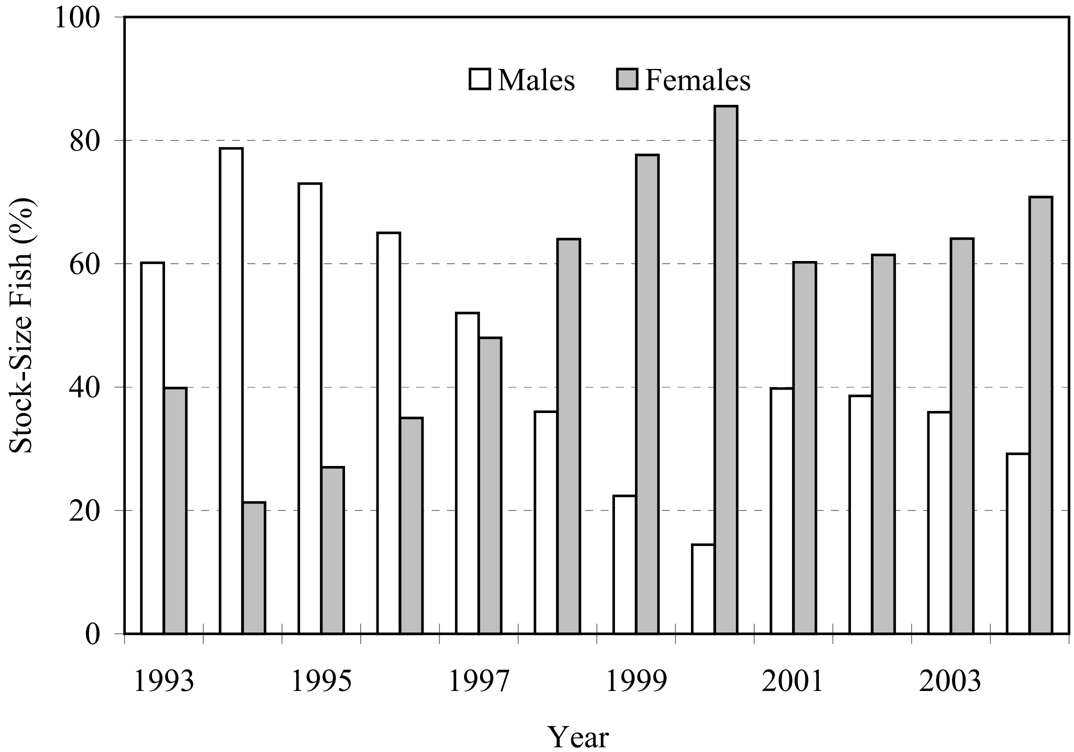

Figure 3-13. Sex ratios of stock-size (≥ 130 mm) yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

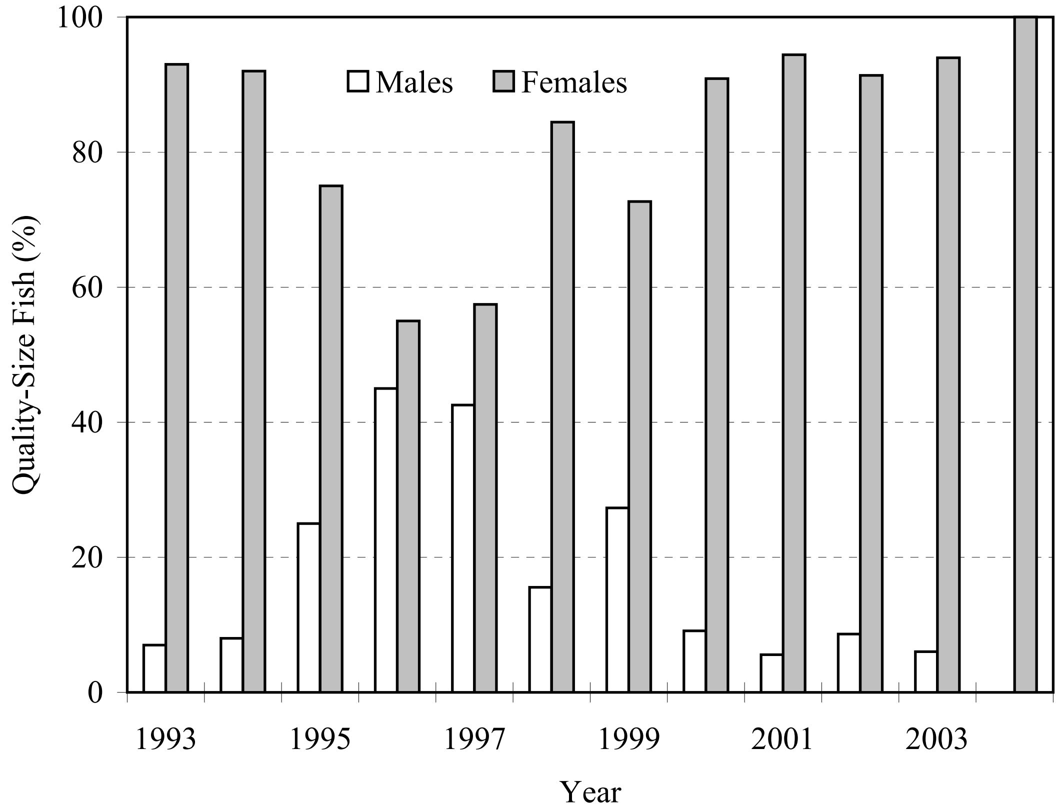

Figure 3-14. Sex ratios of quality-size (≥ 200 mm) yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

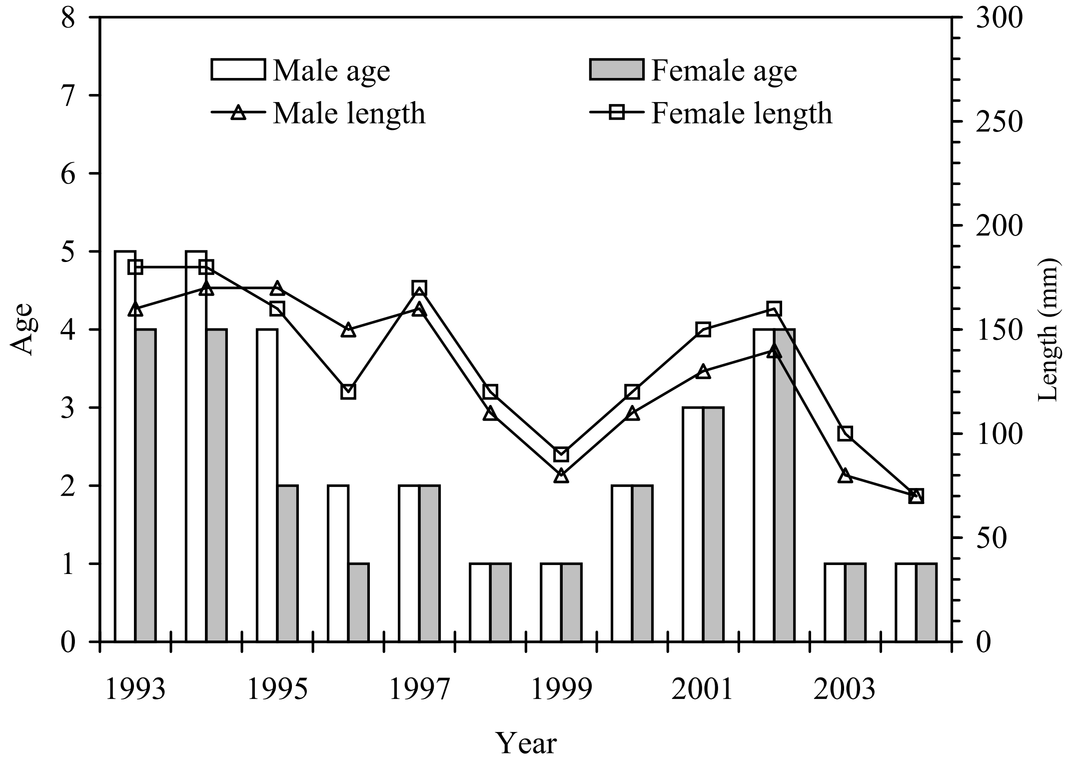

Figure 3-15. Median age and length classes of male and female yellow perch age ≥ 1 in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

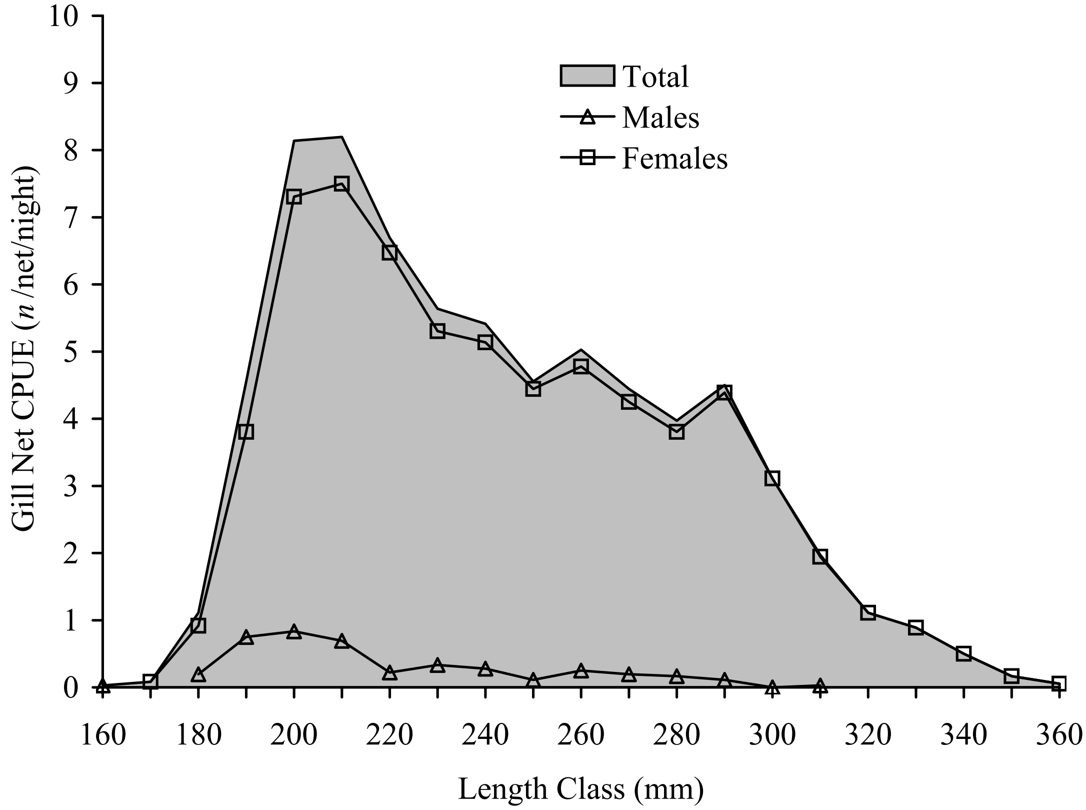

Figure 3-16. Length composition of the pooled 10 m and 15 m gill net catches of yellow perch at pooled sites in Indiana waters of Lake Michigan in 2004.

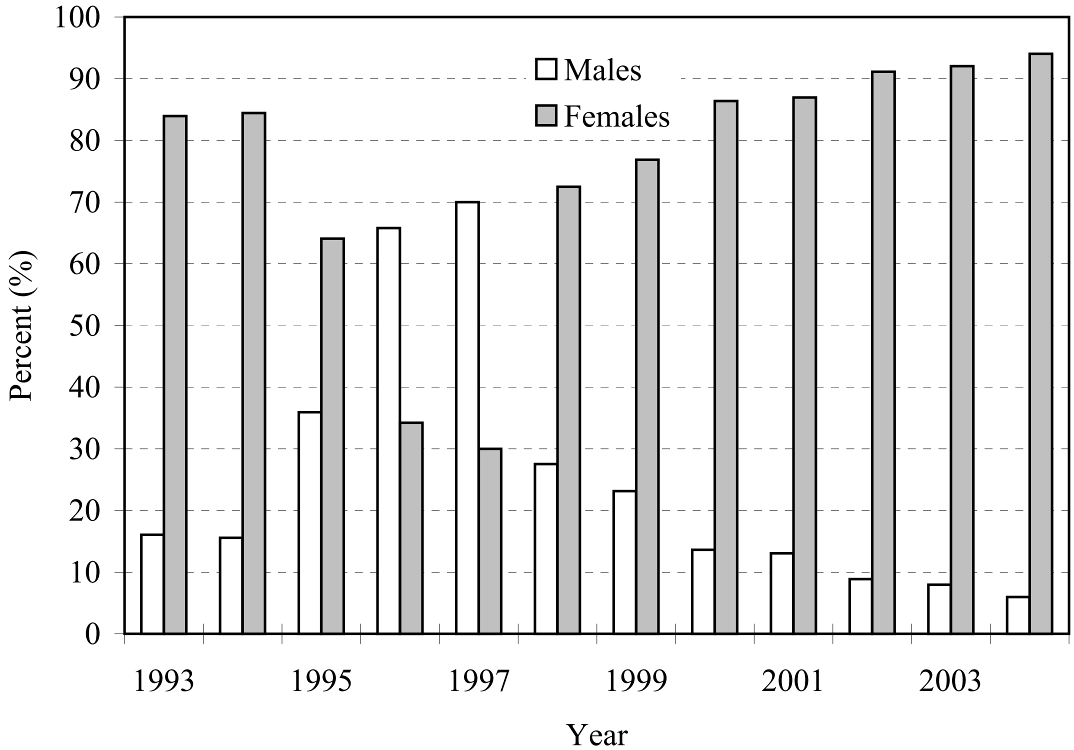

Figure 3-17. Sex ratios of the pooled 10 m and 15 m gill net catches of yellow perch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

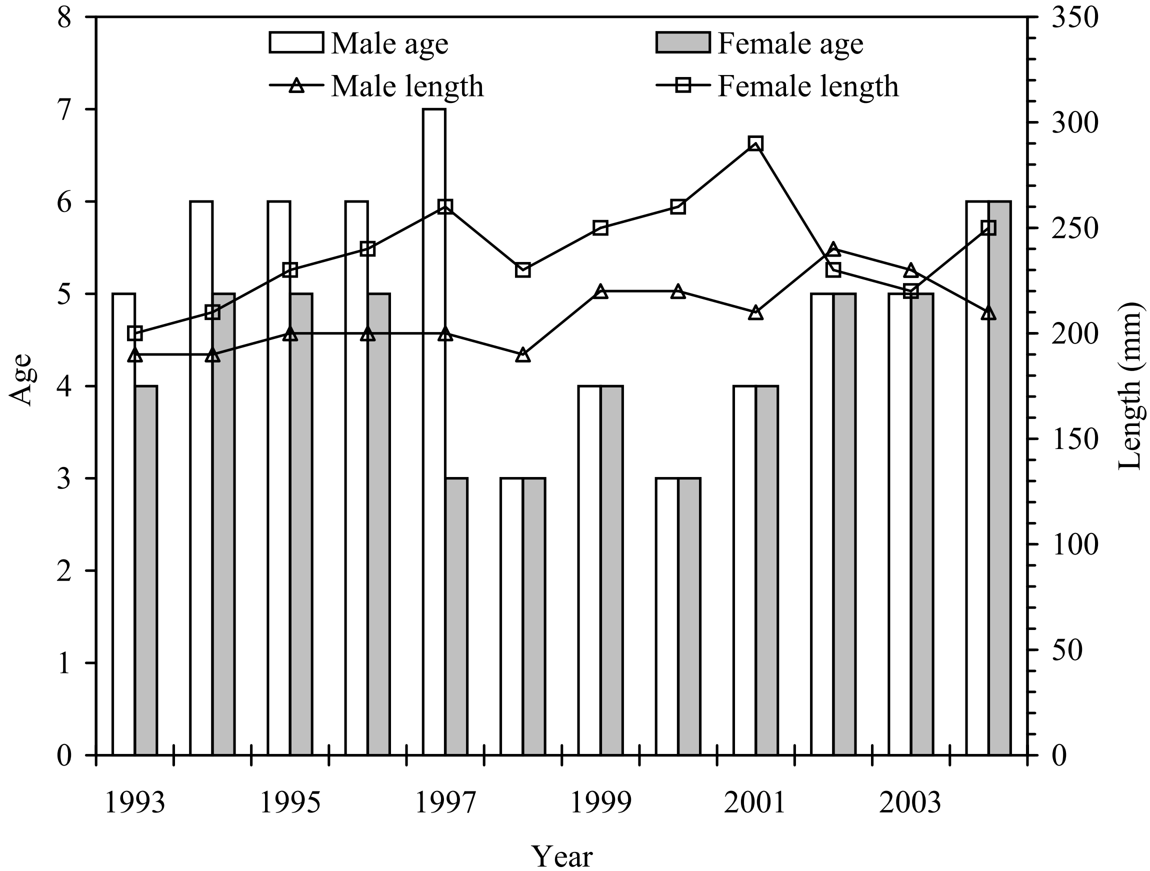

Figure 3-18. Median age and length classes of male and female yellow perch in the pooled 10 m and 15 m gill net catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2004.

