Year Two Progress Report:

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 second year progress results for the Federal Aid Project F-18-R, Study 11, (2003 field sampling) entitled: Dynamics and Models of the Yellow Perch in Indiana Waters of Lake Michigan and Near-Shore Fish Community Characteristics. These findings enhance the work that has been performed since the early 1970's, with emphasis on the years 1984-2003. The ongoing investigations of this fish community, with a focus on yellow perch, have created one of the most significant and useful long-term data sets of Great Lakes fisheries.

Yellow perch *Perca flavescens* and 10 other near-shore non-salmonine fish species were quantitatively sampled by consistent bottom trawling and gill netting methods at 3 index zones in Indiana waters of Lake Michigan. Two sample zones were located near the Michigan City harbor mouth: zone M was located approximately 2 km east, while sample zone K was located approximately 3 km west. A third sample zone was located approximately 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 the 10 and 15 m depths. For 2003, total night-time trawl effort was 6 h and total gill net effort was 6 net-nights at each station. Fish data (number, lengths, weights, species, station, etc.) were recorded electronically and stored in a computer database. This sampling schedule has remained unchanged for M and K since 1984 and for G since 1989.

Growth rates of the 1983-2003 year classes of yellow perch varied greatly, and generally were inversely related to population abundance. Females usually reached exploitable size at substantially younger ages than males, and therefore were disproportionately affected by recreational and commercial harvest and commercial bycatch (landed or lethally discarded yellow perch <200 mm). Due to the recent low population abundance, growth rates for the 1993-1997 cohorts were unusually high: average females exceeded 200 mm by age 3, and males by age 3 or 4. Growth rates beginning with the 1998-year class have slowed significantly from previous cohorts,

although females are still growing faster than males. The declining trend in growth may be due to several factors including: intraspecific competition particularly among the 1998 year class, selective mortality of the population, biological interactions with other fishes including the newly establish round goby *Neogobius melanostomus*, and physiological factors specifically energy allocation.

The relative abundance of age ≥ 1 yellow perch trawl CPUE in 2003 was 341/h, and was higher than any previous year since 1993. Much of this change was due to the introduction of age 1 fish (185/h, 54% abundance) and the perseverance of age 5 fish (78/h, 23 % abundance) in the population. Should the age 1 cohort fish persist to future years, the yellow perch population may be on an expanding trend for the first time since the late 1980's, although a high degree of uncertainty remains. Unfortunately, ages 2 (11% abundance), 3 (4% abundance), and 4 (6% abundance) are poorly represented in the population, as are fish > age 5 (<3% abundance). Yellow perch age structure has been highly dynamic over the years due to variable recruitment, modal progression, and high total mortality rates. Thus, although some highlights exist, the current population structure remains cause for concern.

There has been a strong negative relationship between abundance of alewives *Alosa pseudoharengus* and abundance of yellow perch. The yellow perch population expanded in the 1980s when average alewife abundance was extremely low, and declined when average alewife abundance increased after 1988. Unfortunately, alewife trawl CPUE values during the period 2000 to 2003 were the highest found since records began in 1984. How this will affect current or future year classes of yellow perch is unknown at this time, but does not appear positive if historic trends hold true.

Other species also appeared to be undergoing density changes since 1984. Juvenile bloaters *Coregonus hoyi* were abundant in the trawl catch when alewives were scarce in the 1980s, but virtually disappeared after the recent resurgence of alewife abundance. None were collected in 2003. Dynamics of rainbow smelt *Osmerus mordax* were similar to those of bloaters, as they declined in recent years, with few caught in 2003. However, the abundance of spottail shiners *Notropis hudsonius* increased dramatically and was the most abundant fish caught in the trawl in 2003. The nonindigenous round goby first appeared in the trawl catches in 1998 and became one of the most abundant species in from 1999-2003. This fish is negatively impacting two bottom-dwelling species, mottled sculpin *Cottus bairdi* and johnny darter *Etheostoma nigrum*, as we have seen a reduction in the abundance of these two native species since 1998. Although the extent of biological interaction of round gobies with yellow perch remains unclear, the yellow perch > 150 mm are commonly using round gobies as prey, composing approximately 40% of the yellow perch diet.

Sex ratios of cohorts have historically been near 50:50 at age 1, but often became skewed at older ages due to sexual differences in total mortality rates. In 2002, females dominated both the smaller (< 130 mm) and larger (≥ 200 mm) size ranges.

Models of relationships among alewife abundance, yellow perch spawning stock abundance, and yellow perch recruitment indicated the initial recruitment failures after the 1988 year class were probably mainly due to high alewife abundance, but low spawning stock abundance was a likely contributing factor in later years, especially 1995. Our models predicted the recruitment of the 1998 year class to age 2 may be somewhat stronger than other recent year classes, but not as strong as the 1983-1986 and 1988 year classes. Although the 1998-year class composed 23% of the yellow perch ≥ age 1 in 2003, the actual strength of the 1998-year class was classified as "extremely weak". A notable increase in recruitment was shown by the 2002-year class (54% of total catch) and may increase total population densities of the yellow perch in southern Lake Michigan. However, based on our models, recruitment of the 2002-year class to age 2 is likely to be extremely weak as the alewife abundance in 2002 was near 200/hr**,** among the highest values recorded since 1984.

A computer simulation model revealed that alewife abundance was the most important factor influencing yellow perch dynamics in most years. If future alewife abundance is consistently high, the yellow perch population will probably remain suppressed even with zero harvest or bycatch. Our modeling has predicted that it would take 4 or 5 consecutive low alewife abundance years to allow the yellow perch to build population densities up to the levels found in the 1980's. Moreover, the densities of alewife in 2003 were the forth consecutive year in which alewife abundance was high and among the highest we have recorded since the study began keeping alewife records in 1984. Unfortunately, this suggests that recruitment of yellow perch is expected to be low, and similar to those years 1995 to present.

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 ages ≥ 2 for the 1982 – 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 2003 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 2003 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 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 2003 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 2003. 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
6/02/03	M	+	+	+
6/03/03	K	+	+	+
6/04/03	G	+	+	+
6/16/03	M	+	+	+
6/17/03	G	+	+	+
6/18/03	K	+	+	+
7/01/03	M	+	+	+
7/02/03	G	+	+	+
7/07/03	K	+	+	+
7/16/03	M	+	+	+
7/24/03	K	+	+	+
7/28/03	G	+	+	+
8/04/03	K	+	+	+
8/05/03	G	+	+	+
8/06/03	M	+	+	+
8/18/03	M	+	+	+
8/19/03	G	+	+	+
8/20/03	K	+	+	+

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 were made in 2002 with the development of a Windows™ based back calculation software package, titled FishBC© (Doll 2003), that was developed to replace the previously used DisBcal program. The Windows format of FishBC allows for better compatibility with the various software programs we utilize during the entire fish aging process and subsequent data analysis. Additionally, this program increases efficiency and quality of our data analysis.

Yellow perch age and growth methods in 2003 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 newly developed 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 1,035 age ≥ 1 fish sub-sampled from trawl and gill net catches at sites M, K, and G from June to August 2003. Within the aged sub-sample, 376 (36%) were males and 659 (64%) 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 2003 are shown in Appendices 2-1 through 2-4. Males up to age 13 and females up to age 9 were present in the aged sub-sample, with fish older than age 8 uncommon (Appendices 2-1, 2-2, 2-3, and 2-4). There were no differences in growth between females and males for ages 1 to 3 during 2003 (Figure 2-1). As expected, female yellow perch grew faster than males from age 4 through 8. Few fish older than age 8 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 5 and males by age 6.

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. To attain the same mean length at last annulus as age 6 fish (1997 year class in 2003), age 5 fish would have to grow at a rate of approximately 22%. This appears unlikely as the 1998 cohort is nearing full maturity (See Job 2) and somatic growth will likely be slowed. 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 2003 show varied trends (Figure 2-2). Only ages 1-4 are used in the display because older ages were not found in abundance in all years, and when present, showed similar trends as ages 1-4. 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 1976-1978 and 1997-2000 and beyond age 4 in other years. Females were quality size by age 3 in 1976 and 1996 to 2000, by age 4 in 1977-1979, 1984, 1995, and 2001, and beyond age 4 in other years. Mean length of males for ages 1 to 4 decreased in 2003 to lengths observed during the mid to late 1980s when the yellow

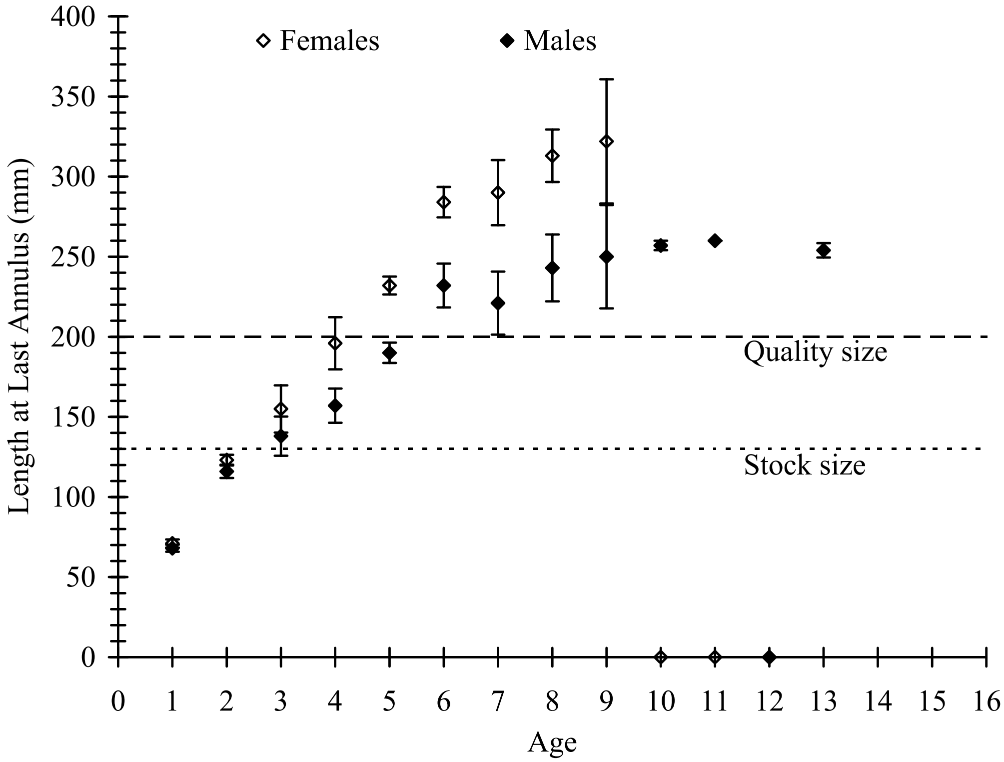

Figure 2-1. Mean back-calculated lengths at last annuli of individual age classes of male and female yellow perch collected from pooled sites in Indiana waters of Lake Michigan in 2003. Error bars represent ± 2 SE. Data points without error bars represent only one fish.