Ages and Lengths at Maturity

In June 2004, 93% of males were mature at age 2 and 61% of females were mature by age 3. The minimum length classes that were ≥ 50% mature were 80 to 89 mm for males and 180 to 189 mm for females (Tables 3-5 and 3-6). Females from the 1998 year class comprised over 78% of all mature females, and thus will largely be responsible for production of future year classes in the population. Size at maturity is particularly important for females, as it determines the number (fecundity) of eggs produced. Larger females have a greater visceral space for egg development when compared to smaller females (Tsai and Gibson 1971). Furthermore, as yellow perch length increases, egg size has been shown to increase (Jansen 1996), which can enhance survivability of larval fish. This same relationship of female size to fecundity and egg size has been shown for yellow perch collected from the Indiana waters of Lake Michigan (Lauer et al., in press). The current yellow perch population structure exhibited by the total number of females captured in June 2004 showed 94% of the reproducing females were quality size. Although we do not yet fully understand how the size composition of mature females in the population effects recruitment, it has been shown that in Lake Michigan, larger females produce smaller larvae with larger yolk sac than smaller female yellow perch which produce larger larvae with small yolk sac (Heyer et al. 2001). The larger larvae have an advantage in survivability over smaller larvae because they can swim faster and farther for food, better avoid predation, and can capture and consume larger prey items. When food resources are limited, larvae with larger yolk sac would have an immediate advantage through a higher endogenous energy source. Although the Heyer et al. (2001) study was limited in scope (n=10 females) and range (no fish < 200 mm), it does give insight as how to best approach stock composition. The inability to manage abiotic factors, especially those that may impact yellow perch recruitment (Clapp and Dettmers 2004) suggests that the reproductive stock should be abundant with different sized females. Under this scenario, larvae collectively should have a greater chance of survivability beyond their first winter.

Table 3-5. Percent maturity by age for yellow perch from pooled trawl and gill net catches in Indiana waters of Lake Michigan in June 2004. Gonads of mature fish were either ripe or recently spent.

	Males			Females		
Age	*N*	Immature %	Mature %	*N*	Immature %	Mature %
1	285	96	4	254	100	0
2	134	7	93	254	100	0
3	19	4	96	107	39	61
4	11	2	98	32	40	60
5	7	0	100	18	12	88
6	49	0	100	468	3	97
7	1	0	100	13	7	93
8	1	0	100	6	0	100
9				5	0	100
10						
11						
12				1	0	100

Table 3-6. Percent maturity by length class of yellow perch from pooled trawl and gill net catches in Indiana waters of Lake Michigan in June 2004. Gonads of mature fish were either ripe or recently spent.

Length class (mm)	Males			Females		
	N	Immature %	Mature %	*N*	Immature %	Mature %
40	102	100	0		100	0
50	145	100	0	68	100	0
60	23	100	0	145	100	0
70	3	67	33	30	100	0
80	12	8	92	7	100	0
90	41		90	8	100	0
100	57	7	93	47	100	0
110	24	0	100	101	100	0
120	9	11	89	83	100	0
130	5	0	100	40	100	0
140	17	6	94	7	100	0
150	25	0	100	4	100	0
160	15	0	100	9	67	33
170	4	0	100	11	82	18
180	9	0	100	19	37	63
190	5	0	100	29	31	69
200	4		100	56	9	91
210	2		100	72	7	93
220	2		100	57	0	100
230	1		100	59	0	100
240				47	0	100
250				44	0	100
260				43	0	100
270	1		100	41	0	100
280	1		100	32	0	100
290				36	0	100
300				27	0	100
310				14	0	100
320				5	0	100
330				7	0	100
340				7	0	100
350				2	0	100
360				1	0	100

Job 4: Selected Population Characteristics of the Near-Shore Non-Salmonine Fish Community Emphasizing Yellow Perch

Historical trends in the near shore fish community of southern Lake Michigan were summarized by McComish et al. (2000). This report will update the major historical findings and focus on data collected in 2004.

<u>Catch Composition</u>

Trawl Catch of Age ≥1

A total of 10 non-salmonine fish species represented by individuals age ≥ 1 was collected by trawling at sites M, K, and G in 2004 (Figure 4-1; Appendix 4-1). Spottail shiners were numerically the most abundant species with a mean trawl CPUE of 359 fish/h and accounted for 41% of all fish captured. Yellow perch was the next most abundant fish, with a mean CPUE of 289 fish/h, representing 33% of the total catch. Other major fish species sampled included alewife at 118 fish/h (14%), round goby at 84 fish/h (10%) and rainbow smelt *Osmerus mordax* at 14 fish/h (2%) of the total catch. The longnose sucker *Catostomus catostomus*, white sucker *Catostomus commersoni*, trout-perch *Percopsis omiscomaycus*, banded killifish *Fundulus diaphanous*, and ninespine stickleback *Pungitius pungitius* were present at low CPUEs.

Among-Site Differences in Trawl Catch

Differences in occurrence and CPUE of some species among sample sites were observed in 2004 (Figure 4-1; Appendix 4-1). The round goby catch rate was significantly greater at site K than the catches at both sites M and G. The white sucker, trout-perch and ninespine stickleback catches were low and only at site M, while the banded killifish was only caught at site G. Catch rates were not significantly different at each site for the spottail shiner, yellow perch, alewife, rainbow smelt, and longnose sucker. Catch rates for those species, excluding the alewife, trended downward starting at site M and heading westward to site G.

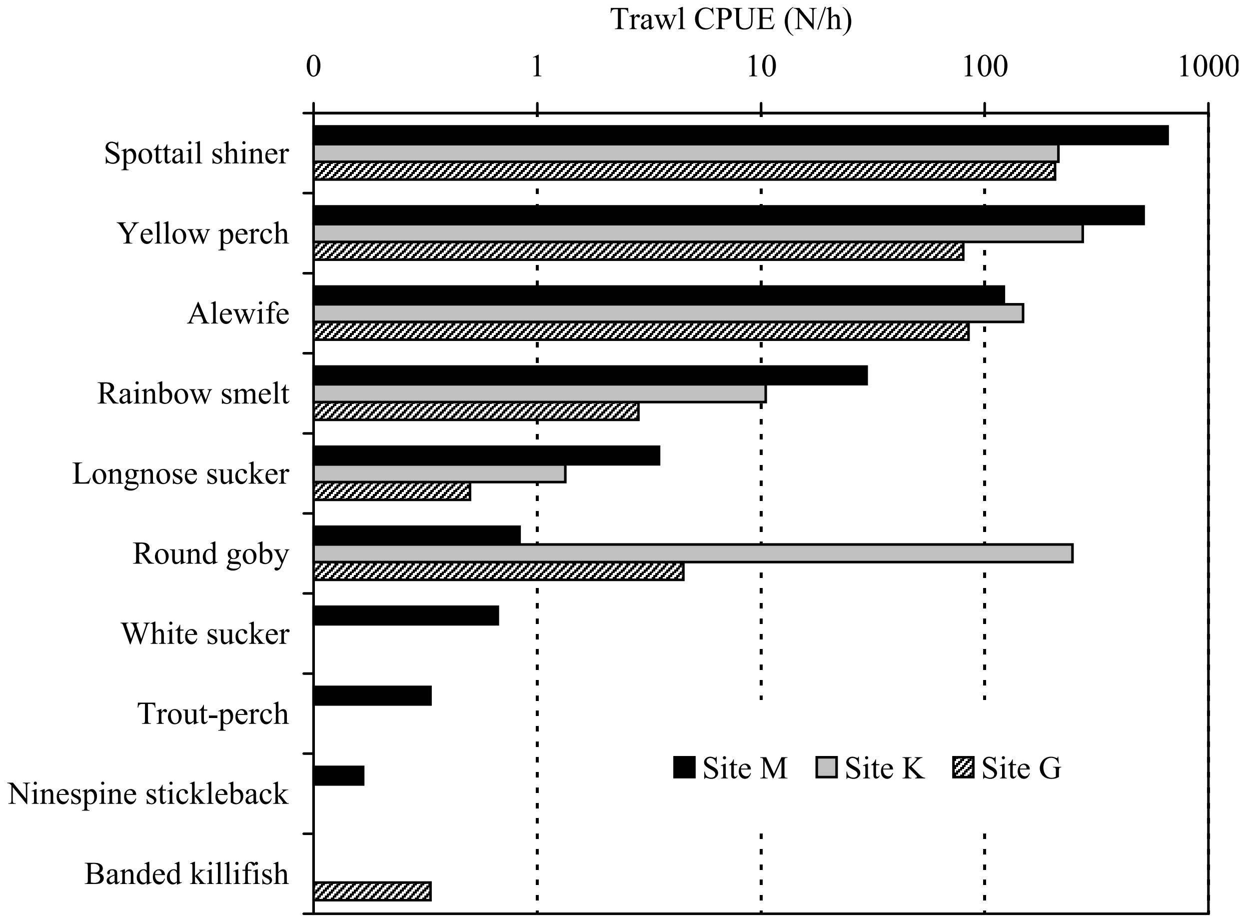

Figure 4-1. Summary of species composition of the trawl catch of non-salmonine fishes age ≥ 1 at sites M, K, and G in Indiana waters of Lake Michigan in 2004.

Trawl Catch of Age 0

Age-0 fishes are not fully vulnerable to the trawl due to their spatial and temporal distributions and small sizes, so catch data must be interpreted accordingly (McComish et al. 2000). Thus, the abundance of age-0 fishes is not always a good indicator of year class strength or recruitment into respective populations. Catches of age-0 fishes occur mainly in late July and August when some of the fish have grown large enough to be retained by the trawl. The total catch for the June-August period for all fish species is how values of CPUE are reported. Therefore, the CPUE of age-0 fish during the last half of the sample season would be approximately twice the reported annual mean. Fish were determined to be age-0 based on their small sizes and late-season initial occurrence in the trawl catch. Yellow perch, alewife, spottail shiner, and round goby were the most commonly caught species, although other species occasionally were found in low and variable numbers. The time series of age-0 yellow perch CPUE (Appendix 3-2) was noted earlier (see Job 3) and data for other species were not tabulated.

Gill Net Catch

Twelve different species were caught in gill nets at sites M, K, and G in 2004 (Appendix 4-2). The composition of the gill net catch included several species also caught in the trawl. However, because gill nets are fished in deeper water and they select fish generally > 150 mm total length, some differences were observed. As was typical of past years (McComish et al. 2000), yellow perch dominated and accounted for 92% of the catch in 2004. The only other species composing ≥ 1% of the catch were longnose sucker (4%) and white sucker (2%). Species caught incidentally (< 1% of CPUE) were alewife, round goby, gizzard shad *Dorosoma cepedianum*, rainbow smelt, freshwater drum *Aplodinotus grunniens*, and lake whitefish *Coregonus clupeaformis*.

Time Series of Relative Abundance

Summary of Trends in Major Species

Trends in trawl CPUE (excluding age 0) of the five historically most abundant species at sites M, K, and G from 1984-2004 are summarized in Figure 4-2. Trawl catches of three species decreased in 2004: spottail shiners, yellow perch, and alewife,

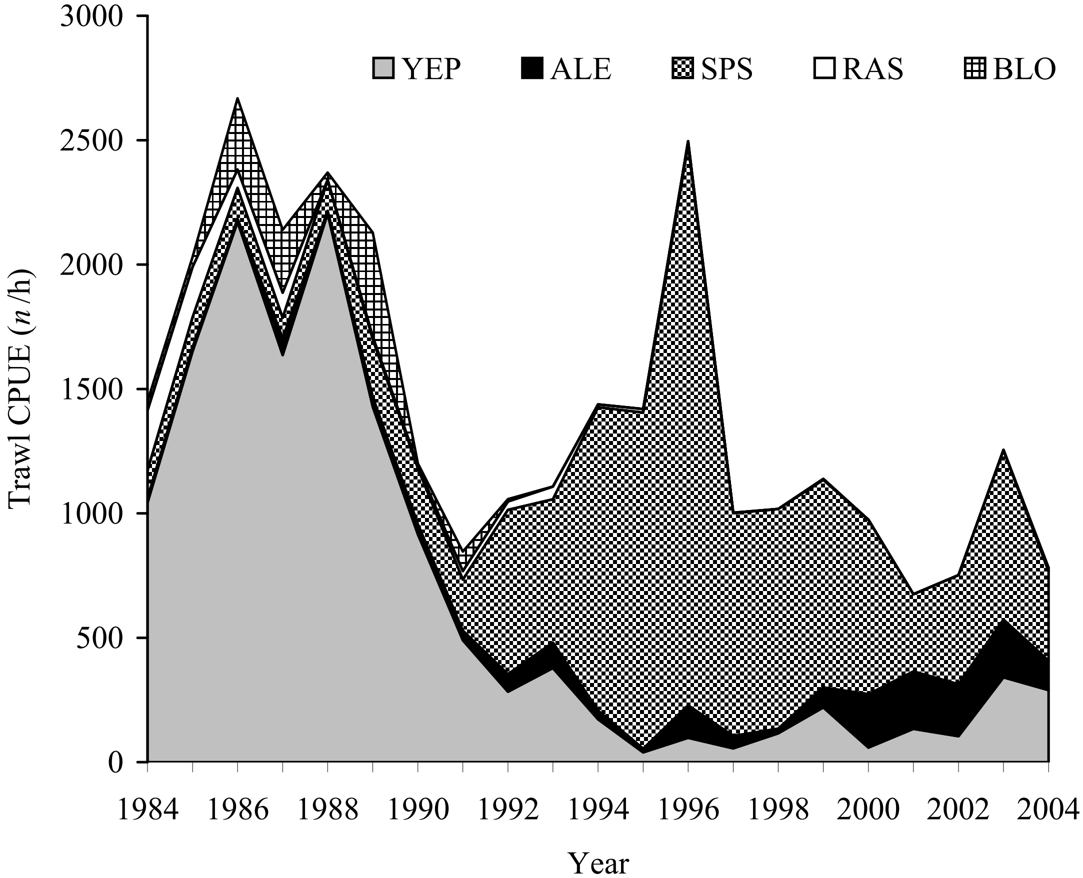

Figure 4-2. Mean annual trawl CPUE (excluding age 0) of five historically abundant species from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. Abbreviations: YEP = yellow perch, ALE = alewife, SPS = spottail shiner, RAS = rainbow smelt, BLO = bloater.

while the rainbow smelt increased. Bloaters *Coregonus hoyi* were last caught in the trawl during 1999.