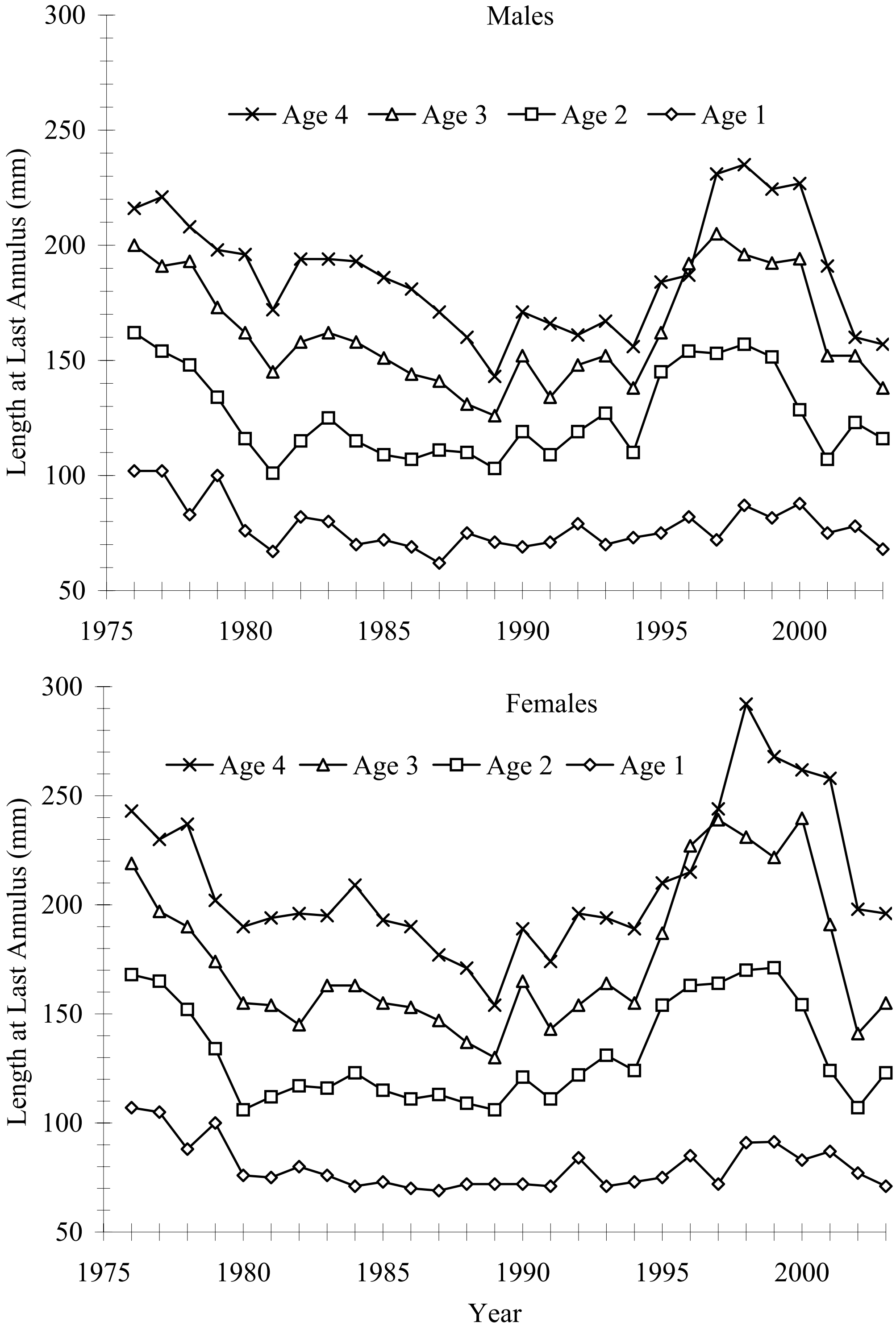

Figure 2-2. Mean back-calculated lengths at last annuli of male and female yellow perch ages 1 to 4 collected in Indiana waters of Lake Michigan from 1976 to 2003.

perch population abundance was at its peak during this time period (Figure 2-2). Similarly, female back-calculated length at age 1 continued its downward trend and falls within the range observed for the mid to late 1980s. Females age 2 and 3 trended slightly higher in 2003 when compared to 2002; however, lengths are still well below those from the late 1990s. Age 4 females continued their downward trend in 2003 from the fast growth seen in the late 1990s.

The average length of the 1998 year class males (age 5) has not yet reached quality size (≥ 200 mm), while the 1993-1997 cohorts reached quality size (≥ 200 mm) by age 3 or 4, the 1991-1992 cohorts by age 5, the 1989-1990 cohorts by age 6, and the 1983-1988 cohorts by age 7 or 8 (Table 2-1). Trends for female cohorts were similar. Mean length at last annulus for the female 1998 year class (age 5) has reached quality size. The 1993-1997 cohorts reached quality size by age 3, compared to age 4 for the 1991-1992 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 the 1998 and 1999 male year classes are unlikely to reach similar asymptotic lengths as earlier cohorts and with moderately low K (≤ 0.476) it appears that growth has slowed (Table 2-3). The 1998 female cohort is exhibiting the trend to slower growth where its asymptotic length will likely be less than previous year classes (Table 2-4). Furthermore, K for this year class is similar to the males and is quickly approaching what would be considered its maximum length. Contrary to the 1998 cohort, the 1999 female cohort is exhibiting a growth pattern more similar to the female cohorts of the early 1990s.

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 2003. 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	
1996	72	157	192	227	218	237	221		
1997	87	151	194	191	225	232			
1998	82	129	152	160	190				
1999	88	107	152	157					
2000	75	123	138						
2001	78	116							
2002	68								

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 2003. 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	
1996	72	170	222	262	279	272	290		
1997	91	171	240	258	271	284			
1998	91	154	191	198	232				
1999	83	124	166	196					
2000	87	107	155						
2001	77	123							
2002	71								

Table 2-3. Von Bertalanffy growth parameters and coefficients of determination (R^2) for the 1983-1999 year classes of male yellow perch in Indiana waters of Lake Michigan. Values fitted to the data Table 2-1 by the Marquardt-Levenburg method of nonlinear least squares. Estimates for the 1994-199 year classes are provisional

Year class	L_∞ (mm)	K	t_0	R^2
1983	232	0.302	-0.174	0.967
1984	231	0.271	-0.370	0.977
1985	251	0.215	-0.528	0.979
1986	221	0.342	0.062	0.986
1987	249	0.243	-0.460	0.974
1988	251	0.236	-0.475	0.985
1989	273	0.201	-0.524	0.984
1990	268	0.224	-0.466	0.986
1991	251	0.300	-0.223	0.958
1992	263	0.298	0.001	0.994
1993	248	0.584	0.418	0.954
1994	262	0.608	0.467	0.986
1995	261	0.525	0.290	0.951
1996	231	0.777	0.525	0.965
1997	240	0.509	0.010	0.934
1998	215	0.357	-0.389	0.888
1999	183	0.476	0.257	0.927
Means	247	0.375	-0.115	0.967

Table 2-4. Von Bertalanffy growth parameters and coefficients of determination (R^2) for the 1983-1999 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 of nonlinear least squares. Estimates for the 1991-1999 year classes are provisional.

Year class	L_∞ (mm)	K	t_0	R^2
1983	567	0.070	-1.120	0.987
1984	446	0.105	-0.718	0.992
1985	502	0.092	-0.593	0.976
1986	399	0.144	-0.212	0.981
1987	333	0.204	-0.101	0.983
1988	346	0.193	-0.175	0.986
1989	433	0.125	-0.463	0.992
1990	463	0.129	-0.308	0.990
1991	498	0.123	-0.423	0.975
1992	468	0.166	0.050	0.992
1993	297	0.596	0.579	0.888
1994	313	0.612	0.596	0.956
1995	333	0.455	0.388	0.987
1996	294	0.595	0.533	0.989
1997	294	0.578	0.378	0.983
1998	249	0.466	0.005	0.919
1999	407	0.145	-0.561	0.999
Means	390	0.291	-0.099	0.974

The declining trend in growth rates starting with the 1998 year class for both male and female yellow perch (Figures 2-1 and 2-2) continues to be of concern. Several 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 2002 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. 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 within a particular system will facilitate slower growth of individual fish at specific ages leading to decreased physical condition. Further consequences could lead to increased predation and reduced survival and reproduction, which would result 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 as expected, an upward shift in growth rates was observed starting in 1994 (Figure 2-2). This was most evident for the age 2, 3 and 4 fish, although some variability was observed. Beginning with the 1998 year class at age 2, a shift toward declining growth rate trends appears. Although the CPUE of the 1998 year class was noticeably higher than other cohorts since 1994, this increase was small by comparison to past year classes (e.g. 1980’s) and likely not large enough to result in slower growth. However, if the 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. Furthermore, any productivity changes in the 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 the yellow perch.

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, and increased abundance of alewife (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. Cannibalism in the 2002 diet study showed young-of-the-year yellow perch composing a mean volume (3.7%) which was similar to the diet of 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 (1992-1993 and 1971-1972) 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. Round goby were shown to prey heavily on chironomids (Edgell 2004). Furthermore, chironomids have been shown to be a main prey item for yellow perch, especially 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, e.g. 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 2003 collection data showed the 2001 yellow perch year class as the 13th 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 2001 year class had a CPUE (37.1/h) which is the highest recorded since the 1998 year class. Although the 2002 year class was not fully vulnerable to the trawl in 2003, the CPUE at age 1 was 185/h and ranked as the highest abundance for age 1 fish since the 1988 year class (Appendix 3-1). The strength of the 2003 year class remains uncertain, but the 2003 age-0 yellow perch CPUE of 133/h was slightly less that what was recorded for the 2002 year class (Appendix 3-2).

Mortality Rates

Annual total mortality rates (*A*; Ricker 1975) of yellow perch age ≥ 1 were first estimated using pooled males and females because catch records most years prior to 1993 did not allow individual sex ratio calculations. We estimated *A* using two different methods. The first method was to calculate *A* from decreases in trawl CPUE of cohorts over one-year age intervals which provides information only on discrete age intervals. Mean estimated *A* ranged from 53% to 63% for ages 2-6 and 70% or higher for older ages (Table 3-1). Estimates of *A* for all age classes during the current year could not be calculated due to greater catches in 2003 when compared to 2002 for ages 2 through 9. The low mortality rate for the 1998 year class is likely due to the relative slow growth being exhibited.

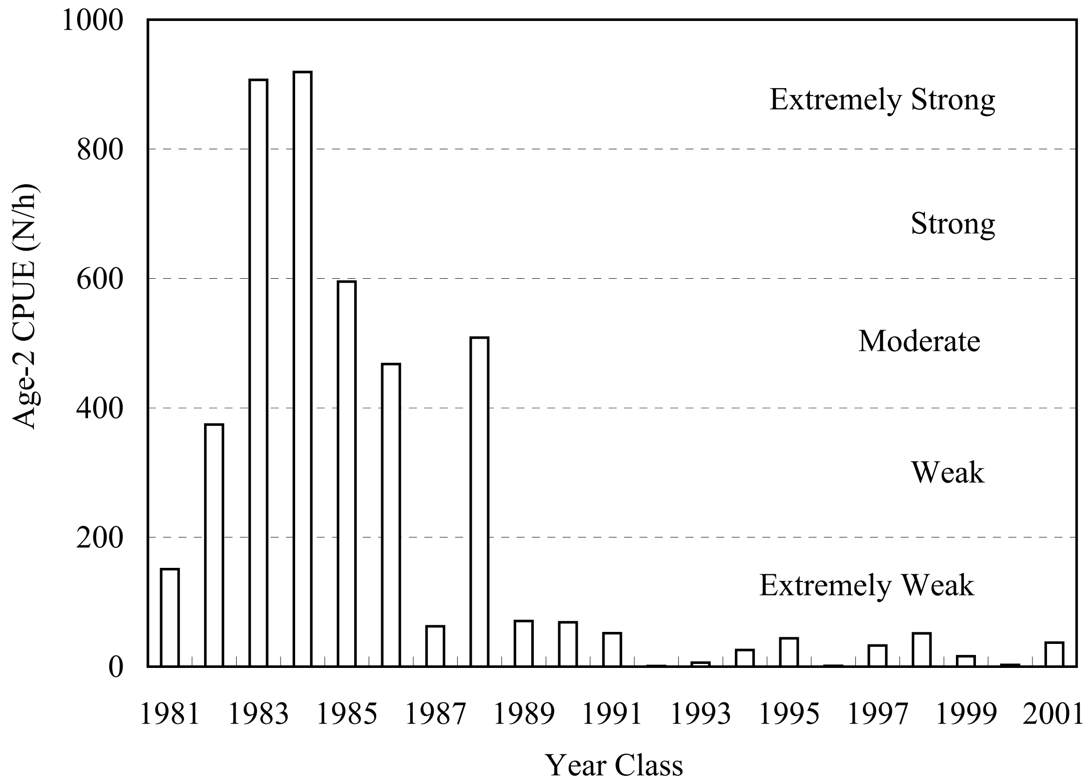

Figure 3-1. Relative strength of yellow perch year classes based on mean annual trawl CPUE of age 2 fish in Indiana waters of Lake Michigan, from 1981 to 2001.