Yellow Perch

The relative abundance of the 2004 trawl catch of age ≥ 1 fish at pooled sites M, K, and G decreased slightly but remains the second highest level since 1993 (Figure 4-3). The decline in yellow perch abundance after 1988 continued because of reduced recruitment and high mortality, as discussed under Job 3.

Contrary to the trawl catch, gill net (51, 64, and 76 mm stretch measure) caught yellow perch increased for the second straight year in 2004 (Figure 4-4). Trends in gill net CPUE were similar at both depths, with the catch somewhat higher at 10 m when compared with 15 m. The combined mean value increased in 2004 to its second highest level since the early 1990s due the prominence of the 1998 year class.

The selective bias of the gill net (Hamley 1975) and trawl sampling gear (Bethke et al. 1999; Hjellvik et al. 2001) may not provide a complete representation of a whole fish population when analysis is based solely or mainly with on gear type (Olin and Malinen 2003). Currently trawl CPUE is used as the main data source for understanding Lake Michigan yellow perch population dynamics, with fish captured in gill nets used primarily to increase the number of larger fish in the aging process. Although separate analysis is performed and provides useful information, incorporating different types of effort into one standard unit may provide a more comprehensive understanding of the population (Ricker 1975). Thompson et al. (1931) combined different gear types into a standard unit by scaling to the dominate gear among all gears assessing the Pacific halibut fishery. Although combining trawl and gill net data to form a single unit of effort may be more difficult (Ricker 1975), analyzing the differences in yellow perch demographics between the trawl and gill net catches could provide a more comprehensive understanding of the yellow perch population.

Alewife

An alewife aging study was initiated using four boney structures: scales, opercules, vertebrae, and whole otoliths. Previously, length frequencies distributions were used solely to determine alewife population age (Allen et al. 2002).

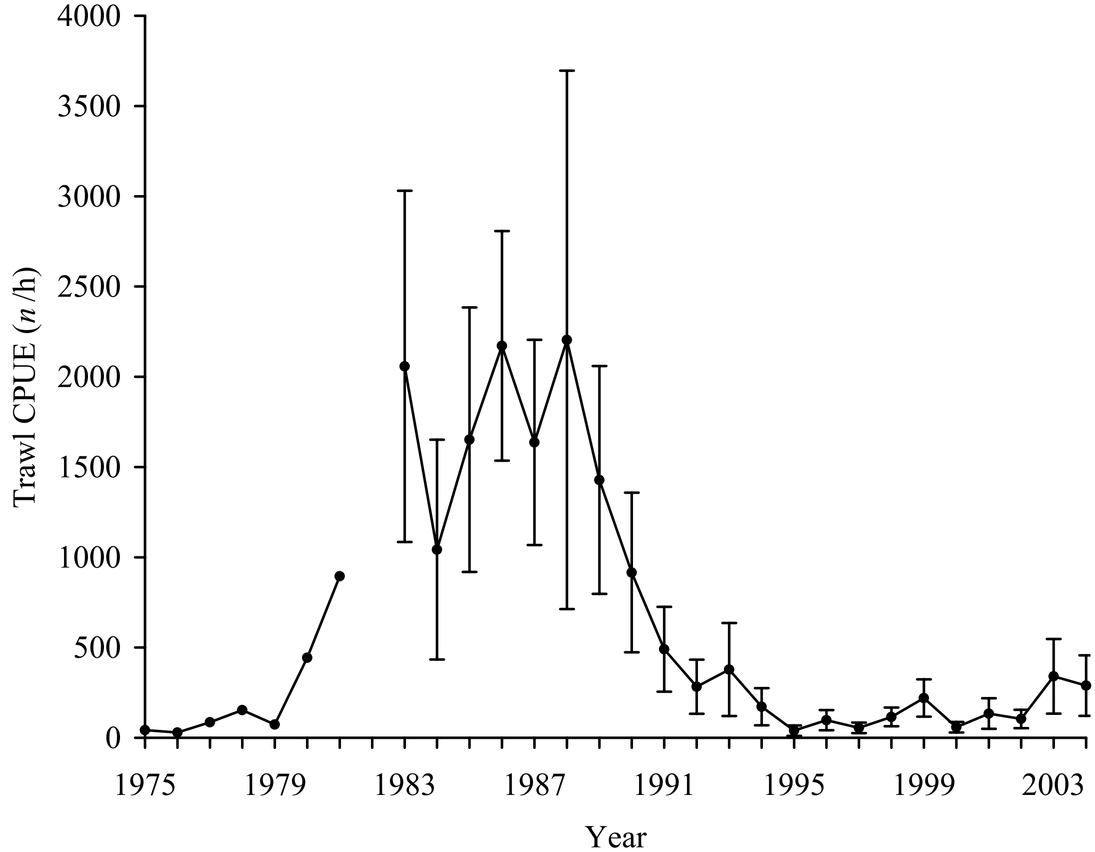

Figure 4-3. Mean annual trawl CPUE of yellow perch age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1975 to 2004. Only site K was sampled from 1975 to 1983; 1984 to 1988 data represent pooled sites M and K; and 1989 to 2004 data represent pooled sites M, K, and G. No trawling was conducted in 1982. Error bars for 1983 to 2004 are ± 2 SE.

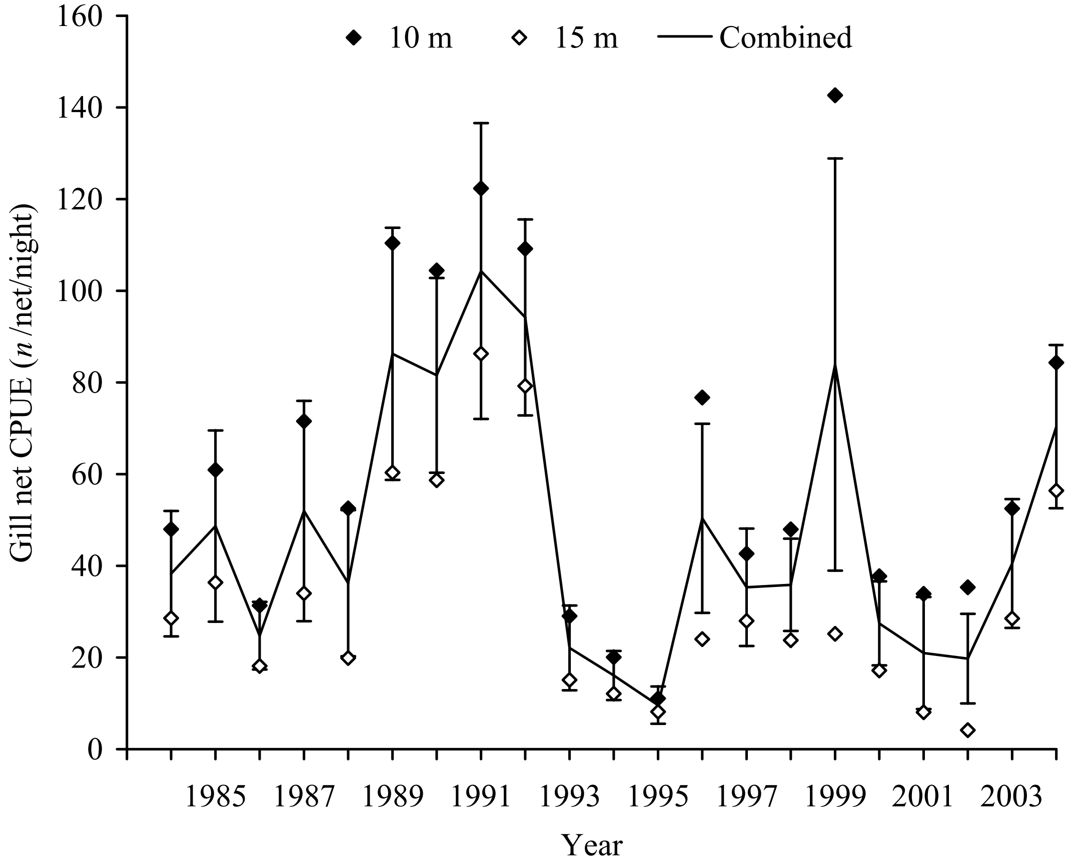

Figure 4-4. Mean annual gill net CPUE of yellow perch at 10 m, 15 m, and combined depths from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. Error bars represent ± 2 SE of combined means.

The results of the study suggest otoliths ($CV_{\bar{x}} = 0.10$) provided greater precision than scales ($CV_{\bar{x}} = 0.14$), vertebrate ($CV_{\bar{x}} = 0.17$) and opercules ($CV_{\bar{x}} = 0.23$) (LaBay 2005). Using the aging results from whole otoliths and information from the length frequency distributions, approximately 62% of the alewife population consisted of age 5 fish (1998 year class) in 2003. Similar to our findings, lakewide assessment by the Great Lakes Science Center found the 1998 year class comprised 73.1% of alewife age 1 and older in 2003 (Madenjian et al. 2005). We will continue to closely monitor alewife abundance due to its impact on yellow perch recruitment (see Job 5).

The relative abundance trend of alewife in 2004 decreased to approximately half its level of 2003 (Figure 4-5). The decrease in alewife abundance is likely due to mortality associated with the dominate 1998 year class and minimal observed alewife recruitment based on aging and length frequencies analysis (Labay 2005). Mean alewife gill net CPUE remained very low in 2004 (Figure 4-6). Gill net CPUE is probably not a reliable index of overall alewife abundance because the deployed mesh sizes catch only the largest fish in the population.

Spottail Shiner

The mean trawl CPUE of spottail shiners in 2004 trended down from 2003 (Figure 4-7). Abundance continues to be significantly reduced from the peak abundance of 1996. We will continue to closely monitor the spottail shiner and examine any potential impact they may have on yellow perch.

Bloater

The bloater trawl CPUE at pooled sites M, K, and G was zero again in 2004 (Figure 4-8). Bloaters have been almost non-existent in the trawl catch since 1993 and only in 1992 was CPUE significantly different from zero. The bloater continues to be sharply depressed due likely to the alewife impacts noted by numerous authors (Wells and McLain 1973; Brown et al. 1987; Eck and Wells 1987; Brown and Eck 1992).

Rainbow Smelt

The trawl CPUE of rainbow smelt in 2004 increased to its highest level since 1993 (Figure 4-9). This marked only the second time since 1984 that rainbow smelt CPUE was significantly different than zero. As with the bloater, the rainbow smelt

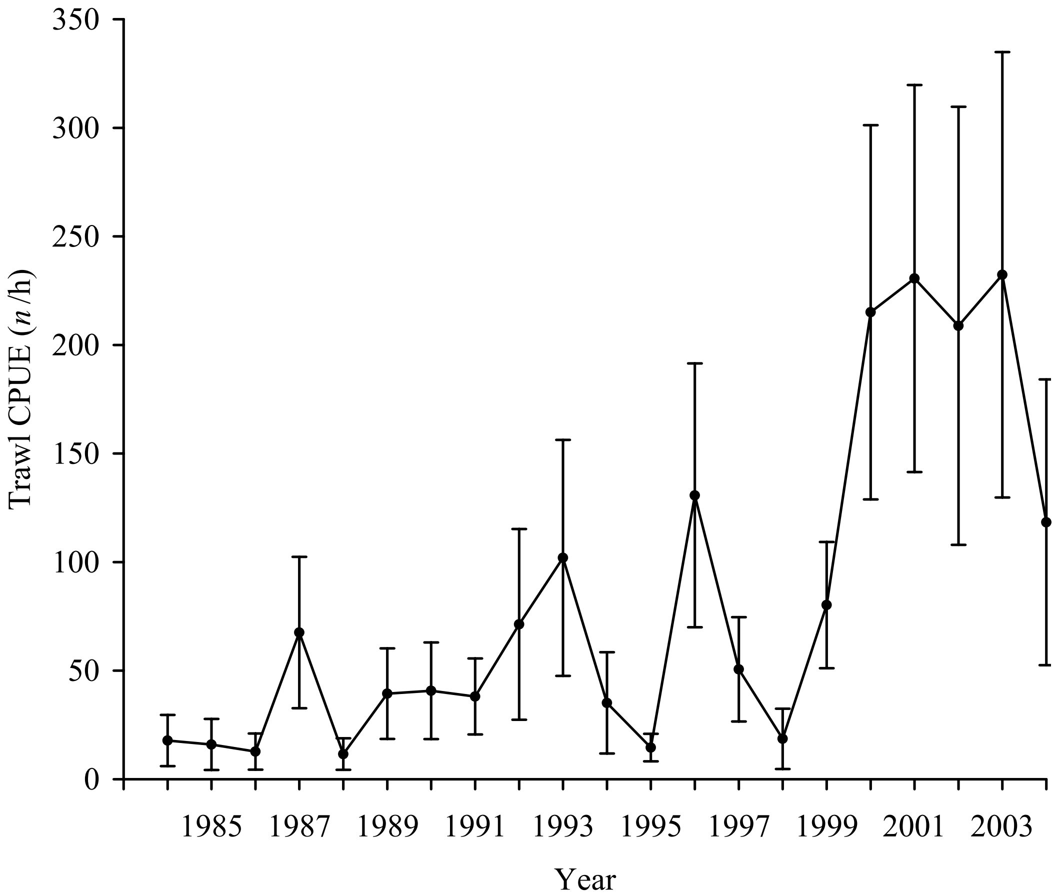

Figure 4-5. Mean annual trawl CPUE of alewives age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2004 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

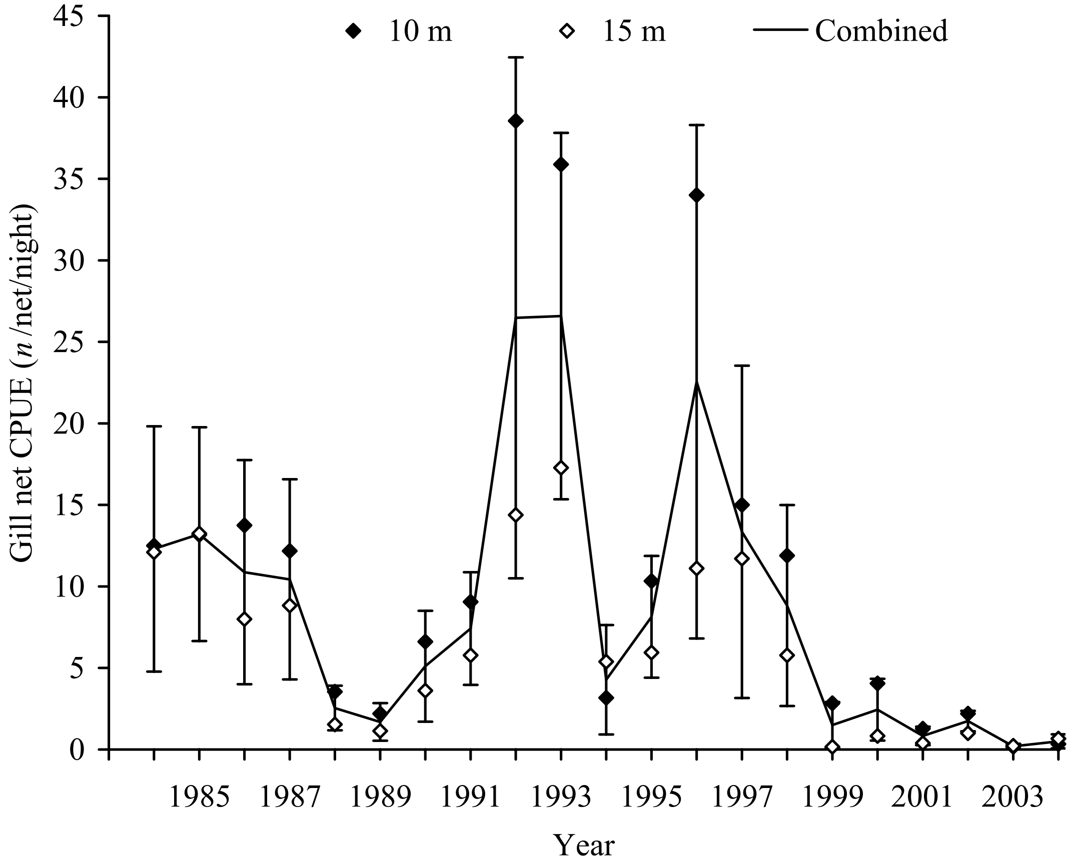

Figure 4-6. Mean annual gill net CPUE of alewives at 10 m, 15 m, and combined depths from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. Error bars represent ± 2 SE of combined means.

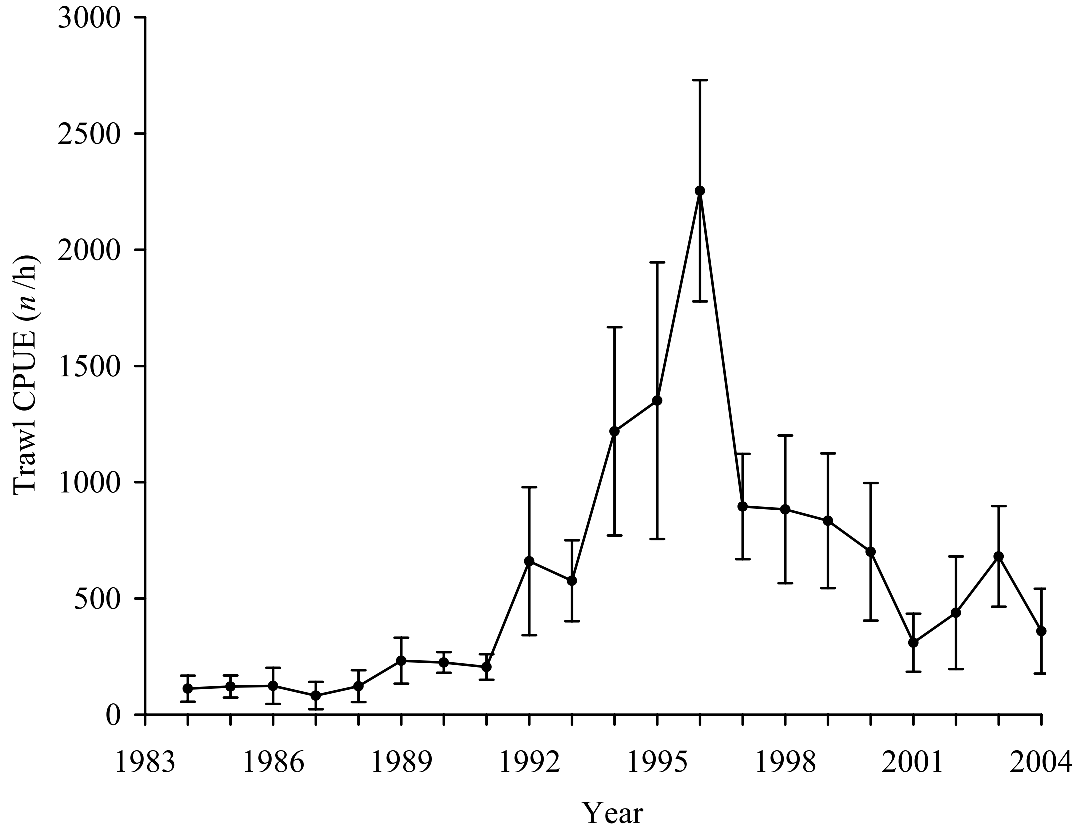

Figure 4-7. Mean annual trawl CPUE of spottail shiners age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2004 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

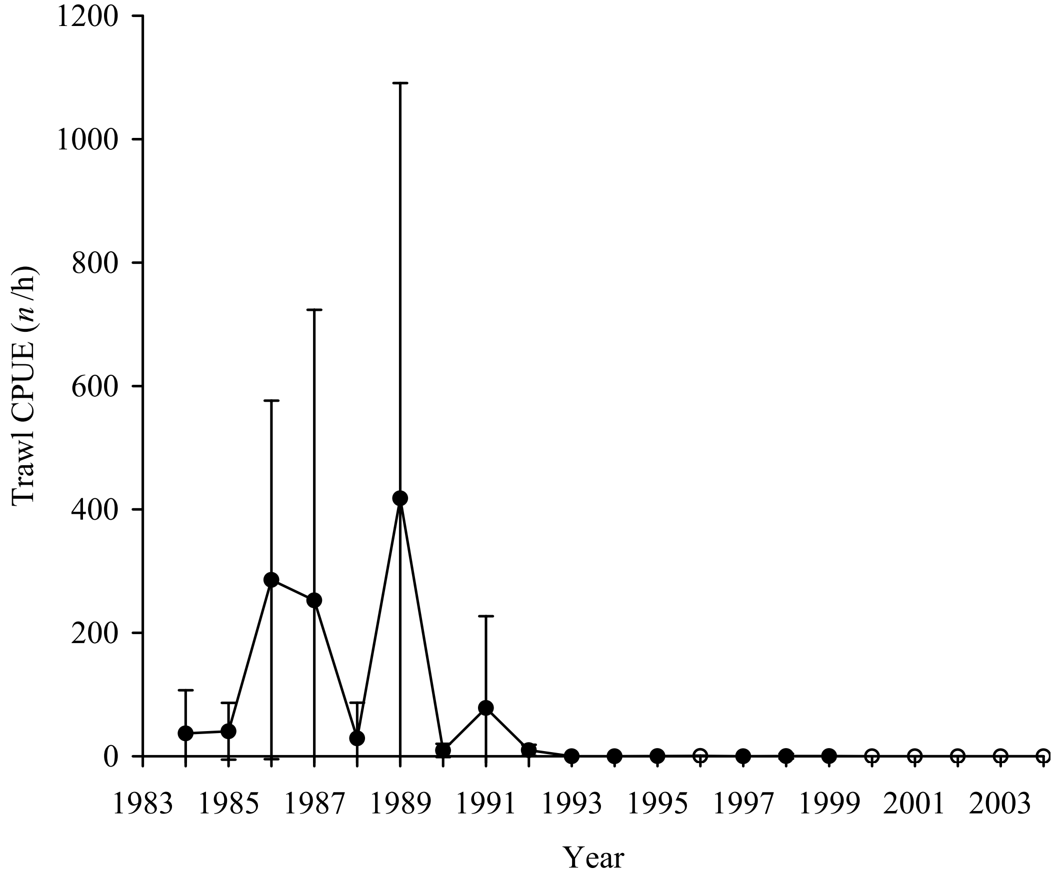

Figure 4-8. Mean annual trawl CPUE of bloaters age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2004 data represent pooled sites M, K, and G. Open circles represent no fish collected and error bars are ± 2 SE.

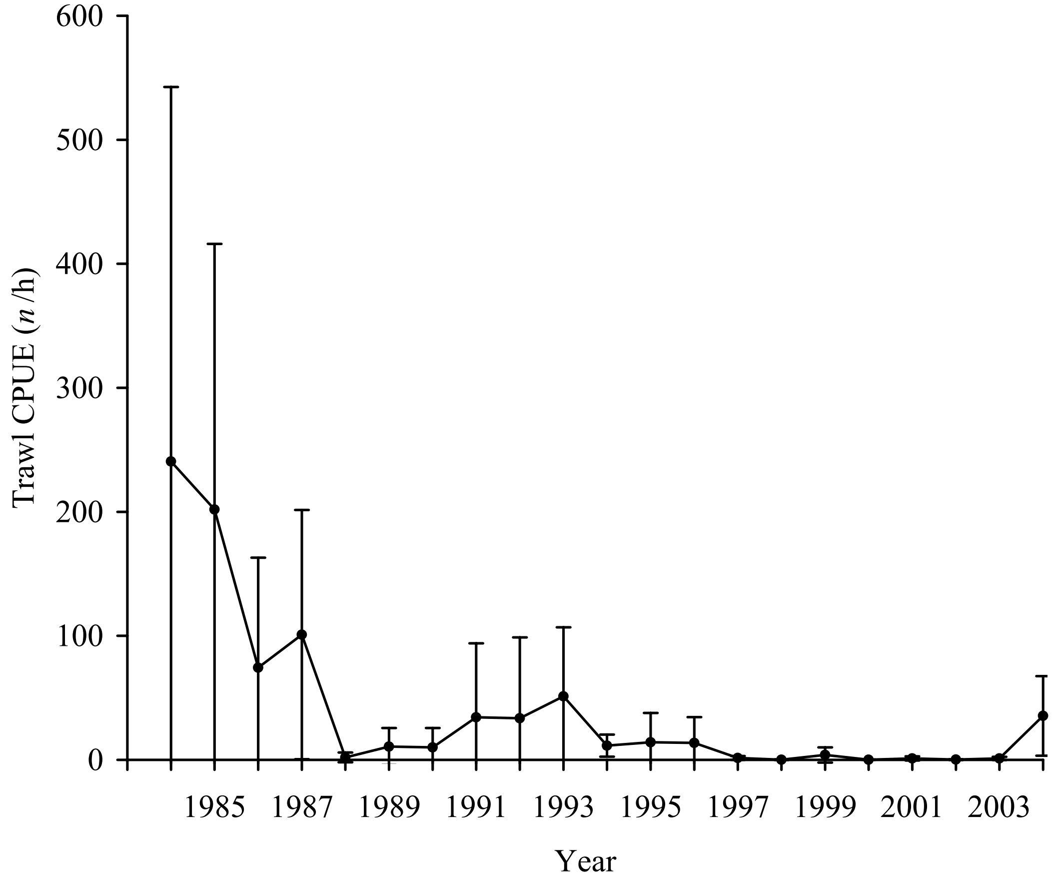

Figure 4-9. Mean annual trawl CPUE of rainbow smelt age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2004 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

continues to be depressed due likely to continued alewife effects (Smith 1970; Emery 1985).

Round Goby/Mottled Sculpin/Johnny Darter

Several changes have occurred over the past two decades in the population abundance of three benthic fishes: mottled sculpin, johnny darter, and round goby. Although the mottled sculpin and johnny darter population between 1984 and 1999 never showed high densities or frequency of occurrence (Lauer et al. 2004), they were ever-present in the population. Mottled sculpins were primarily found at site K, with sites M and G showing only a limited and sporadic abundance, although from 1994 to 1998, mottled sculpins were found in 87% of all samples. In contrast, johnny darters were present at all three stations during the period 1984-1999 but in low abundance. Both the mottled sculpin and johnny darter populations declined after 1999, eventually falling to zero beginning in 2001 and continued to be nonexistent at our sampling locations since that time. This change in abundance corresponded with the population expansion of the non-indigenous round goby, with our first capture in the trawl in 1998 (Figure 4-10). Round gobies are known to negatively impact mottled sculpins (Jude et al. 1995) and appear responsible for the decline of this species and the johnny darter in Indiana waters of Lake Michigan (Lauer et al. 2004). A more complete analysis of this interaction is provided by Lauer et al. (2004).

Trout-Perch

Trawl CPUE of trout-perch in 2004 remained at a level similar to the past four years and the years prior to 1996 (Figure 4-11). It is unclear why trout-perch CPUE has recently shown (1996 to 1999) wide fluctuations during the 1984 to 2003 period. Currently, no apparent correlation between CPUE of trout-perch and yellow perch or alewives has been defined (Sapp 1999).

Other Species

Several other species occur incidentally in the trawl catch, but annual catches are too low to make meaningful comparisons of relative abundance among years. The species composition of the incidental catch in 2004 was generally similar to that reported in other years. We will continue to carefully monitor the species present and be on the lookout for additional nonindigenous species.

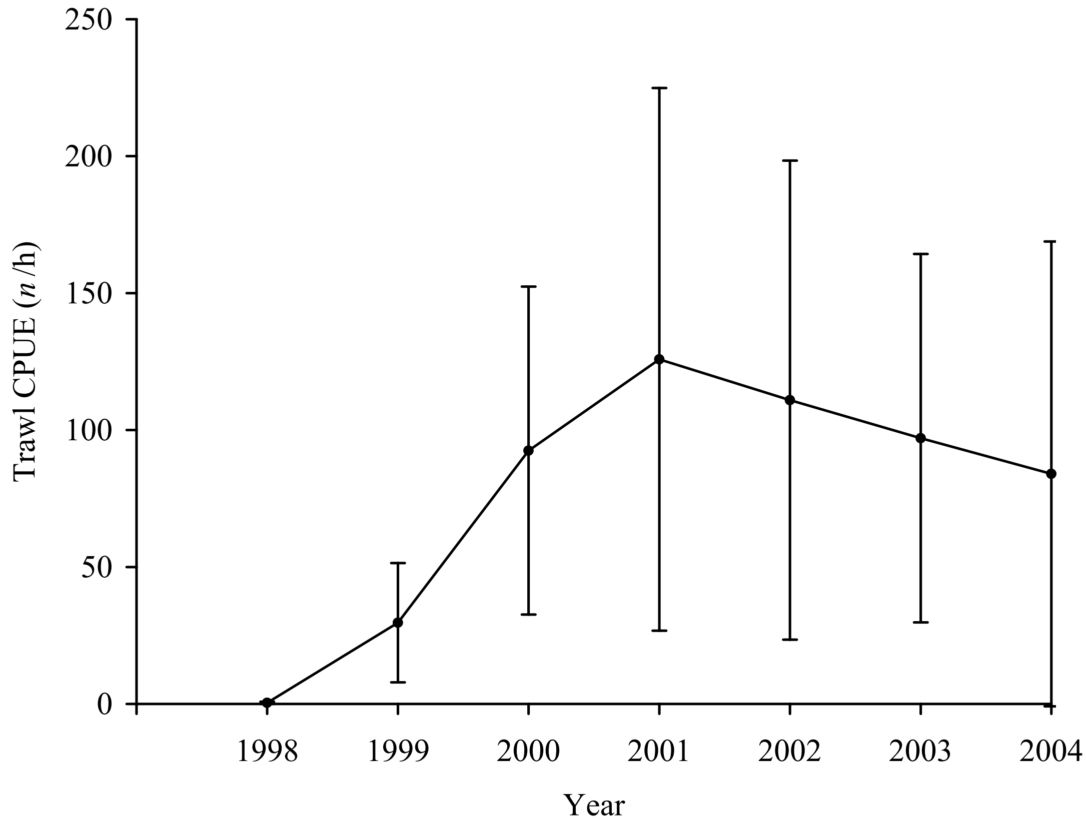

Figure 4-10. Mean annual trawl CPUE of round gobies age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1998 to 2004. Error bars are ± 2 SE.