Table 3-1. Annual total mortality rates (*A*) of yellow perch cohorts in Indiana waters of Lake Michigan from 1980 to 2000. Rates based on decreases from 1984 to 2003 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	Mean	Med.
2-3			4	47	51	14	73		60	39		80		25	85	68		90		85		55	60
3-4		35	70	34		72	55	7	61		67	31		74	74	27	95		36			53	58
4-5	69	91	67		79	52	37	54	2	46	79		55	72		94		80				63	68
5-6	90	56	18	69	55	74	40	30	39	92		92	96	3	97		81					62	69
6-7				70	86	41	51	73	97	26	86	91				77						70	75
7-8				95	75	56	68	99		90	84				86							82	85
8-9				35	82	94	99		83	87	48			91								78	85
Mean	79	61	40	58	71	58	61	53	57	63	73	73	76	53	85	67	88	85	36	85		66	
Med	79	56	42	58	77	56	55	54	60	67	79	86	76	72	85	73	88	85	36	85			69

The second method used catch curve analysis of individual cohorts (Ricker 1975) over successive years and has been demonstrated as more accurate for comparing individual cohorts. Means of *A* for 1982-1999 cohorts at age ≥ 2 ranged from 52 to 68% (Table 3-2). Due to the low catches and/or variability, catch curve analysis could not be accurately estimated for 1992, 1996, 1997, 1998, and 1999.

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 (Ricker 1975) 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*). Total mortality (*Z*) showed a decreasing trend for both male and female cohorts from 1991 to 1999 (Table 3-3). Other mortality values (*F*, *m*, and *u*) also showed a decreasing trend for males and females starting with the 1991 year class (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 and female instantaneous natural mortality (*M*) trended upward from the 1991 through the 1999 cohorts (Table 3-4).

Length Frequencies, Sex Ratios, and Age Frequencies

Length frequencies, sex ratios, and age frequencies were calculated as described by McComish et al. (2000). Yellow perch were enumerated for each sex per 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 379 mm in 2003 (Appendix 3-3). Males ranged from 50 to 299 mm (Appendix 3-4), and females from 50 to 379 mm (Appendix 3-5). Two major modes were prevalent in length frequency; one at

Table 3-2. Total mortality and survival rates of yellow perch cohorts (combined sexes) in Indiana waters of Lake Michigan from 1982 to 1999. Rates based on catch curve analysis of individual cohorts at ages 2 to 9 from 1984 to 2003 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[a]	0.43	0.65	0.35	6	0.34
1993	0.83	0.44	0.56	8	0.94
1994	0.73	0.48	0.52	8	0.66
1995	0.77	0.46	0.54	7	0.72
1996[a]	-0.02	1.02	-0.02	6	0.00
1997[a]	0.47	0.63	0.37	5	0.46
1998[a]	-0.08	1.08	-0.08	4	0.13
1999[a]	-0.09	1.09	-0.09	3	0.01
Mean	0.96	0.39	0.61	8	0.85
Median	0.97	0.38	0.62	8	0.87

[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 1999. Rates based on catch curve analysis of individual cohorts at ages 2 to 9 from 1993 to 2003 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[a]	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	0.73	0.48	0.52	7	0.73
1996[a]	0.08	0.92	0.08	6	0.01	0.01	0.99	0.01	6	0.0002
1997[a]	0.34	0.71	0.29	5	0.27	0.71	0.49	0.51	5	0.53
1998[a]	-0.18	1.20	-0.20	4	0.16	-0.05	1.05	-0.05	4	0.14
1999[a]	-0.73	2.08	-1.08	3	0.21	0.17	0.84	0.16	3	0.03
Mean	0.76	0.47	0.53	6	0.61	0.84	0.44	0.56	8	0.77
Median	0.73	0.48	0.52	7	0.58	0.83	0.44	0.56	8	0.73

[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 1999. 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[a]	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	-0.09	0.77	-1.59	0.54	-0.07	0.56	0.07	0.66	0.07	0.48	0.05	0.47
1996[a]	-0.95	1.03	-0.54	0.64	-0.92	0.99	-0.80	0.81	-1.23	0.56	-0.80	0.81
1997[a]	-0.43	0.77	-0.54	0.54	-0.37	0.66	-0.09	0.80	-0.09	0.55	-0.06	0.57
1998[a]	-0.81	0.63	-1.26	0.47	-0.89	0.69	-0.77	0.72	-1.17	0.52	-0.79	0.74
1999[a]	-1.53	0.80	-3.62	0.55	-2.25	1.18	0	0	0	0	0	0
Mean	0.02	0.75	-0.37	0.52	0.01	0.52	0.21	0.63	0.14	0.45	0.13	0.44
Median	0.01	0.81	-0.05	0.55	0.00	0.55	0.10	0.73	0.09	0.52	0.07	0.50

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

70 to 79 mm and the second ranging from 140 to 169 mm (Figure 3-2). Sub-stock (< 130 mm) CPUE increased from 2002 to a mean of 199/h in 2003 and was comprised mainly of age 1 fish (Figure 3-3 and 3-4; Appendix 3-2). Trawl CPUE of stock-size (≥ 130 mm) fish increased to 142/h in 2003 and more than 50% of the catch was from the 1998 year class (age 5) (Figures 3-5 and 3-6; Appendix 3-2). Quality-size fish (≥ 200 mm) increased to 20/h in 2003, with age 5 fish making up 73% of the catch (Figure 3-7 and 3-8; Appendix 3-2). Although the 2003 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 while the stock and quality components are at their highest levels since 1994 and 1993, respectively (Appendix 3-2). However, further stock stability will depend on the 1998 year class to produce similar or potentially stronger cohorts than observed for the 2002 year class (Figure 3-9).

Proportional stock density (PSD; the percentage of stock-size fish ≥ 200 mm) for 2003 increased to 14% and surpassed 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 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 42%:58% male:female in 2003 (Figure 3-11). The sub-stock composed 58% the total catch (Appendix 3-3) with a sex ratio of 46%:54% male:female (Figure 3-12). Fish of stock size (≥ 130 mm) made up 42% of the catch (Appendix 3-3) with a sex ratio of 36%:64% male:female (Figure 3-13). Quality-size (≥ 200 mm) fish comprised 6% of the total catch (Appendix 3-3) with a sex ratio of 6%:94% 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 decreased from age 3 in 2002 to age 1 in 2003. Concurrent with the decrease in age, median length classes of

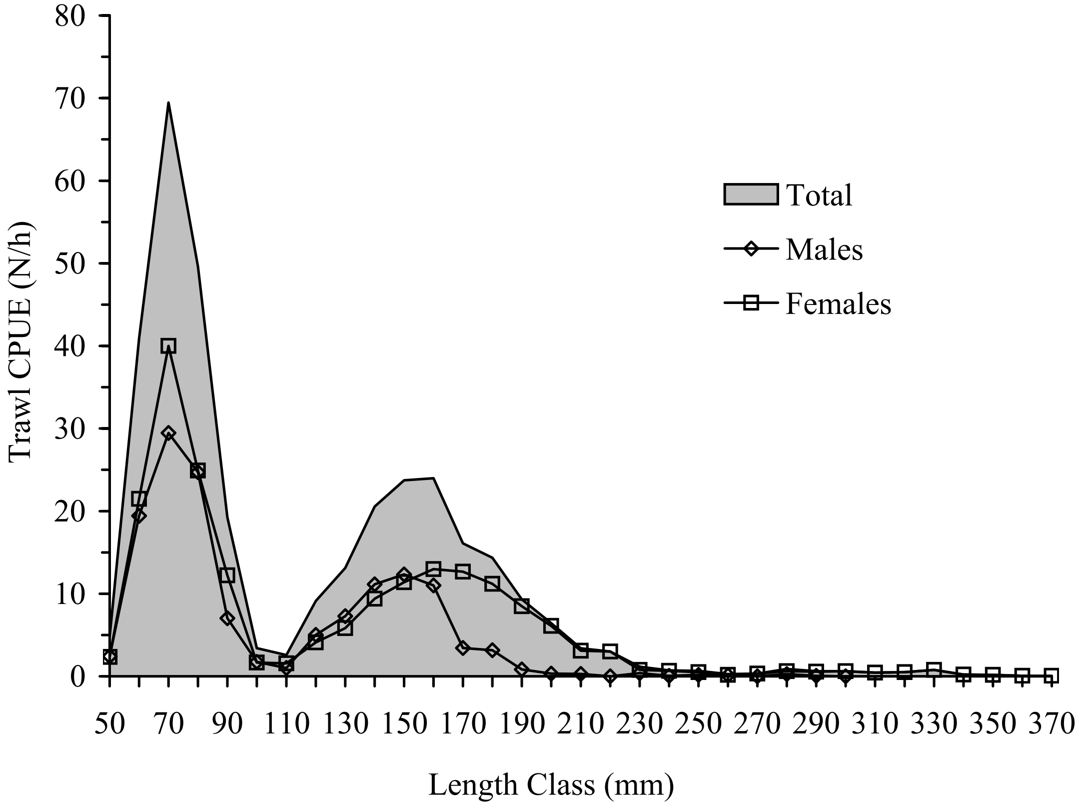

Figure 3-2. Length composition of the trawl caught yellow perch age ≥1 at pooled sites in Indiana waters of Lake Michigan in 2003.

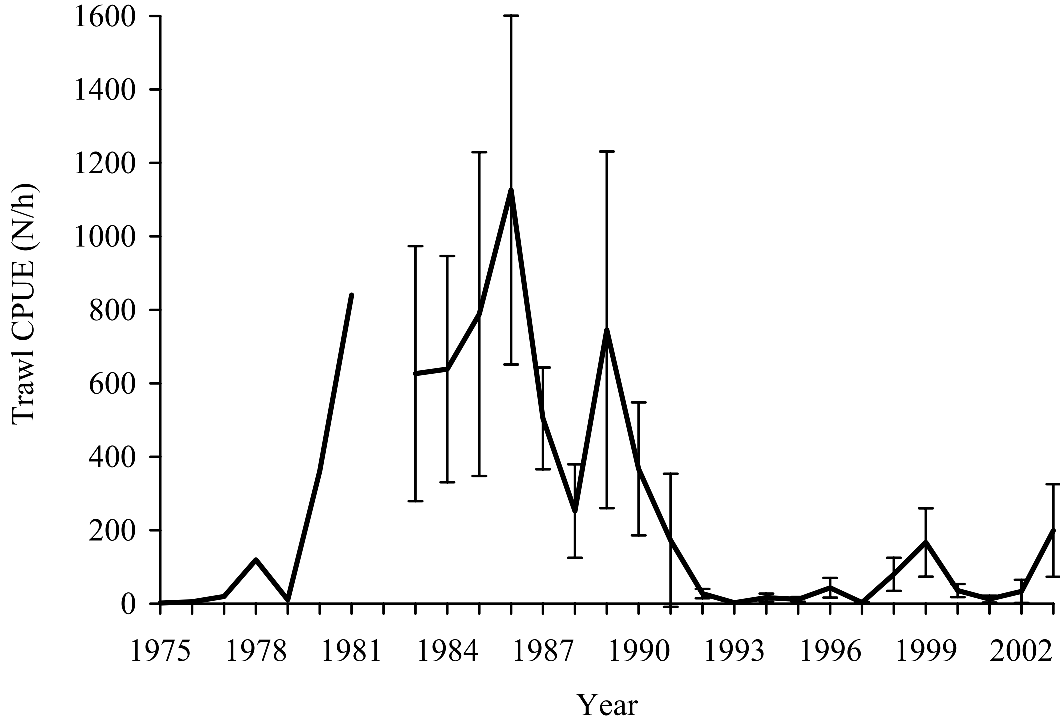

Figure 3-3. Trawl CPUE of sub-stock size (<130 mm and age ≥1) yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2003. No trawling was conducted in 1982. Error bars for 1983-2003 represent ± 2 SE.