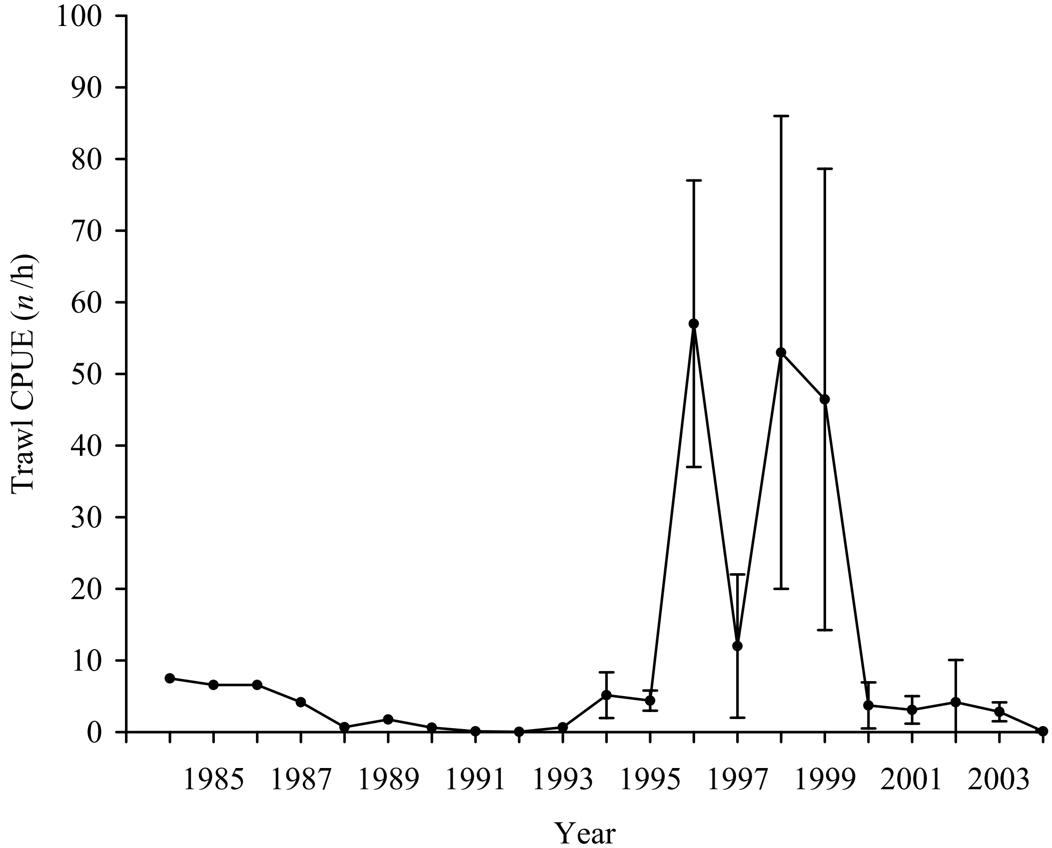

Figure 4-11. Mean annual trawl CPUE of trout-perch age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2004. The 1984 to1988 data represent pooled sites M and K; the 1989 to 2004 data represent pooled sites M, K, and G. Error bars for 1994 to 2004 are ± 2 SE.

Job 5: The Development and Refinement of Descriptive, Predictive, and Simulation Models of the Yellow Perch Population in Indiana Waters of Lake Michigan

Forecasting Quality Sized Yellow Perch CPUE

Shroyer and McComish (1998) used cross-correlation to forecast quality sized yellow perch CPUE and identified a strong positive relation between trawl CPUE of stock-size fish (*S*) in year *t* and quality-size fish (*Q*) in year *t* + 2 for *t* = 1975-1979, 1981, and 1983-1994. This relationship was described for pooled sites M and K by the linear model,

$$(1)\ \sqrt{Q_{t+2}} = 2.68 + 0.00572 \bullet S_t$$

and was due to survival and growth of sub-quality (< 200 mm) stock-size fish from *t* to *t* +2. The CPUE of quality-size fish predicted by the model closely approximated the trend in observed values, and the model correctly predicted that quality CPUE would remain less than about 40/h in 1997-1998 (Appendix 3-2).

Figure 5-1 is an updated plot of the relationship between trawl CPUE of quality-size and stock sized fish. The updated model includes data from the years 1975 to 2004 with incorporation of site G beginning in 1989 and recalculation of stock and quality CPUE for earlier years. The data points for *t* = 1997 to 2002 fell well within the cluster of other points at the low end of stock and quality CPUE, providing no evidence of a recent change in the relationship. The 95% confidence intervals for the slope and intercept of the updated regression line include the slope and intercept of model (1), indicating no significant difference. The updated model for pooled sites M, K, and G is,

$$(2)\ \sqrt{Q_{t+2}} = 3.08 + 0.0045 \bullet S_t \qquad (\text{adjusted } R^2 = 0.62)$$

Model (2) predicts with 95% confidence that quality CPUE will be less than 56 fish/h from 2005 through 2006.

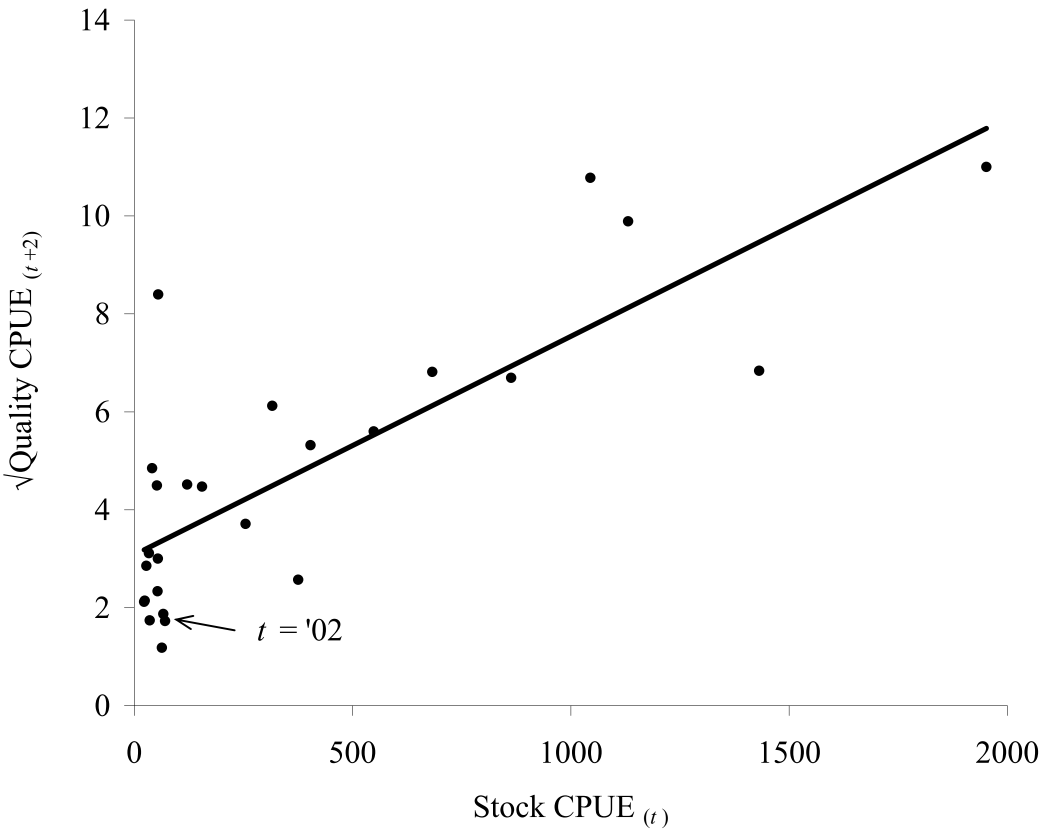

Figure 5-1. Relationship between trawl CPUE (*n* /h) of stock-size yellow perch and the square root of trawl CPUE (*n* /h) of quality-size yellow perch at sites M, K, and G in Indiana waters of Lake Michigan. *t* includes data from 1975 to 1979, 1981, and 1983 to 2004. Gaps in the time series *t* = 1980 and 1982 are due to a lack of index trawl data for 1982. This plot is an update of Figure 4 in Shroyer and McComish (1998).

Alewife and Yellow Perch Recruitment

Shroyer and McComish (2000) examined the relationship between the abundance of alewives and the recruitment of yellow perch to determine whether alewives were potentially responsible for the yellow perch recruitment failures in southern Lake Michigan after 1988. The relationship between alewife abundance and yellow perch recruitment was modeled for pooled sites M and K as

$$(3)\ \log_e R_{t+2} = 11.7 - (2.12)\ \log_e A_t$$

where R_{t+2} is the CPUE of age-2 yellow perch in year $t + 2$ and A_t is the CPUE of alewives age 1 or older in year t. The model explained more than 70% of the variability in recruitment of the 1984 to 1996 yellow perch year classes. The strong negative relationship between alewife abundance and yellow perch recruitment has important management implications, which were discussed by Shroyer and McComish (2000).

Figure 5-2 updates the model noted above found in McComish et al. (2000) by including data from the years 1984 to 2004 and incorporating site G beginning in 1989. With the addition of the 2004 data, the 95% confidence intervals for the slope of the updated regression line no longer includes the slope of model (3), indicating a difference between the two models. The high alewife abundance observed since 2000 (Figure 4-6) led to an expectation that recruitment of age 2 yellow perch in 2003 and 2004 (2001 and 2002 year classes) would have been further suppressed based on previous knowledge (Allen et al. 2004). The perturbation in the model as a result of the added data points (t = '02 and '03) may be due to factors associated with alewife population demographics. We would expect with the observed alewife abundance at its highest since 1984 (Figure 4-5) that recruitment of yellow perch (age 2 to the trawl) for the years 2003 and 2004 would have been comparable to the recruitment observed in 2002 (Figure 5-2). Alewives (149 to 200 mm TL) have been shown to prey upon larval yellow perch (Brandt et al. 1987; Kohler and Ney 1980), which may be one of several mechanisms explaining the consistent failed yellow perch recruitment in Lake Michigan (Clapp and Dettmers 2004). The alewife population in Indiana waters consisted primarily of the 1998 year class during 2001 and 2002 and was comprised mainly of fish > 120 mm TL with smaller alewives making up less than 20% of the population (Labay 2005). This skewed alewife

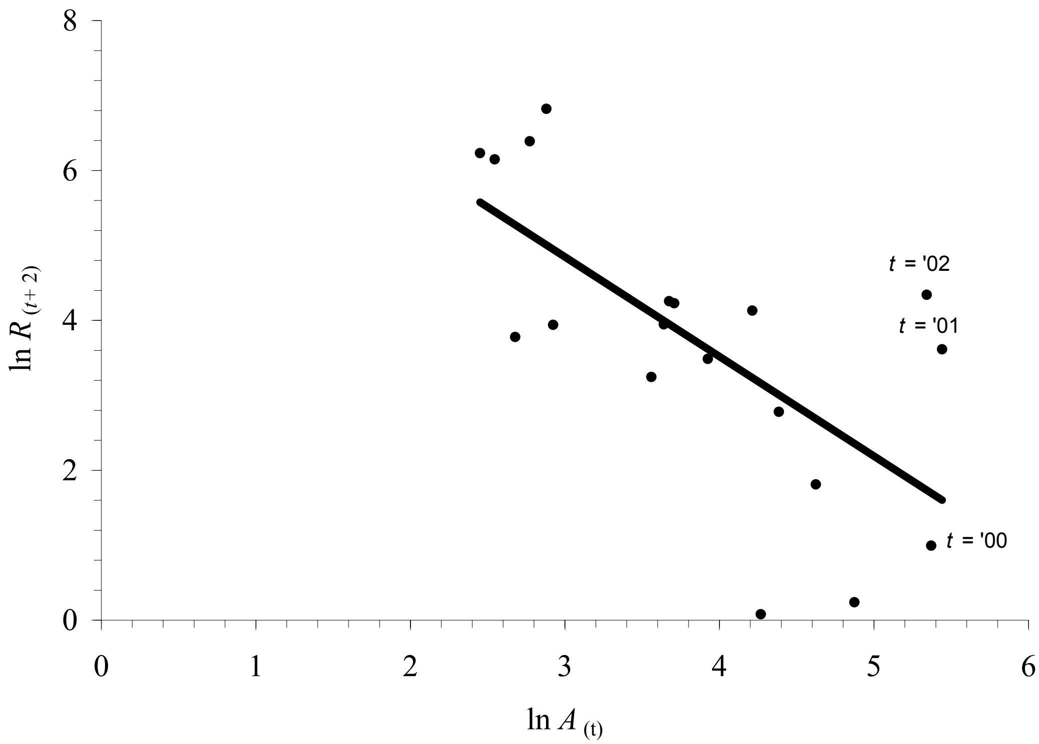

Figure 5-2. Relationship between trawl CPUE (n/h) of age-1 and older alewives in year t (A_t) and trawl CPUE (n/h) of age-2 yellow perch in year t (R_{t+2}) at sites M, K, and G in Indiana waters of Lake Michigan. t includes data from 1984 to 2004.

size and age frequency may be putting differential pressure on prey species in contrast to historic expectations, allowing an increase in yellow perch recruitment. Because this hypothesis is in contrast to the findings of Brookings et al. (1998) and Krueger et al. (1995) who suggest alewives < 149 mm TL have been shown to prey on other larval fish, we will continue to investigate this relationship.

The updated model for pooled sites M, K, and G is:

$$(4)\ \log_e R_{t+2} = 8.83 - (1.33)\log_e A_t \qquad (\text{adjusted } R^2 = 0.42)$$

Model (4) predicts with 95% confidence that age-2 CPUE of the 2004 year class in 2006 will be below 317/h. It appears likely yellow perch recruitment for the 2003 year class will remain relatively low as measured by Figure (3-1). Alewife trawl CPUE in 2003 was at the highest recorded level since 1984 and exceeded the range of values used to compute equation (4), thus predictions should not be made for recruitment of the 2003 yellow perch year class at this time. However, because the model depicts a threshold at which alewife relative abundance above 32 fish/h may result in failed recruitment of age 2 yellow perch, it suggests the 2003 year class strength will likely be similar to year classes since 1989 as shown in Figure 3-1.

Alewife, Stock, and Yellow Perch Recruitment

Shroyer and McComish (2000) discussed the possible importance of yellow perch spawning stock abundance in the prediction of yellow perch recruitment in years when alewife abundance is low enough to allow the potential for strong recruitment, but they did not include spawning stock abundance in their published model. It is possible to include both spawning stock abundance and alewife abundance in a Ricker type stock-recruitment model. A model of this type first appeared in McComish and Shroyer (1996) and was recently updated in McComish et al. (2000). In this section, we present an update to the most recent edition of this model by incorporating $t = 2004$. For a description of the algebraic manipulation of the alewife-yellow perch interaction into the standard Ricker stock-recruitment equation, see McComish et al. (2000). Standard multiple linear regression fitting R_{t+2}, S_t, and A_t from pooled sites M, K, and G for t including 1984 to 2004 resulted in the model:

$$(5)\ \log_e\left(\frac{R_{t+2}}{S_t}\right) = 5.719 - 0.021S_t - 1.119\log_e A_t$$

where R_{t+2} is the trawl CPUE of age-2 yellow perch in year $t + 2$, S_t is the trawl CPUE of quality-size (≥ 200 mm) yellow perch in year *t*, and A_t is the CPUE of alewives age 1 or older in year *t*. Residuals were normally distributed (Anderson-Darling normality test: A^2 = 0.350; P = 0.435), residual plots did not indicate substantial lack of fit or non-constant variance, and residuals were not significantly autocorrelated (Durbin-Watson statistic = 0.78; $P > 0.05$). Regression statistics for model (5) are listed in Table 5-1. The adjusted R^2 for this model is 0.236, compared to 0.42 for model (4) of the previous section. Thus, addition of abundance of quality-size fish resulted in a decrease in statistical significance of the recruitment model. The variable S_t is, at best, only marginally significant (Table 5-1). However, there is strong biological justification for inclusion of the stock-recruitment relationship (Hilborn and Walters 1992). Model (5) is more biologically realistic than model (4) because it forces recruitment to approach zero as spawning stock approaches zero.

Model (5) predicts the 2004 yellow perch year class to average 19.9 fish/h at age 2 (95% prediction interval: 0.03/h to 64.5/h) in 2006. The trawl CPUE of the 2003 yellow perch year class at age 2 is estimated to be less than 1/h (95% prediction interval: 0.01/h to 24/h). Based on trawl catches of the 2003 year class at age 1 (Appendix 3-3) it appears that recruitment to the trawl at age two will exceed the upper end of the prediction interval. As with model (4), predictions using the 2003 alewife CPUE values in model (5) is limited but results would likely suggests prediction intervals similar to those presented for the 2002 year class based on the influence of alewife abundance in this model.

To gain additional insight into the mechanisms effecting yellow perch recruitment we examined abiotic factors that may help to explain additional variability observed in the alewife/stock/recruitment relationship, model (5). We incorporated water temperature, water level, and lake-wide phosphorus levels into the model for the years 1984 to 2002. Average daily water temperature data was obtained from the Saint Joseph Water Filtration Plant in Saint Joseph, Michigan because they had the longest available

Table 5-1. Summary results for the regression of loge(R_{t+2}/S_t) versus S_t and $\log_e A_t$ for sites M, K, and G in Indiana waters of Lake Michigan. t includes data from 1984 to 2004.

Regression Statistics	
Multiple R	0.567
R Square	0.321
Adjusted R Square	0.236
Standard Error	1.714
Observations	19

ANOVA

	df	*SS*	*MS*	*F*	*P*
Regression	2	22.25	11.13	3.79	0.05
Residual	16	47.01	2.94		
Total	18	69.26			

	Coefficients	*SE*	*t*	*P*	Lower 95% C. I.	*Upper 95% C. I.*
Intercept	5.719	1.90	3.01	0.01	1.692	9.746
$S_{(t)}$	-0.021	0.01	-1.80	0.09	-0.045	0.004
$\log_e A_{(t)}$	-1.119	0.44	-2.57	0.02	-2.042	-0.195

data set within proximity of our sampling sites. Water temperature was taken from the filtration plants raw water intake which extends approximately 0.5 km offshore, 1.61 km south of the St. Joe River, and is positioned midway in the water column at a depth of 6.1 m. We examined water temperature three different ways, including, the number of degree days above 14 C from May to October (LeCren et al. 1977), the warming rate for the months April through May as described by Busch et al. (1975), and monthly average water temperature from May to October (Henderson and Brown 1985). Water level data was obtained from the United States Army Corp of Engineers Detroit Division. Mean annual lake-wide phosphorus (µg/L) data for Lake Michigan were obtained from Madenjian et al. (2005). We used step-wise regression with a marginal significance level of $\alpha = 0.1$ to enter to determine whether any of the abiotic factors could account for the unexplained variability (76.4%) in the alewife/stock/recruitment relationship, model (5). Although none of the abiotic variables were significant enough to be included in model (5), nonetheless we performed best subset analysis to determine which abiotic variables improved the adjusted R^2 value shown in Table (5-1) from model (5). Warming rate alone or included with water depth and the number of days above 14 C improved the models adjusted R^2, albeit slightly (Table 5-2).

The current stock/recruitment relationship, model (5) uses stock as the relative abundance of all quality sized (≥ 200 mm) trawl caught yellow perch in a given year. Although reproduction would not exist without males, recruitment is likely limited by the number of reproducing females, thus characterizing stock as only mature females may be more appropriate than combing all quality sized yellow perch (Ricker 1975). Furthermore, Lauer et al. (in press) established a length-fecundity relationship for southern Lake Michigan yellow perch which exhibited a positive relationship between female length and the number of eggs produced. Thus, recruitment may be influenced by the size of the reproducing females and not just by the total number of females in the reproducing population. Prior to 1993, the method by which we collected data limited our ability to accurately determine the sex ratio of the yellow perch population. However, since 1993 our sampling protocol has been modified and now provides us the opportunity to determine sex ratios and reproductive maturity (see Job 3). Using the length-fecundity

Table 5-2. Best subsets regression of $\log_e (R_{(t+2)}/S_{(t)})$ versus $S_{(t)}$ and $\log_e A_{(t)}$ with added environmental variables for the years t including 1984 to 2002.

Number of environmental variables in equation	Water Level	Lake-wide Phosphorus	Water Temperature			R-Sq(adj)
			Days >14 C	Warming Rate	Average Monthly Temperature	
1				X		25.2
1	X					21.3
2	X			X		26.0
2			X	X		25.3
3	X		X	X		25.4
3	X			X	X	22.8
4	X	X	X	X		19.7
4	X		X	X	X	19.5
5	X	X	X	X	X	12.7

relationship along with our understanding of the yellow perch populations' sex and maturity composition since 1993 allows us to examine three different expressions of stock: trawl CPUE of quality sized yellow perch, trawl CPUE of mature females, and egg potential (eggs/hr) as predictors of recruitment.

We used the base Ricker stock/recruitment equations to compare the effectiveness of the different stock variables in predicting yellow perch recruitment.

$$(6) \quad R_{t+2} = \alpha * P_t e^{-\beta_p P_t}$$

To fit each of the three models via linear regression we divided each side of equation (6) by *P*, and then lognormally transformed both sides of the equation resulting in the following equation:

$$(7) \quad \log_e\left(\frac{R_{t+2}}{P_t}\right) = \log_e \alpha - \beta P_t$$

Where, *R* is the trawl CPUE of age-2 yellow perch in year $t + 2$; *P* is the stock variable in year *t*; α is slope at origin; and β_p is parameter with dimensions of $1/P$ (Ricker 1975). Data were from pooled sites M, K, and G for *t* including years 1993 to 2002.

The best model for predicting recruitment was using trawl caught quality sized yellow perch (Table 5-3). This model explained 50% of the variation in recruitment of age two yellow perch to the trawl. Although the female model was not significant ($P > 0.05$), egg potential as a predictor of recruitment was marginally significant ($P = 0.057$) and additional years of data may increase its significance in predicting recruitment. Due to the rather short data set used to develop these models and the fact the overall population abundance has been relatively low during this time period the use of quality sized yellow perch as a sole predictor of recruitment is questionable. For example, when we expanded the data set to include the years 1984 through 2002, a period of time with both high and low yellow perch population abundance, quality sized yellow perch was not a significant ($P > 0.40$) predictor of age two trawl caught yellow perch. Even in model (5) which includes alewife abundance and quality sized fish as predictors of recruitment, quality sized fish is only marginally significant (Table 5-1).

Table 5-3. Results from fitting stock-recruitment regression models using age two trawl caught yellow perch recruits to estimates of stock for the year classes 1993 through 2002. The stock variables were as follows: QUALITY = trawl CPUE yellow perch ≥ 200 mm; EPUE = egg potential; and FEMALE = trawl CPUE of mature female yellow perch.

Model Rank	List of Variables	α	β	*P*	R^2
1	QUALITY	2.16	-0.126	< 0.05	0.50
2	EPUE	-8.83	-0.000002	> 0.05	0.30
3	FEMALE	-0.05	-0.017	> 0.05	0.14

We have attempted to further our understanding of the relationship between alewife, stock, and recruitment by replacing A_t, alewife CPUE with weight of fish per hour, in model (5). We performed this analysis to determine whether alewife size is more significant in effecting yellow perch recruitment based on the interference mechanism of predation and competition for food. Analysis of alewife trawl catches for the years 1984 through 1999 suggested minimal differences in their length frequency distributions from one year to the next. Furthermore, because alewife weight is proportional to its length, we can expand the data set and assume that weight (g/h) should explain a similar amount of variation in recruitment when compared to abundance. We re-ran model (5) using weight (g/h), rather than CPUE (*n*/h) values, and found this assumption was supported. Therefore, we have eliminated any identifiable differences in abundance vs. weight based model results.

Indiana Yellow Perch Simulation Model

The Indiana Yellow Perch Simulation Model (IYPM) was developed to predict yellow perch abundance trends using variables associated with their population dynamics. The application of the IYPM has the potential to further enhance the ability to effectively manage the yellow perch fishery in Indiana waters of Lake Michigan. A complete and detailed description of the model and its application to southern Lake Michigan yellow perch is found in Allen (2000). The model was updated by incorporating data from the years 1984 to 2004. Annual average natural mortality v (male = 0.44 and female = 0.31) and fishing mortality u (male = 0.32 and female = 0.34) was recalculated for the years 1984 to 1998, recent years were excluded due to low or variable catches. The growth functions (length-at-age predicted by trawl CPUE) for both sexes were updated with the most recent data. Furthermore, an add-in mechanism was incorporated which accumulates fish greater than age 8 rather than releasing them from the system as the previous version did. Historically, the yellow perch population contains fish older than age 8 and should be accounted for, thus this feature adds more realism to the model. The mathematical interpretation of the model is as follows:

$$N_{t+1} = \sum_{k=1}^{2} \sum_{i=2}^{8} (N_{i,k,t} - N_{i,k,t}(v_{k,t} + u_{k,t})) + f(g) + R_t$$

(6)

Where, N_{t+1} is the total CPUE of age-2 - 8 yellow perch in the year t+1, $N_{i,k,t}$ is the CPUE of yellow perch for each age class (i) and sex (k), in year t, $v_{,k,t}$ is the natural mortality rate for sex (k) during year t, $u_{,k,t}$ is rate of exploitation for sex (k) during year t, $f(g)$ is a function of growth, and R_t is CPUE of age-2 recruits with an assumed sex ratio of 1:1 based on prior work (McComish et al. 2000). After redeveloping, the model was calibrated using data starting in 1984. The resulting direct relationship between actual and predicted CPUE is described by the equation, Actual = 1.69 * (Predicted) + 25.9 with an R^2 = 0.75. The updated model provided a slightly weaker relationship than its predecessor. The model had a tendency to underestimate the actual CPUE values observed, particularly at higher levels. This underestimation is likely a result of the stock-recruitment function (model 5) which predicts recruitment (age 2 yellow perch) at a maximum of ~ 400 fish/h. During the mid to late 1980s recruitment exceeded 400 fish/h in 5 out of 6 years (Figure 3-1) so as the trend in actual trawl CPUE was heading upward beginning in 1984 the model underestimated recruitment thus the predicted values where lower and as a result the slope (1.64) of the equation deviated from the ideal slope of 1.00.

Model projections were run to forecast yellow perch abundance under three differing alewife scenarios. The first forecast allowed alewife abundance to fluctuate annually based on the observed log-normal distribution (mean = 3.976; SD = 1.014; Anderson-Darling normality test: A^2 = 0.414; P = 0.307) of alewife catches in Indiana waters of Lake Michigan from 1984 through 2004 (Figure 4-5). Alewife abundance was not allowed to extrapolate beyond the range of values (12/h to 230/h) used to develop the recruitment function. The second forecast simulated a strategy that suppressed alewife abundance below 34/h on an annual basis. Alewife abundance was randomly generated from a uniform distribution ranging from 12.0 to 33.9. The last forecast simulated high alewife abundance with values randomly generated from a uniform distribution ranging from 34 to 230.

The model was initialized using observed 2003 yellow perch and alewife trawl CPUEs as starting values. As discussed before, male and female age 8 and older yellow perch CPUEs were summed and the totals were recorded as the age 8 starting value. In addition, the yellow perch CPUE of age 2 fish and the alewife CPUE from 2004 was forced into the model to represent the two-year time lag needed to compute recruitment for the year 2006. Exploitation and natural mortality rates were modified to represent the current yellow perch population dynamics. The changes in commercial fishing regulations beginning in 1995 has resulted in a downward trend in the total mortality rate *A* (Table 3-2) since that time. Therefore, exploitation rates *u* were set at 0.14 for females and 0.02 for males using the data from Table (3-4). All yellow perch were assumed vulnerable to exploitation, regardless of size. Similarly, natural mortality *v* was set at 0.49 and 0.39 for males and females, respectively (Table 3-4). Model projections were run 100 times and forecasts extended 20 years. Yellow perch mean relative abundance and standard errors were computed using model predictions beginning in 2003 and continuing through 2022.

The 20 year model projection revealed distinctly different yellow perch (age ≥ 2) abundance trends as influenced by the three alewife abundance scenarios (Figure 5-3). The model predicted that, on average, yellow perch abundance will be greatest when alewife CPUE is below 34/h rather than when alewife abundance fluctuates either randomly or at consistently high levels (≥ 34/h). The forecast abundance of yellow perch was similar from 2004 to 2006 because alewife abundance was forced into the stock-recruitment model in each of the three scenarios. After 2006, low alewife abundance allowed yellow perch abundance to increase to 300 fish/h by 2008 and climb to and remain between 350 and 400 fish/h through 2023. Model projections of yellow perch abundance using random alewife CPUEs forecast a slower increase after 2006 reaching a plateau of 150 to 200 fish/h with no significant change after 2008. When alewife CPUE remained high, at or above 34/h, the model forecasts the yellow perch population to generally trended downward over the 20 year projection.