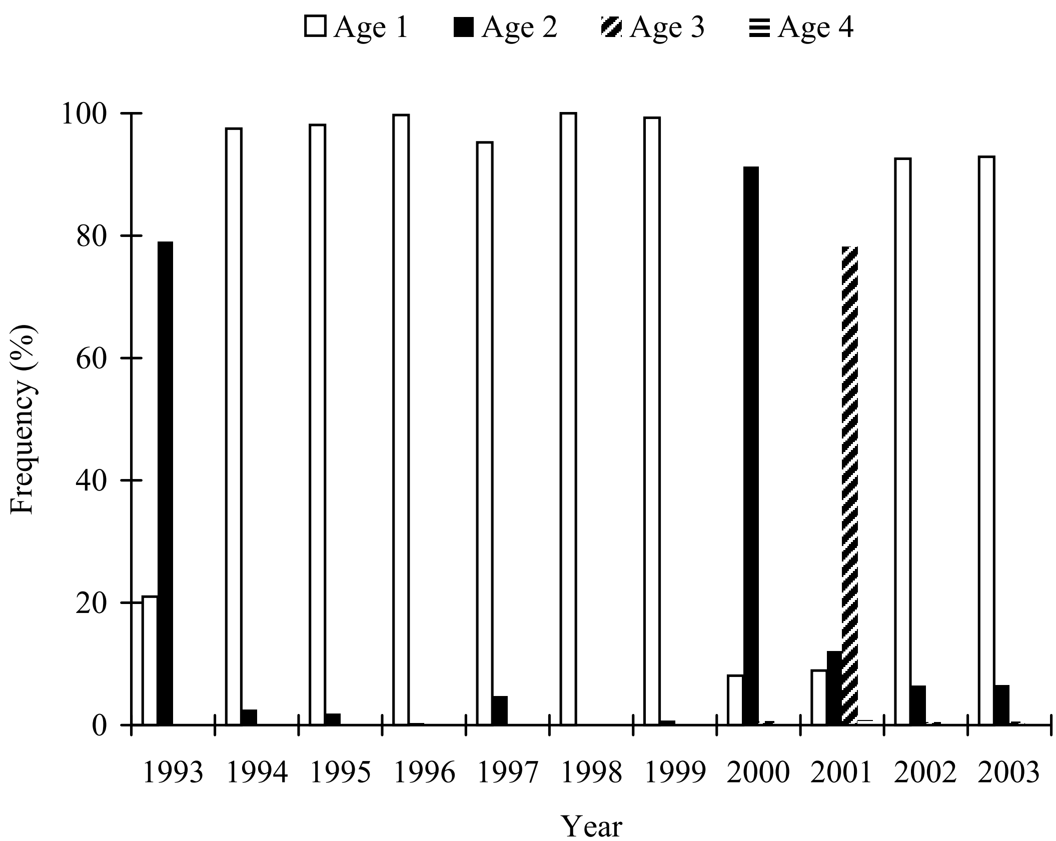

Figure 3-4. Age frequency of trawl caught sub-stock (<130 mm and age ≥1) yellow perch at pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

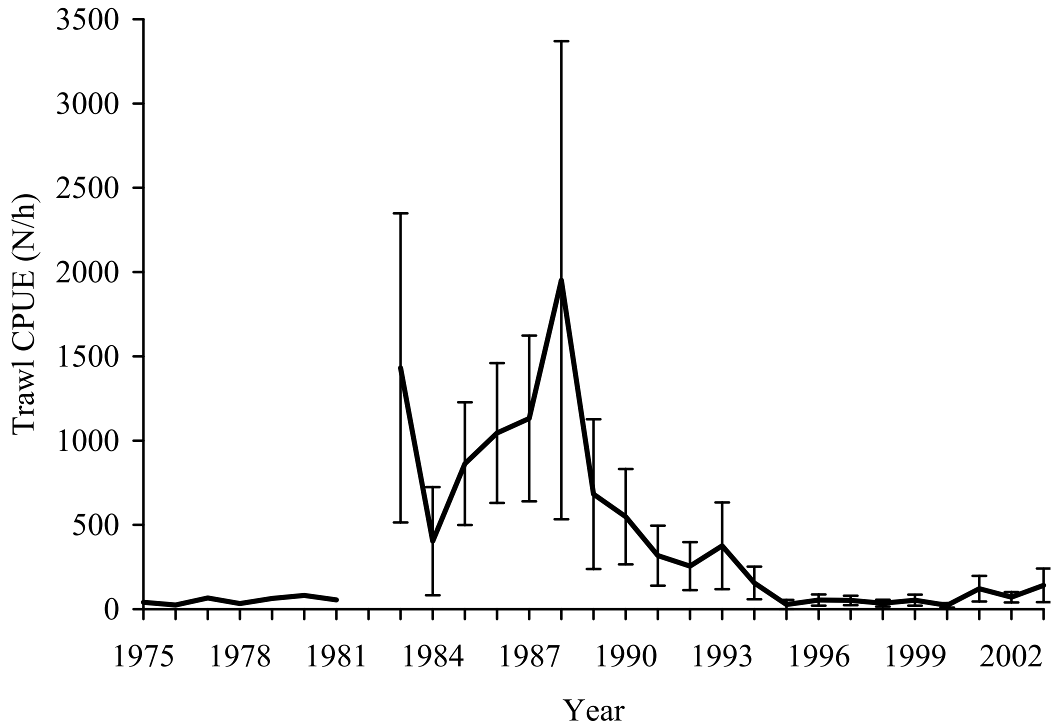

Figure 3-5. Trawl CPUE of stock size (≥130 mm) yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2003. No trawling was conducted in 1982. Error bars for 1983-2003 represent ± 2 SE.

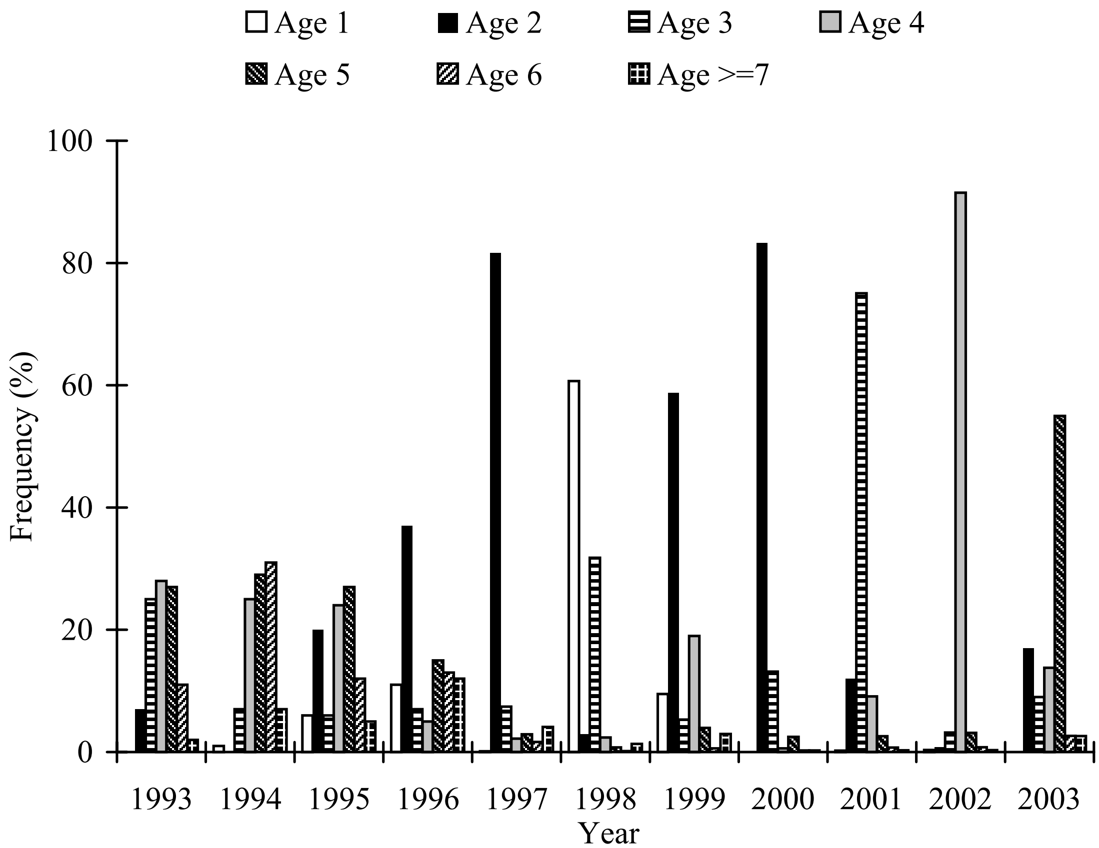

Figure 3-6. Age frequency of trawl caught stock (≥ 130 mm) yellow perch at pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

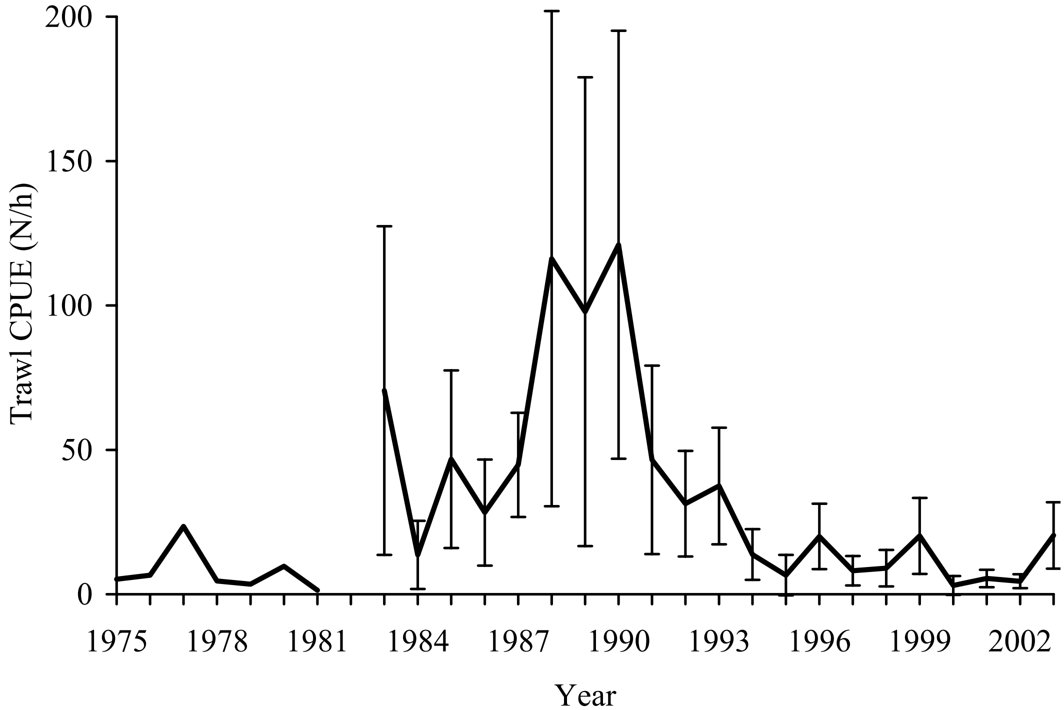

Figure 3-7. Trawl CPUE of quality size (≥200 mm) yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2003. No trawling was conducted in 1982. Error bars for 1983-2003 represent ± 2 SE.