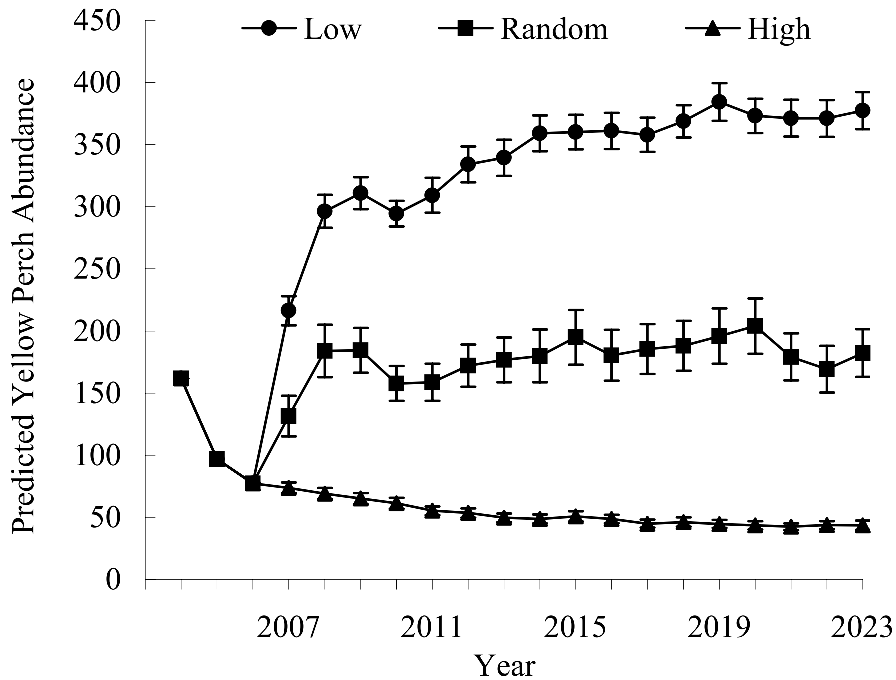

Figure 5-3. Mean 20 year forecast (2004 to 2023) of projected yellow perch abundance (age ≥ 2 trawl CPUE) with alewife CPUE at low (< 34/h), random, and high levels (≥ 34/h). Error bars represent ± 2 SE.

The stock-recruitment function (model 5) within the IYPM predicts point estimates rather than taking into account the variability of the predictor variables S_t and A_t. As a result and discussed earlier, predicted recruitment of age 2 yellow perch never exceeded 400 fish/h, even when alewife abundance was always below 34/h. Although recruitment of age 2 yellow perch in Indiana has not exceeded 400 fish/h since the 1988 year class (Figure 3-1) incorporating variability into the stock recruitment function will predict a broader range of potential outcomes. To express the variability associated within the stock-recruitment function, the coefficients of the predictor variables S_t and A_t along with the intercept were modified. The IYPM model was run with each coefficient from the stock-recruitment function expressed as a normal distribution about its respective mean and standard deviation derived from Table (5-1). The initial results provided unrealistic predictions of yellow perch abundance thus modifications were made to determine the most appropriate way to express the variability in the stock-recruitment function. Eventually, the coefficients for the predictor variables S_t and A_t were randomized between the lower and upper 95% confidence interval (β for S_t = -0.045 to 0.004 and β for A_t = -2.042 to -0.195) and the intercept (5.72) remained constant as expressed in Table (5-1). Due to the uncertainty of incorporating variability into the stock-recruitment function, model projections were run 200 times and forecast for 30 years to better understand the trends in yellow perch CPUE predicted under each of the three different alewife scenarios established earlier.

The 30 year yellow perch model projections under each of the three alewife scenarios resulted in similar trends when variability in the stock-recruitment function was taken into account, thus only the random alewife abundance scenario is described. The general yellow perch abundance trend is upward beginning in 2004 to approximately 1200 fish/h by 2015 and fluctuates about 1000 fish/h until 2034 (Figure 5-4). The variability of the predicted mean values are much wider than observed in Figure (5-3) and maybe more realistic based on the historical catches of yellow perch in Indiana waters of Lake Michigan. For example, in 2024 the variability about the mean value is ± 648 fish/h and is more representative of the actual variability in the trawl catches observed in Figure (4-3), particularly when catches are above 1,000 fish/h. Furthermore, when catches are

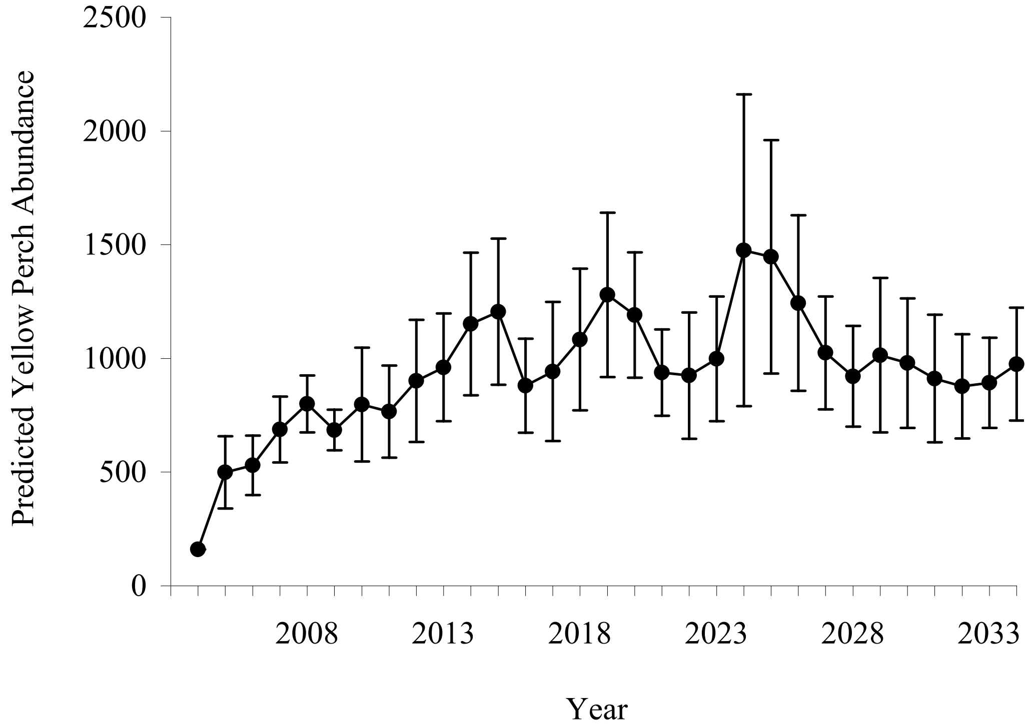

Figure 5-4. Mean 30 year forecast of projected yellow perch abundance (age ≥ 2 trawl CPUE) with alewife CPUE random and variability accounted for in the stock-recruitment function. Error bars represent ± 2 SE.

below 1,000 fish/h variability about the mean catch narrows both in the models predicted mean and the actual observed yellow perch trawl CPUE. Although Figure (5-3) shows narrow errors bars when the population is low, recruitment is always less than 400 fish/h and as a result variability in mean values are low, as expected.

Incorporating variability into the stock recruitment function may provide more useful information to understanding yellow perch population dynamics. It is apparent point estimates used within the IYPM, although useful, can limit the results and understanding of yellow perch population dynamics. Future work on the model should incorporate variability in other components of the model, when necessary. Additional work updating the model will focus on developing it as length-based and incorporating differing forms of stock as predictors of recruitment. For example, Lauer et al. (in press) have developed a length fecundity equation which may be incorporated in the recruitment component of the IYPM and may help provide information about adequate female stock size and size distribution of those females which will allow for population expansion. Furthermore, by converting to a length-base model the ability to understand the impact of commercial and sport harvest on the yellow perch population will be improved thus providing additional tools necessary for the management of yellow perch in the Indiana waters of Lake Michigan.

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Appendix 2-1. Mean back-calculated total lengths (mm) of male yellow perch from pooled sites M, K, and G in Indiana waters of Lake Michigan in 2004.

Year			Total length (mm) at annulus											
class	Age	*n*	1	2	3	4	5	6	7	8	9	10	11	12
2003	1	68	66											
2002	2	74	71	107										
2001	3	25	75	112	140									
2000	4	10	76	114	141	160								
1999	5	22	81	122	152	178	202							
1998	6	100	79	116	145	164	181	198						
1997	7	12	78	118	148	172	184	198	218					
1996	8	3	69	123	165	182	197	207	215	224				
1995	9	3	83	155	189	214	237	244	255	262	275			
1994	10	1	105	139	172	219	236	258	261	267	271	275		
All Classes			74	114	146	168	186	200	226	246	274	275		
n		318	318	250	176	151	141	119	19	7	4	1		

Appendix 2-2. Mean back-calculated total lengths (mm) of female yellow perch from pooled sites M, K, and G in Indiana waters of Lake Michigan in 2004.

Year			Total length (mm) at annulus											
class	Age	*n*	1	2	3	4	5	6	7	8	9	10	11	12
2003	1	77	67											
2002	2	118	68	111										
2001	3	57	79	133	182									
2000	4	15	83	127	173	219								
1999	5	19	85	129	163	191	221							
1998	6	307	82	124	160	184	207	243						
1997	7	34	86	139	193	222	246	264	289					
1996	8	4	87	152	204	235	265	280	298	332				
1995	9	16	88	148	202	243	284	301	315	325	335			
1994	10	0	0	0	0	0	0	0	0	0	0	0		
1993	11	1	77	94	118	140	163	172	179	185	195	211	228	
1992	12	1	80	140	173	193	253	267	275	299	306	311	316	335
All Classes			78	124	167	192	215	248	295	319	326	261	272	335
n		649	649	572	454	397	382	363	56	22	18	2	2	1

Appendix 2-3. Standard errors (SE) of mean back-calculated total lengths (mm) of male yellow perch from pooled sites M, K, and G in Indiana waters of Lake Michigan in 2004.

Year			Total length (mm) at annulus											
class	Age	*n*	1	2	3	4	5	6	7	8	9	10	11	12
2003	1	68	1.4											
2002	2	74	1.2	1.5										
2001	3	25	1.9	3.9	5.1									
2000	4	10	3.2	6.5	6.6	5.4								
1999	5	22	2.1	4.2	5.0	5.1	7.0							
1998	6	100	1.3	2.1	2.2	2.3	2.4	3.0						
1997	7	12	5.6	7.8	8.8	9.0	9.3	11.0	13.3					
1996	8	3	7.5	21.7	18.4	16.4	13.8	13.1	13.7	15.3				
1995	9	3	5.8	14.8	17.5	12.8	17.0	14.2	9.8	10.7	16.3			
1994	10	1												
All Classes			0.7	1.3	1.8	2.0	2.4	2.9	9.3	10.6	11.6			
n		318	318	250	176	151	141	119	19	7	4			

Appendix 2-4. Standard errors (SE) of mean back-calculated total lengths (mm) of female yellow perch from pooled sites M, K, and G in Indiana waters of Lake Michigan in 2004.

Year			Total length (mm) at annulus											
class	Age	*n*	1	2	3	4	5	6	7	8	9	10	11	12
2003	1	77	1.2											
2002	2	118	0.7	1.3										
2001	3	57	1.0	2.0	3.8									
2000	4	15	4.9	5.1	9.0	15.0								
1999	5	19	3.4	5.3	7.1	8.4	12.4							
1998	6	307	0.8	1.2	1.3	1.6	2.1	2.6						
1997	7	34	2.7	4.8	7.6	8.1	9.0	9.6	9.2					
1996	8	4	11.2	12.0	20.2	21.4	23.0	23.4	25.2	14.3				
1995	9	16	3.0	3.3	5.1	5.7	5.7	4.2	3.4	2.7	2.7			
1994	10													
1993	11	1												
1992	12	1												
All Classes			0.56	0.9	1.41	1.79	2.19	2.5	6.39	7.17	8.21			
n		649	649	572	454	397	382	363	56	22	18			

Appendix 3-1. Mean annual trawl CPUE (*n* /h) of both sexes of yellow perch age ≥ 1 in Indiana waters of Lake Michigan, by year class and year of capture. Data for 1984 to 1988 are for pooled sites M and K; later years are for pooled sites M, K, and G. Year classes before 1981 are excluded.

	Year class																							
Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
1984	37	113	374	518																				
1985	12	74	358	907	301																			
1986	1.2	6.8	106	484	919	655																		
1987		3.0	35	320	453	595	230																	
1988			29	377	675	515	468	141																
1989				118	145	142	125	62	837															
1990				36	65	68	56	90	509	93														
1991			0.56	1.7	8.9	18	35	83	205	68	70													
1992			0.12	1.1	2.2	11	21	38	80	42	69	19												
1993					0.39	4.6	10	27	79	85	119	52	0.78											
1994			0.12	0.11	0.19	0.28	3.3	7.1	48	46	39	10	1.1	17										
1995							0.04	0.07	1.4	3.5	8.0	7.0	1.9	6.1	11									
1996						0.13	0.60	0.80	3.4	2.6	8.1	11	3.5	4.6	26	60								
1997						0.11	0.05	0.06	0.57	0.27	1.1	0.9	1.6	1.2	4.0	44	1.5							
1998				0.02		0.01		0.02	0.23	0.03	0.18	0.08	0.07	0.33	1.0	14	1.3	98						
1999					0.07	0.03	0.04	0.01	0.31	0.14	0.09	0.42	0.45	0.32	2.1	10	2.8	33	171					
2000									0.03		0.03				0.06	0.56	0.14	3.20	51.41	2.88				
2001						0.02								0.11	0.21	0.88	3.16	11.17	100.9	16.11	1.39			
2002											0.01		0.01	0.01	0.03	0.20	0.60	2.20	65	2.43	2.70	31.35		
2003														0.04	0.37	1.24	2.03	3.73	77.79	19.49	13.82	37.1	185.0	
2004														0.01		0.04	0.03	0.39	9.38	1.30	2.56	7.73	76.8	190.6

Appendix 3-2. Mean annual trawl CPUE (*n* /h) for various components of the yellow perch population in Indiana waters of Lake Michigan from 1975 to 2004. Data from 1975 to 1983 are for site K only; 1984 to 1988 data are pooled sites M and K; 1989 to 2004 data are pooled sites M, K, and G. Definitions: Sub-stock age ≥ 1 and < 130 mm; Stock ≥ 130 mm; Quality ≥ 200 mm; PSD = Quality/Stock*100. No index trawling was completed in 1982.

	Total		Age 0		Age ≥1		Sub-stock		Stock		Quality		PSD
Year	Mean	2SE	Mean	2SE	Mean	2SE	Mean	2SE	Mean	2SE	Mean	2SE	
1975	43		0.2		43		1.8		41		5		13
1976	31		1.5		29		5.1		24		7		27
1977	134		47		86		20		67		24		35
1978	154		1.3		153		119		34		5		14
1979	105		31		74		10		63		4		6
1980	598		155		443		361		82		10		12
1981	896		1.2		895		840		55		1		3
1982													
1983	2550	1258	492	590	2058	973	626	347	1432	917	71	57	5
1984	1207	603	164	206	1042	609	639	308	404	321	14	12	3
1985	2641	1706	989	1596	1652	733	788	441	863	364	47	31	5
1986	2559	873	387	392	2171	636	1126	475	1045	415	28	18	3
1987	1703	574	67	80	1636	568	504	138	1132	492	45	18	4
1988	2216	1493	12	14	2204	1491	252	127	1952	1418	116	86	6
1989	1759	667	331	315	1428	631	746	485	683	444	98	81	14
1990	1026	424	110	141	916	442	367	181	549	283	121	74	22
1991	538	219	48	37	490	235	173	181	318	178	47	33	15
1992	284	150	0.83	1.0	283	150	28	13	255	143	31	18	12
1993	386	256	8	10	378	258	2.4	1.3	376	257	37	20	10
1994	179	102	7	6	172	103	17	11	156	97	14	9	9
1995	50	33	10	14	40	29	12	7	28	28	7	7	24
1996	98	57	1	1	98	56	43	27	54	33	20.0	11	37
1997	67	36	12	11	55	29	3	2	52	28	8.2	5	16
1998	1070	836	954	849	116	52	80	45	36	21	9.0	6	25
1999	224	102	4	4	220	103	167	93	53	33	20.2	13.2	38
2000	59	30	1	1	58	30	36	18	23	13	3.04	3.3	13
2001	138	84	4	4	134	85	13	9	121	76	5.46	3.0	4
2002	105	51	142	157	104	51	34	31	71	31	4.50	2.4	6
2003	474	226	133	161	341	207	199	126	142	99	20.4	11	14
2004	363	165	73	61	289	168	249	160	40	27	3.0	2	7

Appendix 3-3. Mean annual trawl CPUE (*n* /h) of both sexes of yellow perch age ≥ 1 by length class and age from pooled sites in Indiana waters of Lake Michigan in 2004.

Length class	Age																
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	%	Cum%
50	39.77														39.77	13.77	14
60	80.52														80.52	27.87	42
70	44.60	0.46													45.06	15.60	57
80	15.95														15.95	5.52	63
90	5.02	3.02													8.04	2.78	66
100	3.43	10.13													13.56	4.69	70
110	1.31	21.23	1.24												23.79	8.23	78
120		19.47	1.76	0.98											22.22	7.69	86
130		14.14	0.83			0.09									15.06	5.21	91
140		5.01	0.49	0.09		0.09	0.07								5.75	1.99	93
150		2.51	0.99	0.50		1.37									5.37	1.86	95
160		0.72	0.42	0.65	0.74	2.23	0.09								4.86	1.68	97
170		0.11	1.07	0.12	0.28	1.51									3.08	1.07	98
180			0.40	0.15	0.14	1.32									2.01	0.69	99
190			0.23	0.01	0.08	0.47	0.05	0.01							0.85	0.29	99
200			0.15	0.03	0.03	0.39									0.60	0.21	99
210			0.02			0.06									0.08	0.03	99
220			0.05			0.27	0.02								0.34	0.12	99
230			0.03		0.01	0.33	0.01								0.38	0.13	99
240			0.04		0.02	0.11	0.02				0.01				0.20	0.07	100
250						0.22	0.03								0.24	0.08	100
260						0.18	0.01								0.19	0.06	100
270			0.01	0.01		0.05	0.01								0.07	0.02	100
280				0.03		0.16	0.05								0.24	0.08	100
290						0.37		0.02							0.40	0.14	100
300						0.05	0.01								0.06	0.02	100
310						0.06									0.06	0.02	100
320																	100
330						0.06	0.03		0.04						0.13	0.05	100
340																	100
350																	100
360																	100
370																	100
Total	190.61	76.82	7.73	2.56	1.30	9.38	0.39	0.03	0.04		0.01				288.9	100	
%	66.0	26.6	2.7	0.9	0.4	3.2	0.1	0.01	0.02		0.003						
Cum%	66	93	95	96	97	100	100	100	100		100						100

Appendix 3-4. Mean annual trawl CPUE (*n* /h) of male yellow perch age ≥ 1 by length class and age from pooled sites in Indiana waters of Lake

Length class	Age																
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	%	Cum%
50	24.00														24.00	18.68	19
60	37.68														37.68	29.34	48
70	22.05														22.05	17.16	65
80	7.21														7.21	5.62	71
90	1.96	2.39													4.35	3.39	74
100	1.07	5.26													6.33	4.93	79
110		8.50	0.08												8.58	6.68	86
120		5.80	0.78												6.57	5.12	91
130		1.64	0.83			0.09									2.56	1.99	93
140		0.54	0.49	0.09		0.09	0.07								1.28	1.00	94
150		0.00	0.69	0.50		1.16									2.35	1.83	96
160		0.07	0.07	0.45	0.58	1.91	0.09								3.17	2.47	98
170					0.28	1.32									1.60	1.25	99
180				0.03	0.11	0.41									0.55	0.43	100
190			0.01		0.05	0.07	0.02	0.01							0.15	0.12	100
200																	
210																	
220																	
230																	
240																	
250																	
260																	
270																	
280																	
290																	
300																	
310																	
320																	
330																	
340																	
350																	
360																	
370																	
Total	93.97	24.2	2.9	1.1	1.0	5.0	0.2	0.01							128.4	100	
%	73.2	18.8	2.3	0.8	0.8	3.9	0.1	0.01									
Cum%	73	92	94	95	96	100	100	100									100

Appendix 3-5. Mean annual trawl CPUE (*n* /h) of female yellow perch age ≥ 1 by length class and age from pooled sites in Indiana waters of Lake Michigan in 2004.

Length class (mm)	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	%	Cum%
50	15.78														15.78	9.8	9.8
60	42.84														42.84	26.7	36.5
70	22.56	0.46													23.02	14.3	51
80	8.74	0.00													8.74	5.4	56
90	3.05	0.64													3.69	2.3	59
100	2.36	4.87													7.23	4.5	63
110	1.31	12.73	1.16												15.20	9.5	73
120		13.68	0.98	0.98											15.65	9.8	82
130		12.50													12.50	7.8	90
140		4.47													4.47	2.8	93
150		2.51	0.30			0.21									3.03	1.9	95
160		0.66	0.36	0.20	0.16	0.32									1.69	1.1	96
170		0.11	1.07	0.12		0.18									1.48	0.9	97
180			0.40	0.12	0.02	0.91									1.45	0.9	98
190			0.22	0.01	0.04	0.40	0.03								0.69	0.4	98
200			0.15	0.03	0.03	0.39									0.60	0.4	99
210			0.02			0.06									0.08	0.1	99
220			0.05			0.27	0.02								0.34	0.2	99
230			0.03		0.01	0.33	0.01								0.38	0.2	99
240			0.04		0.02	0.11	0.02								0.20	0.1	99
250						0.22	0.03								0.24	0.2	99
260						0.18	0.01								0.19	0.1	99
270			0.01	0.01		0.05	0.01								0.07	0.0	99
280				0.03		0.16	0.05								0.24	0.1	100
290						0.37		0.02							0.40	0.2	100
300						0.05	0.01								0.06	0.0	100
310						0.06									0.06	0.0	100
320																	
330						0.06	0.03		0.04						0.13	0.1	100
350																	
360																	
370																	
Total	96.6	52.6	4.8	1.5	0.3	4.3	0.2	0.02	0.04						160.4	100	
%	60.2	32.8	3.0	0.9	0.2	2.71	0.13	0.01	0.03								
Cum%	60	93	96	97	97	100	100	100	100								100

Appendix 3-6. Mean annual gill net CPUE (*n* /net/night) of both sexes of yellow perch by length class and age from pooled sites in Indiana waters of Lake Michigan in 2004.

Length class	Age															
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	%	Cum%
50																	
60																	
70																	
80																	
90																	
100																	
110																	
120																	
130																	
140																	
150																	
160				0.003	0.01	0.02									0.03	0.04	0.04
170			0.02	0.003		0.06									0.08	0.12	0.2
180			0.16	0.06	0.14	0.75									1.11	1.58	2
190			0.81	0.13	0.34	3.11	0.13	0.03							4.56	6.49	8
200			1.16	0.17	0.22	6.59									8.14	11.60	20
210			0.81	0.05	0.47	6.75	0.10								8.19	11.68	32
220			0.93			5.43	0.33								6.69	9.54	41
230			0.83		0.28	3.85	0.68								5.64	8.03	49
240			1.07		0.43	3.02	0.63	0.06			0.21				5.41	7.72	57
250			0.20	0.33	0.06	3.81	0.17								4.56	6.49	63
260					0.03	4.78	0.19		0.03						5.03	7.17	70
270			0.16	0.16	0.04	3.63	0.43		0.03						4.44	6.33	77
280				0.22	0.14	3.33	0.29								3.97	5.66	82
290			0.22	0.22	0.22	3.63	0.03	0.10		0.08					4.50	6.41	89
300				0.09	0.25	2.50	0.27								3.11	4.43	93
310				0.09		1.85			0.03						1.97	2.81	96
320						0.78	0.15		0.19						1.11	1.58	98
330					0.03	0.57	0.15		0.11			0.03			0.89	1.27	99
340					0.04	0.12	0.14	0.06	0.15						0.50	0.71	100
350							0.12		0.05						0.17	0.24	100
360							0.03	0.03							0.06	0.08	100
370																	
Total			6.38	1.53	2.70	54.56	3.83	0.27	0.57	0.08	0.21	0.03			70.16	100	
%			9.1	2.2	3.9	77.8	5.5	0.4	0.8	0.1	0.3	0.04					
Cum%			9	11	15	93	98	99	100	100	100	100					100

Appendix 3-7. Mean annual gill net CPUE (*n* /net/night) of male yellow perch by length class and age from pooled sites in Indiana waters of Lake Michigan in 2004.

Length class (mm)	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	%	Cum%
50																	
60																	
70																	
80																	
90																	
100																	
110																	
120																	
130																	
140																	
150																	
160				0.003	0.01	0.02									0.03	0.66	1
170																	
180				0.034	0.02	0.14									0.19	4.64	5
190			0.03		0.14	0.50	0.06	0.03							0.75	17.88	23
200					0.04	0.79									0.83	19.87	43
210				0.052	0.12	0.42	0.10								0.69	16.56	60
220			0.03		0.00	0.17	0.03								0.22	5.30	65
230					0.08	0.21	0.04								0.33	7.95	73
240					0.00	0.22		0.06							0.28	6.62	79
250					0.06	0.06									0.11	2.65	82
260					0.03	0.19			0.03						0.25	5.96	88
270					0.04	0.06	0.07		0.03						0.19	4.64	93
280					0.06	0.08	0.03								0.17	3.97	97
290							0.03			0.08					0.11	2.65	99
300																	99
310									0.03						0.03		100
320																	
330																	
340																	
350																	
360																	
370																	
Total			0.06	0.09	0.60	2.84	0.36	0.08	0.08	0.08					4.19	100	
%			1	2	14	68	9	2	2	2							
Cum%			1	3	18	85	94	96	98	100							100

Appendix 3-8. Mean annual gill net CPUE (*n* /net/night) of female yellow perch by length class and age from pooled sites in Indiana waters of Lake Michigan in 2004.

Length class (mm)	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total	%	Cum%
130																	
140																	
150																	
160																	
170			0.02			0.056									0.1	0.1	0.1
180			0.16	0.03	0.12	0.61									0.9	1.4	2
190			0.79	0.13	0.20	2.62	0.07								3.8	5.8	7
200			1.16	0.17	0.17	5.80									7.3	11.1	18
210			0.81		0.36	6.33									7.5	11.4	30
220			0.91		0.00	5.26	0.30								6.5	9.8	40
230			0.83		0.20	3.64	0.64								5.3	8.0	48
240			1.07		0.43	2.79	0.63				0.21				5.1	7.8	55
250			0.20	0.33		3.75	0.17								4.4	6.7	62
260						4.59	0.19								4.8	7.2	69
270			0.16	0.16		3.57	0.35								4.3	6.4	76
280				0.22	0.09	3.24	0.26								3.8	5.8	82
290			0.22	0.22	0.22	3.63		0.10							4.4	6.7	88
300				0.09	0.25	2.50	0.27								3.1	4.7	93
310				0.09	0.00	1.85	0.00								1.9	2.9	96
320					0.00	0.78	0.15		0.19						1.1	1.7	98
330					0.03	0.57	0.15		0.11			0.03			0.9	1.3	99
340					0.04	0.12	0.14	0.06	0.15						0.5	0.8	100
350							0.12		0.05						0.2	0.25	100
360							0.03	0.03							0.06	0.08	100
370																	
Total			6.3	1.44	2.11	51.71	3.47	0.19	0.49		0.21	0.03			66	100	
%			9.6	2.2	3.2	78.4	5.3	0.3	0.7		0.3	0.04					
Cum%			10	12	15	93	99	99	100		100	100					100

Appendix 4-1. Summary of the species composition of the mean annual trawl CPUE of age ≥ 1 fish at sites M, K, and G in Indiana waters of Lake Michigan in 2004. Species are listed by descending abundance (alphabetically in cases of ties) in M, K, and G combined catches. Abbreviations: CPUE = catch per unit effort (*n* /h); SE = standard error; % = percentage of total.

	Site M			Site K			Site G			M, K & G combined		
Species	CPUE	2SE	%	CPUE	2SE	%	CPUE	2SE	%	CPUE	2SE	%
Spottail shiner	657.5	458.7	49.5	213.3	130.9	23.8	206.3	71.1	54.4	359.1	182.4	41
Yellow perch	513.3	410.6	38.6	274.2	199.4	30.7	80.2	59.1	21.1	289.2	167.8	33
Alewife	121.8	87.3	9.2	148.5	224.1	16.6	84.7	91.3	22.3	118.3	87.3	14
Round goby	0.8	0.8	0.1	246.7	204.1	27.6	4.5	4.8	1.2	84.0	84.9	10
Rainbow smelt	29.7	57.7	2.23	10.5	21.0	1.17	2.83	4.57	0.75	14.3	20.1	2
Longnose sucker	3.5	2.3	0.3	1.3	1.6	0.1	0.5	0.7	0.1	1.8	1.1	0.2
White sucker	0.7	0.8	0.05							0.2	0.3	0.03
Chinook salmon[1]	0.3	0.4	0.03							0.1	0.2	0.01
Trout-perch	0.3	0.4	0.03							0.1	0.15	0.01
Banded kilifish							0.17	0.33	0.04	0.1	0.1	0.01
Ninespine stickleback	0.17	0.33	0.01							0.1	0.1	0.01
Totals	1328		100	895		100	379		100	867		100

[1]Fingerlings.

Appendix 4-2. Summary of the species composition of the mean annual gill net catch at sites M, K, and G in Indiana waters of Lake Michigan in 2004. Species are listed by descending abundance (alphabetically in cases of ties) in M, K, and G combined catches. Abbreviations: CPUE = catch per unit effort (*n* /net/night); SE = standard error; % = percentage of total.

	Site M			Site K			Site G			M, K & G combined		
Species	CPUE	2SE	%	CPUE	2SE	%	CPUE	2SE	%	CPUE	2SE	%
Yellow perch	63.0	25.5	87.5	88.8	44.4	94.8	59.3	14.7	91.8	70.4	17.8	92
Longnose sucker	6.8	6.4	9.4	2.2	1.9	2.3	0.9	1.3	1.4	3.3	2.3	4
White sucker	1.3	1.0	1.7	1.3	1.1	1.3	2.3	2.0	3.5	1.6	0.8	2
Alewife	0.5	0.5	0.7	0.8	1.2	0.8	0.3	0.4	0.4	0.5	0.4	0.7
Round Goby	0.1	0.2	0.1				1.3	1.4	2.1	0.5	0.5	0.6
Brown trout	0.2	0.2	0.2	0.4	0.5	0.4	0.1	0.2	0.1	0.2	0.2	0.3
Gizzard shad							0.3	0.5	0.4	0.1	0.2	0.2
Chinook salmon				0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1	0.1
Rainbow smelt	0.2	0.3	0.2	0.1	0.2	0.1				0.08	0.1	0.1
Freshwater drum				0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Lake trout	0.1	0.2	0.1							0.03	0.1	0.04
White perch							0.1	0.2	0.1	0.03	0.1	0.04
Totals	72.0		100.0	93.7		100.0	64.7		100.0	76.8		100.0