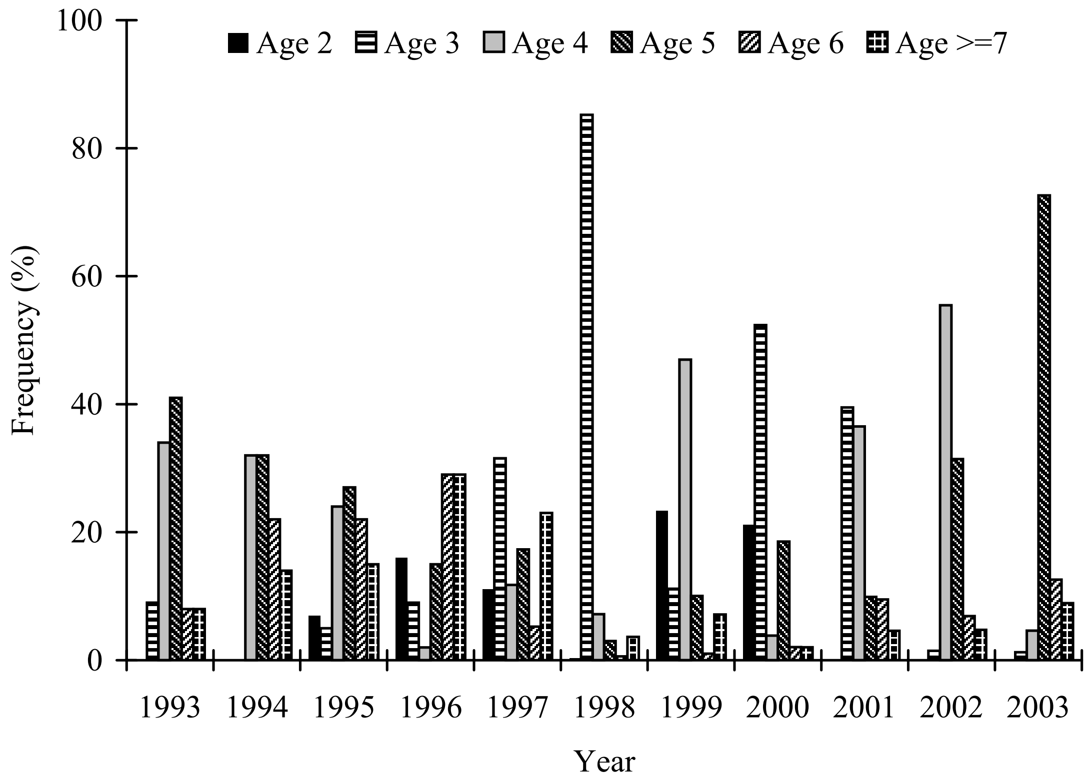

Figure 3-8. Age frequency of trawl caught quality size (≥ 200 mm) yellow perch at pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

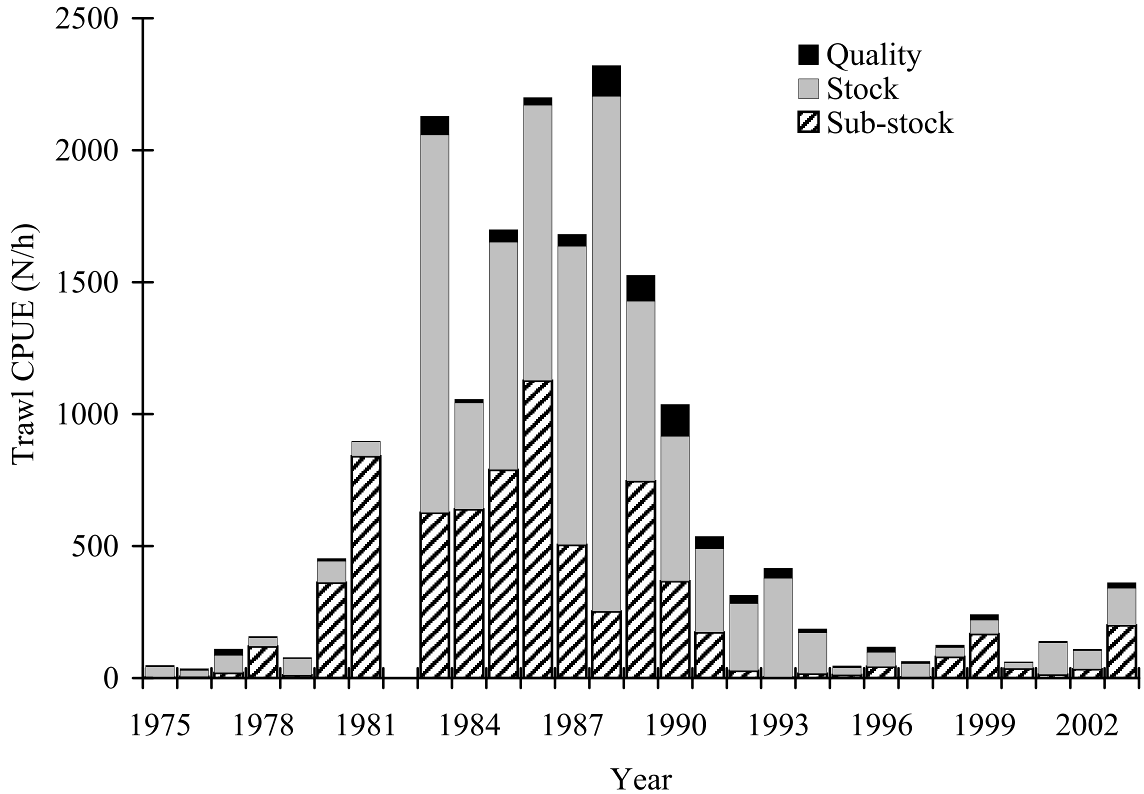

Figure 3-9. Trawl CPUE of sub-stock, stock, and quality size yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2003. No index trawling was conducted in 1982.

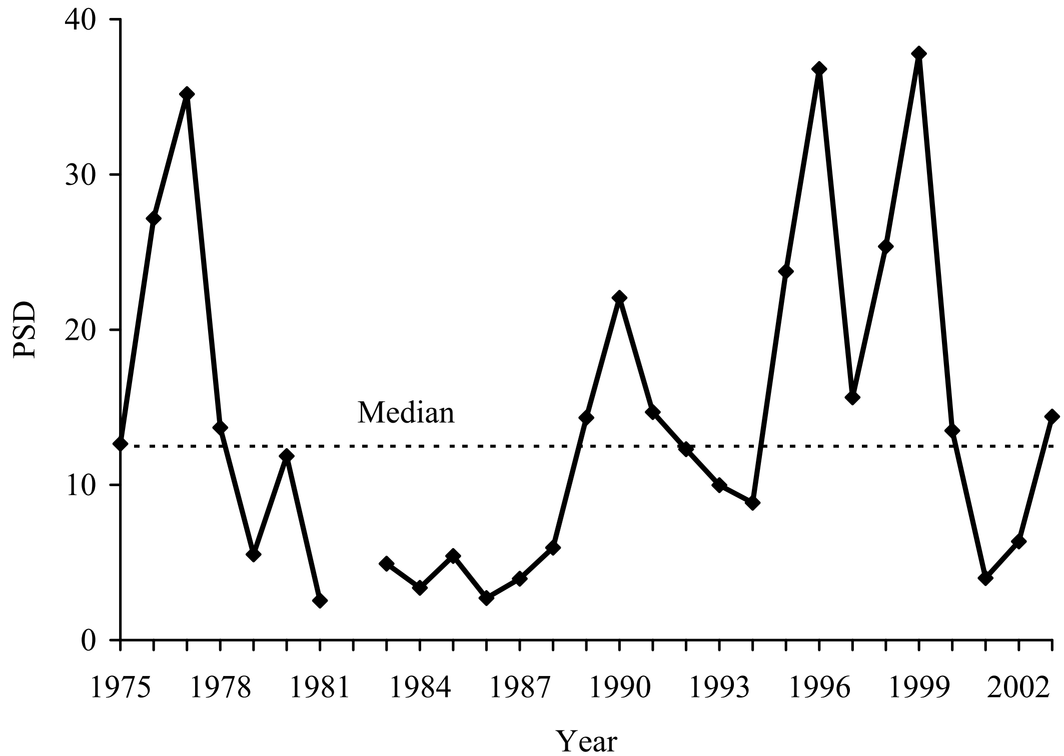

Figure 3-10. Proportional stock density (PSD) of yellow perch from pooled sites in Indiana waters of Lake Michigan from 1975 to 2003. No index trawling was conducted in 1982.

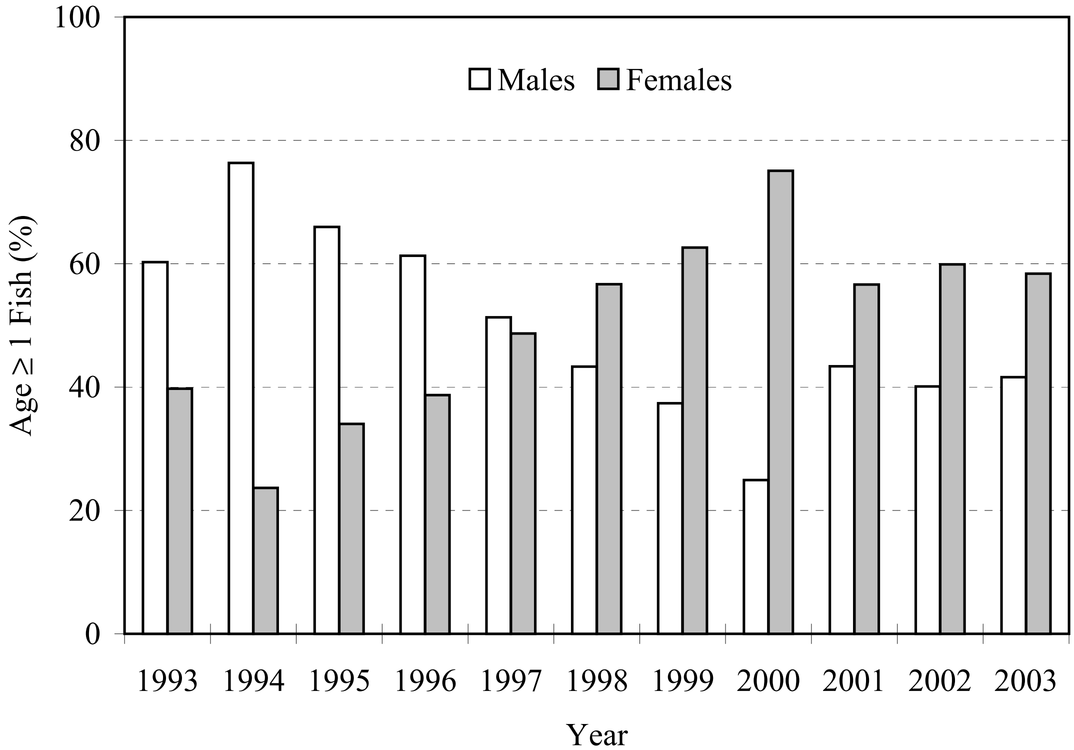

Figure 3-11. Sex ratios of age ≥1 yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

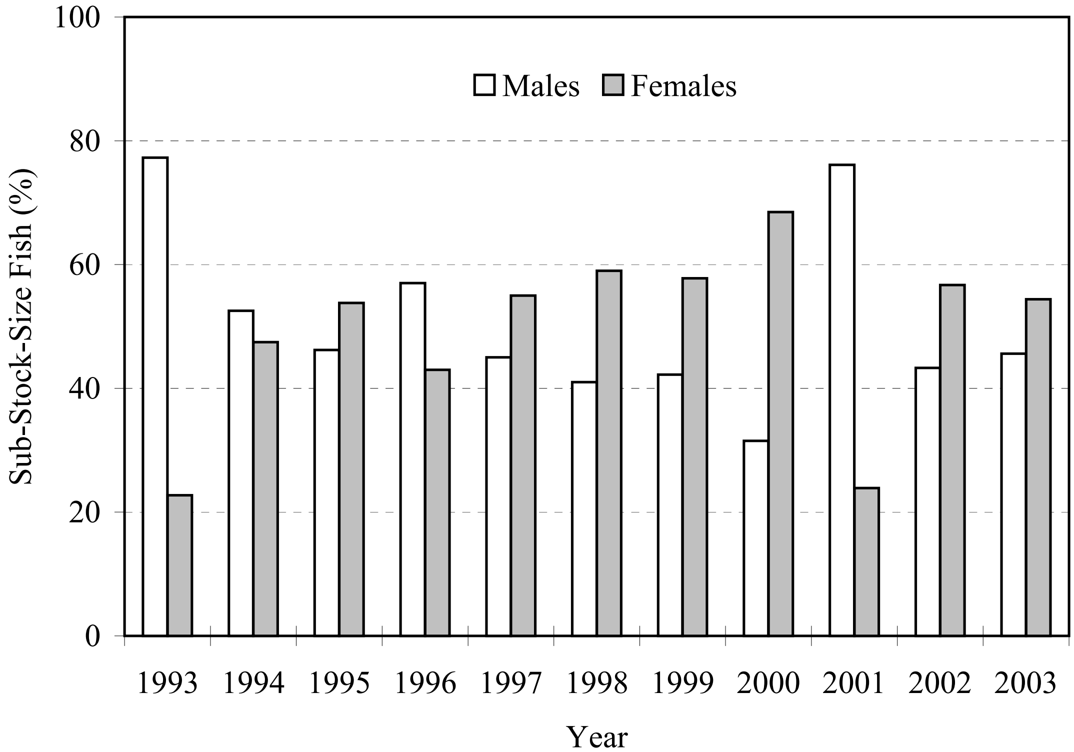

Figure 3-12. Sex ratios of sub-stock-size (age ≥1 and <130 mm) yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

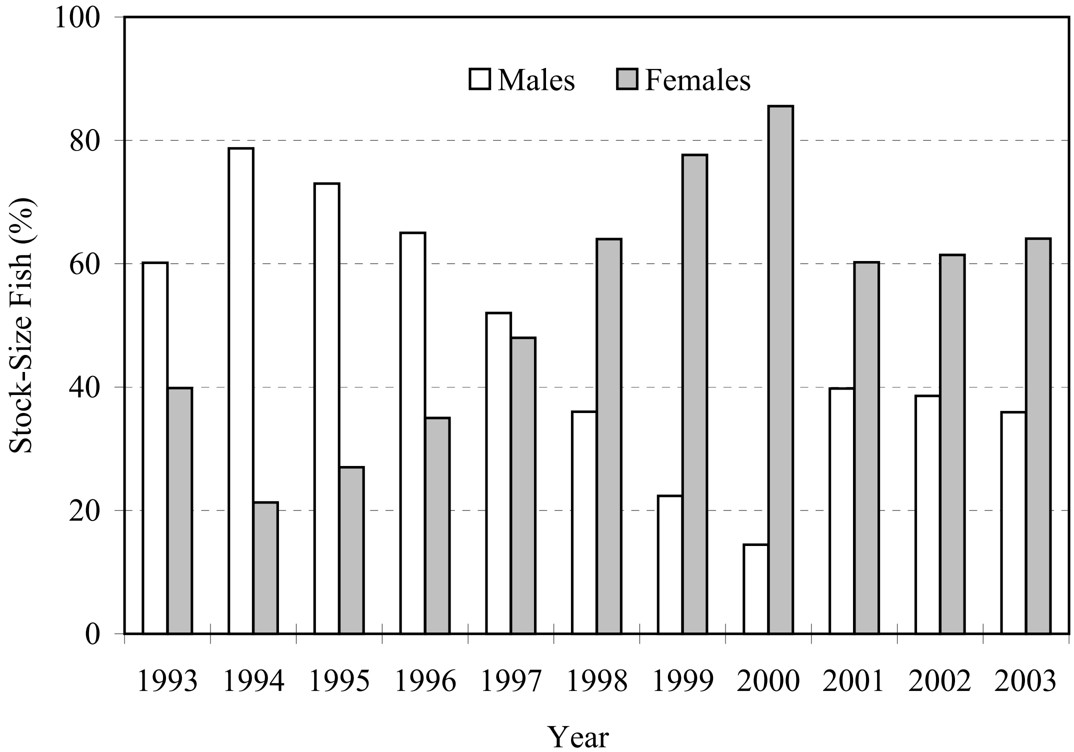

Figure 3-13. Sex ratios of stock-size (≥130 mm) yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

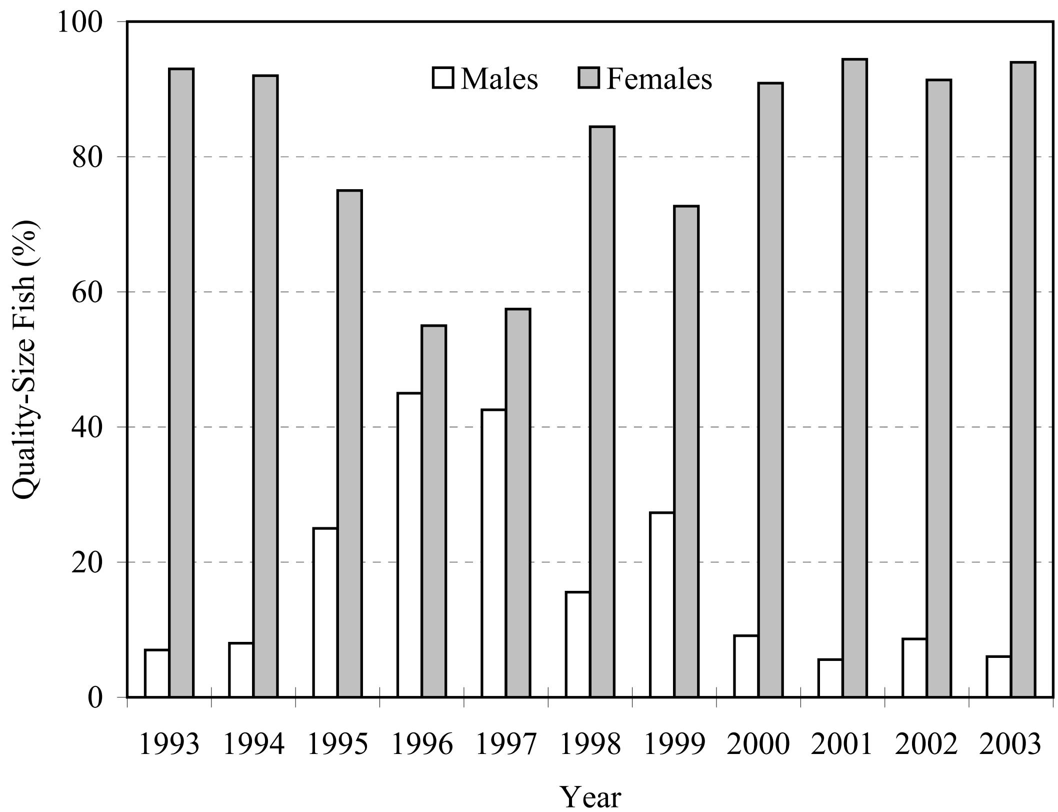

Figure 3-14. Sex ratios of quality-size (≥200 mm) yellow perch in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

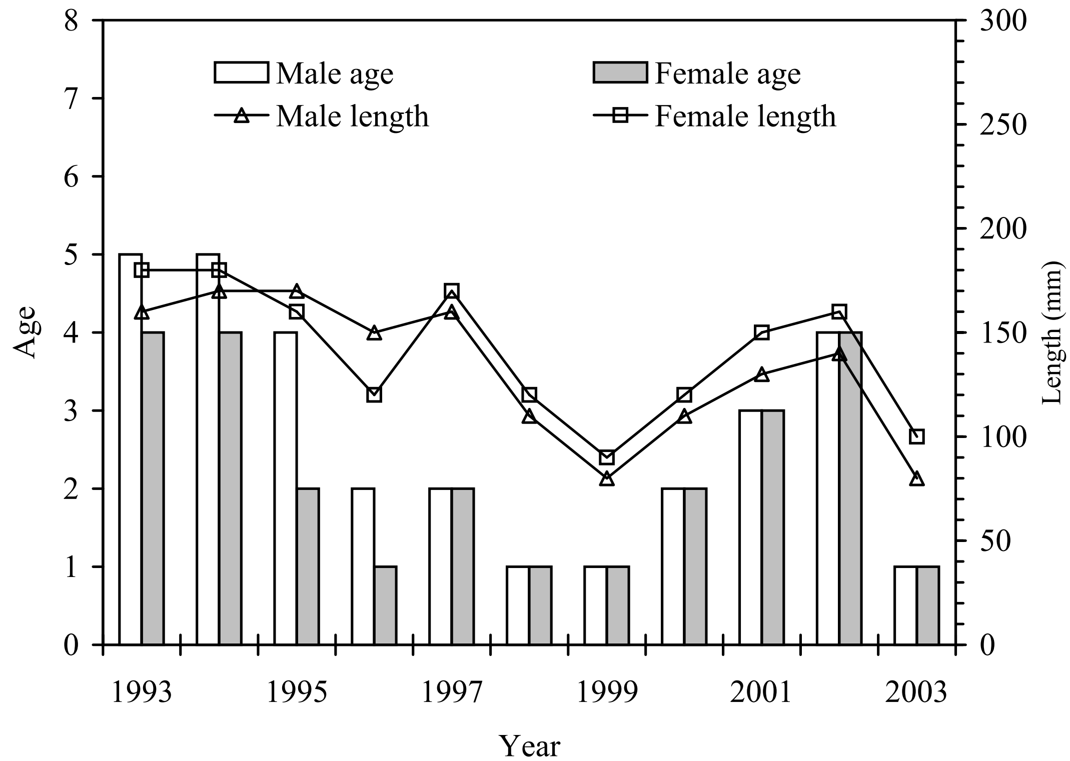

Figure 3-15. Median age and length classes of male and female yellow perch age ≥ 1 in the trawl catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

both males and females decreased to 80 and 100 mm, respectively, during the same period. The shift in trawl median age and length, from 2002 to 2003, for both male and female yellow perch is due the prominence of the 2002 year class in the population.

Gill Net Catch

Gill nets captured yellow perch ranging in lengths from 160-369 mm in 2003; males from 180-329 mm, and females from 160-369 mm (Appendices 3-6, 3-7, and 3-8). The gill net length frequency was a positively skewed distribution with the mode centered at 200 - 209 mm (Figure 3-16). The 1998 year class (age 5) dominated the catch at 74%, while the 1997 year class (age 6) comprised 12% of the gill net catch (Appendices 3-6).

Sex ratios of gill net catches have been dominated by females in the past six years (Figure 3-17). In 2003, females comprised 92% of the total gill net catch (Figure 3-17), while median age of both sexes was 5 (Figure 3-18). Median length classes of both males and females decreased slightly from 2002 to 2003 and during this same period (Figure 3-18), males had a median greater length than females. The shift in median lengths is likely due to gill net selectivity. Males from the 1998 year class did not appear fully vulnerable to the gill net. Furthermore, males from the 1998 year class comprised 51% of the male gill net catch, while females from that year class made up 76% of the female catch (Appendix 3-7 and 3-8). The male length frequency distribution was bimodal and resulted in a median length of 230 mm, which fell between the two modes (Figure 3-16). The length frequency distribution for females was positively skewed, with the median length shifted downwards towards the mode. Once the 1998 year class becomes fully vulnerable to the gill net, median lengths should indicate what has been observed since 1993, that female median length was greater than males.

Ages and Lengths at Maturity

In June 2003, 86% of age 2 males were mature and 58% of females were mature by age 3 (Table 3-5), while minimum length classes that were ≥ 50% maturity were 120-129 mm for males and 170-179 mm for females (Table 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

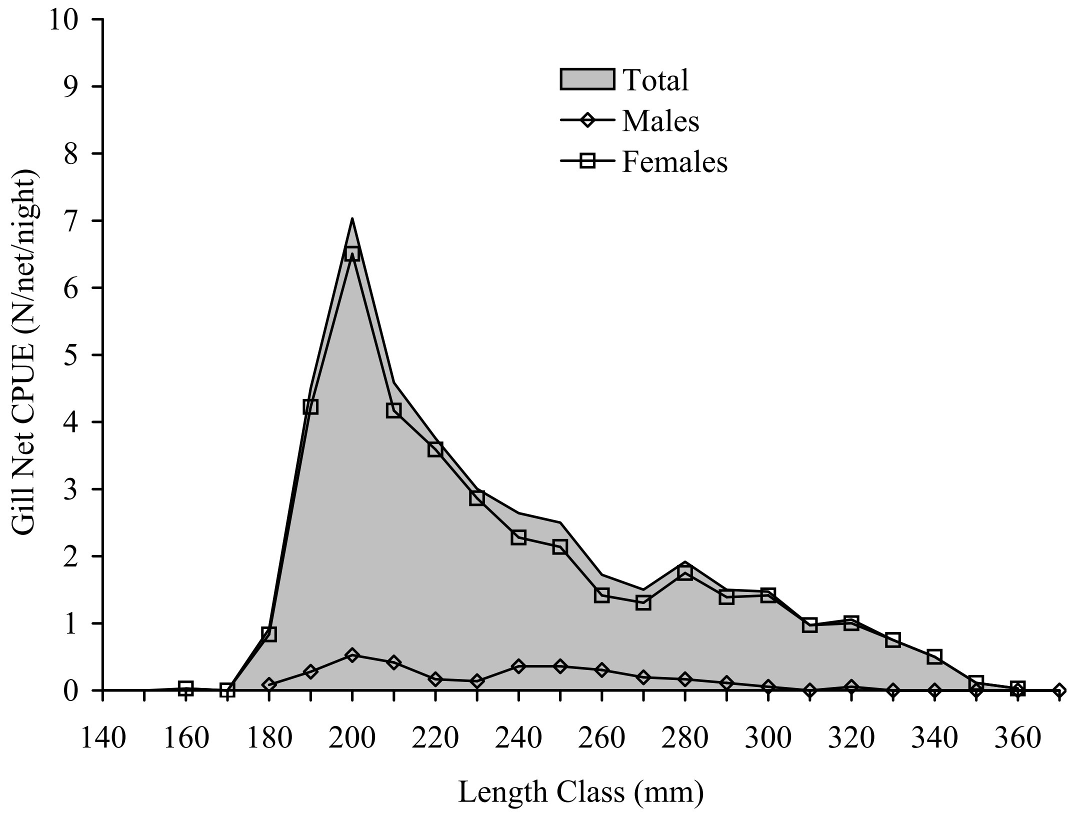

Figure 3-16. Length composition of the pooled 10-m and 15-m gill net catches of yellow perch at pooled sites in Indiana waters of Lake Michigan in 2003.

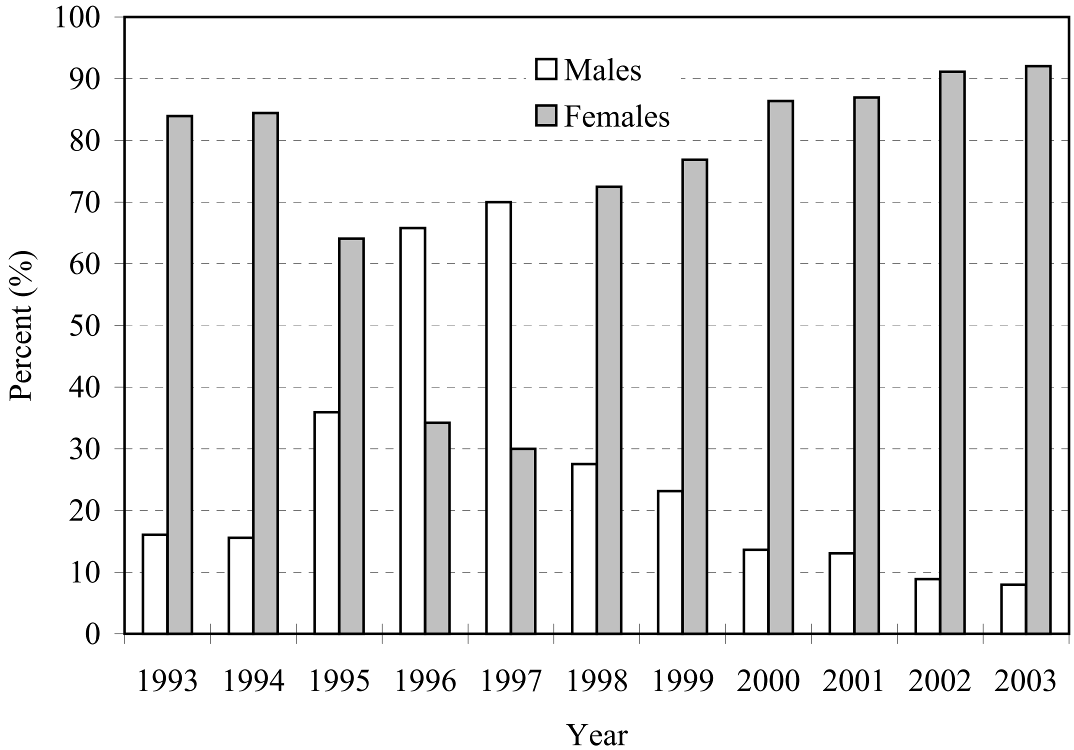

Figure 3-17. Sex ratios of the pooled 10-m and 15-m gill net catches of yellow perch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

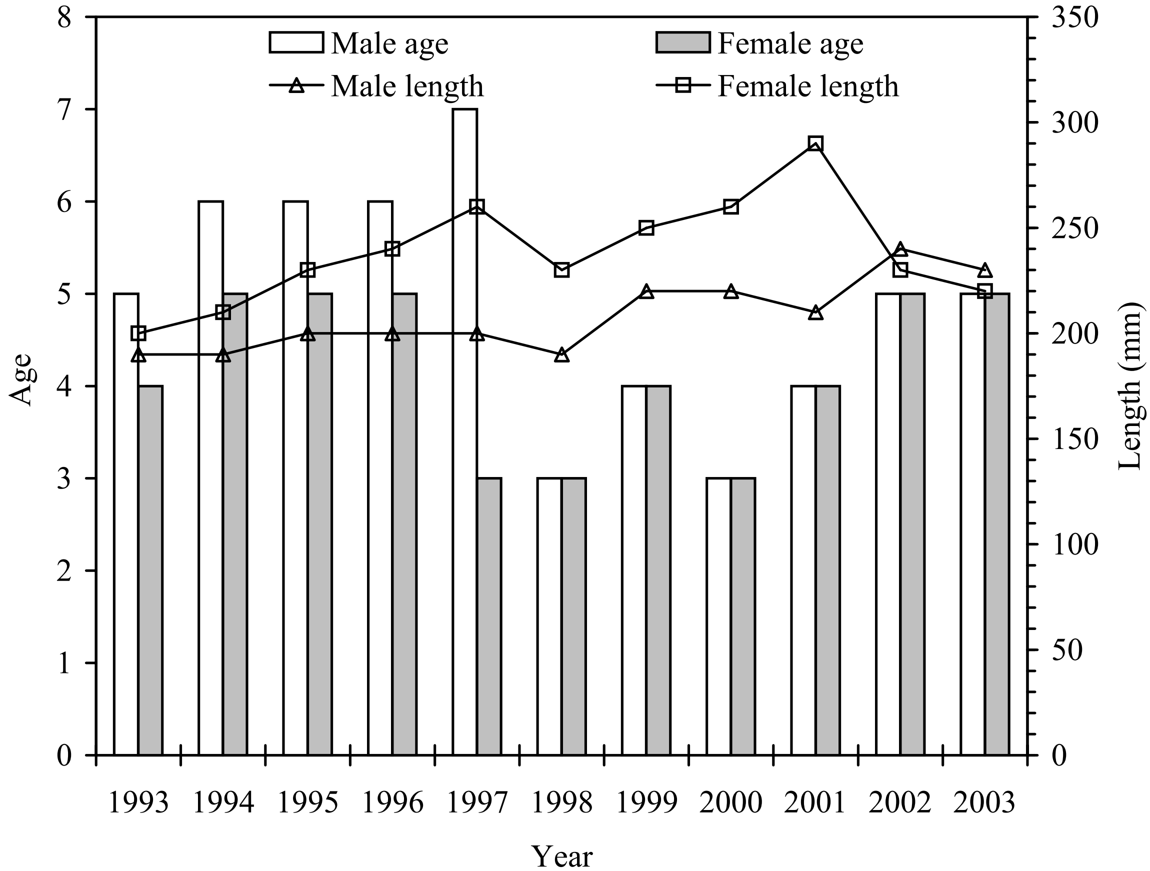

Figure 3-18. Median age and length classes of male and female yellow perch in the pooled 10-m and 15-m gill net catch from pooled sites in Indiana waters of Lake Michigan from 1993 to 2003.

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 2003. Gonads of mature fish were either ripe or recently spent.

	Males			Females		
Age	*N*	Immature %	Mature %	*N*	Immature %	Mature %
1	248	99	1	307	100	0
2	7	14	86	28	96	4
3	3	0	100	15	42	58
4	1	0	100	40	29	71
5	74	1	99	637	12	88
6	12	2	98	75	0	100
7	6	0	100	23	5	95
8	4	0	100	22	0	100
9	2	0	100			
10						
11	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 2003. Gonads of mature fish were either ripe or recently spent.

Length class (mm)	Males			Females		
	N	Immature %	Mature %	*N*	Immature %	Mature %
50	30	100	0	31	100	0
60	182	100	0	194	100	0
70	31	94	6	58	100	0
80	4	100	0	18	100	0
90	1	100	0	4	100	0
100				4	100	0
110	1	100	0			
120	2	0	100	1	100	0
130	2	0	100	10	100	0
140	6	0	100	11	91	9
150	9	0	100	15	80	20
160	17	0	100	10	60	40
170	10	0	100	16	31	69
180	7	0	100	44	20	80
190	11	0	100	130	12	88
200	18	0	100	135	10	90
210	4	25	75	71	3	97
220	2	0	100	60	3	97
230	6	0	100	56	0	100
240	5	0	100	45	0	100
250	4	0	100	39	0	100
260	2	0	100	23	0	100
270	2	0	100	23	0	100
280	1	0	100	39	0	100
290				22	0	100
300	1	0	100	21	0	100
310				19	0	100
320				19	0	100
330				21	0	100
340				4	0	100
350				2	0	100
360				1	0	100

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. The current yellow perch population structure exhibited by the total number of females captured in June 2003 showed 78% of the reproducing females are quality size, while 22% are less than 200 mm. Although we do not fully understand female size composition effects and how it relates to survivability of larval yellow perch, a majority of the 1998 females remain below quality size (Appendix 3-5) and thus may produce smaller and less viable larvae. Many abiotic factors can also affect fish fecundity including, but not limited to, changes in environmental conditions, resource availability, and predators (Nikolskii 1969; Bagenal and Braum 1971; Treasurer 1981).

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 will focus on data collected in 2003.

Catch Composition

Trawl Catch of Age ≥1

A total of 11 non-salmonine fish species represented by individuals age ≥ 1 were collected by trawling at sites M, K, and G in 2003 (Figure 4-1; Appendix 4-1). Spottail shiners were numerically the most abundant species with a mean trawl CPUE of 681 fish/h, accounting for 50% of all fish captured. Yellow perch was the next most abundant fish, with a mean CPUE of 341 fish/h, representing 25% of the total catch. Other major fish species sampled included alewife at 232 fish/h (17%), and round goby at 97 fish/h (7%) of the total catch. The trout-perch *Percopsis omiscomaycus* and longnose sucker *Catostomus catostomus*, white sucker *Catostomus commersoni*, and rainbow smelt *Osmerus mordax* were present at low CPUEs, but exceeded 1 fish/h on at least one site. Additional non-salmonine species caught incidentally (CPUE < 1 fish/h and, < 1%) were: banded killifish *Fundulus diaphanous*, common carp *Cyprinus carpio*, and ninespine stickleback *Pungitius pungitius*.

Among-Site Differences in Trawl Catch

Differences in occurrence and CPUE of some species among sample sites were observed in 2003 (Figure 4-1; Appendix 4-1). The catch rate for the spottail shiner was greatest at site M when compared to K and G. Yellow perch were caught in greatest abundance at site M with lower catch rates at G and K. Alewife catch rates were high and more similar at sites K and M but lower at site G. The round goby catch rate at site K was greater than the catches at both sites M and G. Trout-perch catches were similar at sites M and G when compared to site K. The longnose sucker catch was higher at site K

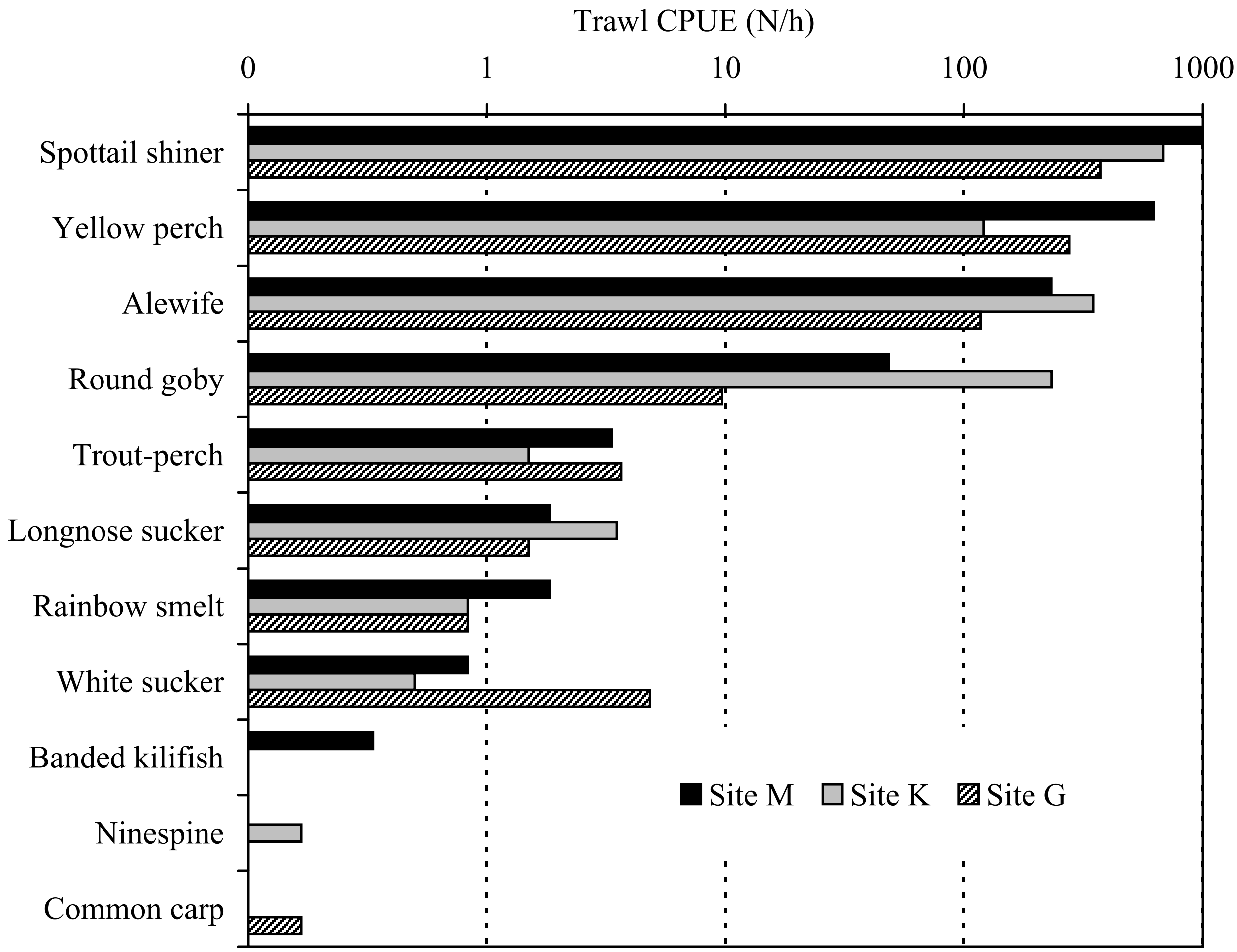

Figure 4-1. Summary of species composition of the trawl catch of non-salmonine fishes age ≥ 1 at sites M, K, and G in Indiana waters of Lake Michigan in 2003.

than at sites M and G. Rainbow smelt catch rates were highest at site M than sites K and G. The catch rate for white sucker was greatest at site G when compared to site M and K. Catches of banded killifish, ninespine sticklebacks, and common carp were very low and only at sites M, K and G, respectively.

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 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 the reported values of CPUE. 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

Thirteen different species were caught in gill nets at sites M, K, and G in 2003 (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 83% of the catch in 2003. The only other species composing ≥ 1% of the catch were longnose sucker (11%) and white sucker (4%). Species caught incidentally (< 1% of CPUE) were alewife, round goby, channel catfish *Ictalurus punctatus*, lake whitefish *Coregonus clupeaformis*, and rainbow smelt.

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 1984-2003 are summarized in Figure 4-2. Trawl catches of four species increased in 2003: spottail shiners, yellow perch, alewife, and rainbow smelt. Bloaters *Coregonus hoyi* were last caught in the trawl during 1999.

Yellow Perch

The relative abundance of the 2003 trawl catch of age ≥1 fish at pooled sites M, K, and G increased to its highest level since 1992 (Figure 4-3). The decline in yellow perch abundance after 1988 continued because of reduced recruitment and high mortality, as discussed under Job 3.

Another supporting view of the trend in yellow perch abundance was provided by CPUE of gill nets (51, 64, and 76 mm stretch measure) set at 10 m and 15 m depths at sites M, K, and G from 1984-2003 (Figure 4-4). Trends in gill net CPUE were similar at both depths, with the catch somewhat higher at 10m when compared with 15 m. The combined mean value increased in 2003 from 2002. Due to the selective bias of the gill nets for larger fish, gill net CPUE data are not as representative as trawl CPUE for tracking overall population abundance trends. Moreover, yellow perch gill net CPUE interpretation can only be done by additionally evaluating the dynamics of sex ratios and growth rates as discussed under ***Job 3***.

Alewife

The relative abundance of alewife in 2003 reached its highest level since 1984 (Figure 4-5). Attempts were made in 2003 to validate our assumption that the majority of the alewife catch over the past four years were from the 1998 year class by initiating an aging study using four boney structures: scales, opercules, vertebrae, and whole otoliths. Previously, length frequencies distributions were used solely to determine whether the alewife population was being supported by a single dominate year class (Allen et al. 2002). The results of the study suggest both otoliths ($CV_{\bar{x}} = 0.06$) and scales ($CV_{\bar{x}} = 0.09$) provided greater precision than vertebrate ($CV_{\bar{x}} = 0.13$) and opercules ($CV_{\bar{x}} =$

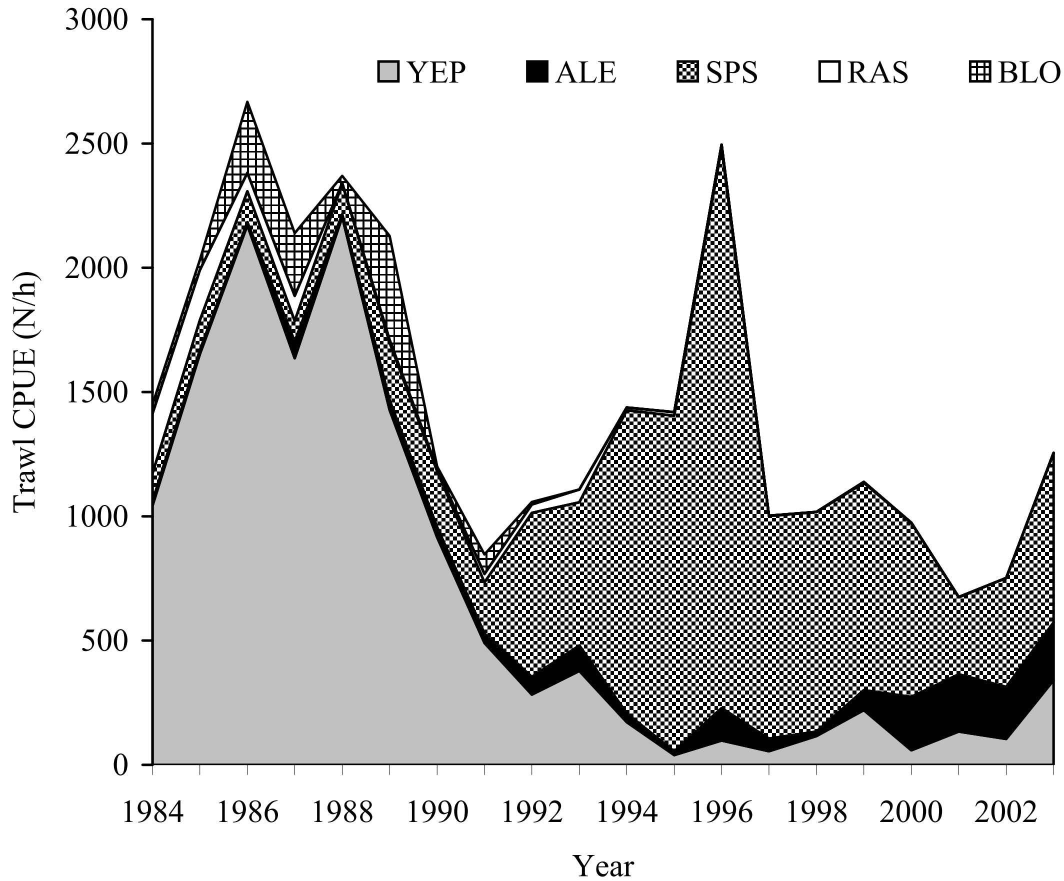

Figure 4-2. Mean annual trawl CPUE (excluding age 0) of five historically abundant species from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. Abbreviations: YEP = yellow perch, ALE = alewife, SPS = spottail shiner, RAS = rainbow smelt, BLO = bloater.

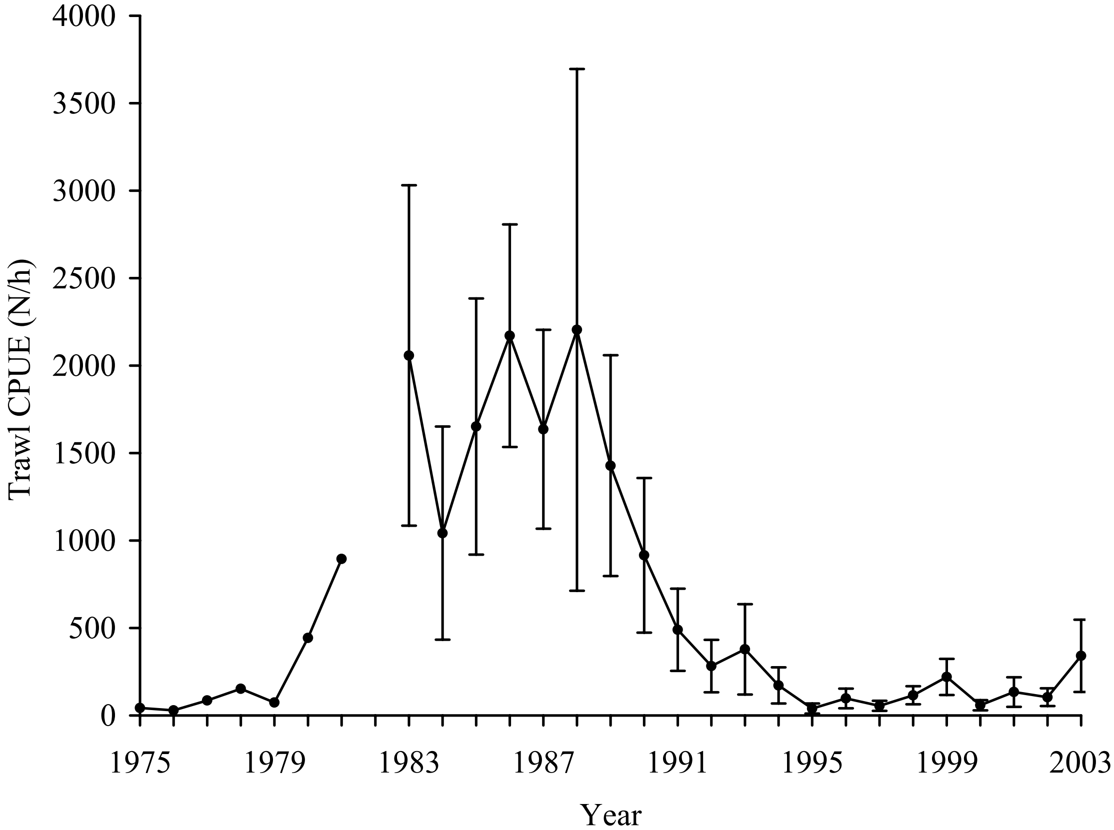

Figure 4-3. Mean annual trawl CPUE of yellow perch age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1975 to 2003. Only site K was sampled from 1975 to 1983; 1984 to 1988 data represent pooled sites M and K; and 1989 to 2003 data represent pooled sites M, K, and G. No trawling was conducted in 1982. Error bars for 1983 to 2003 are ± 2 SE.

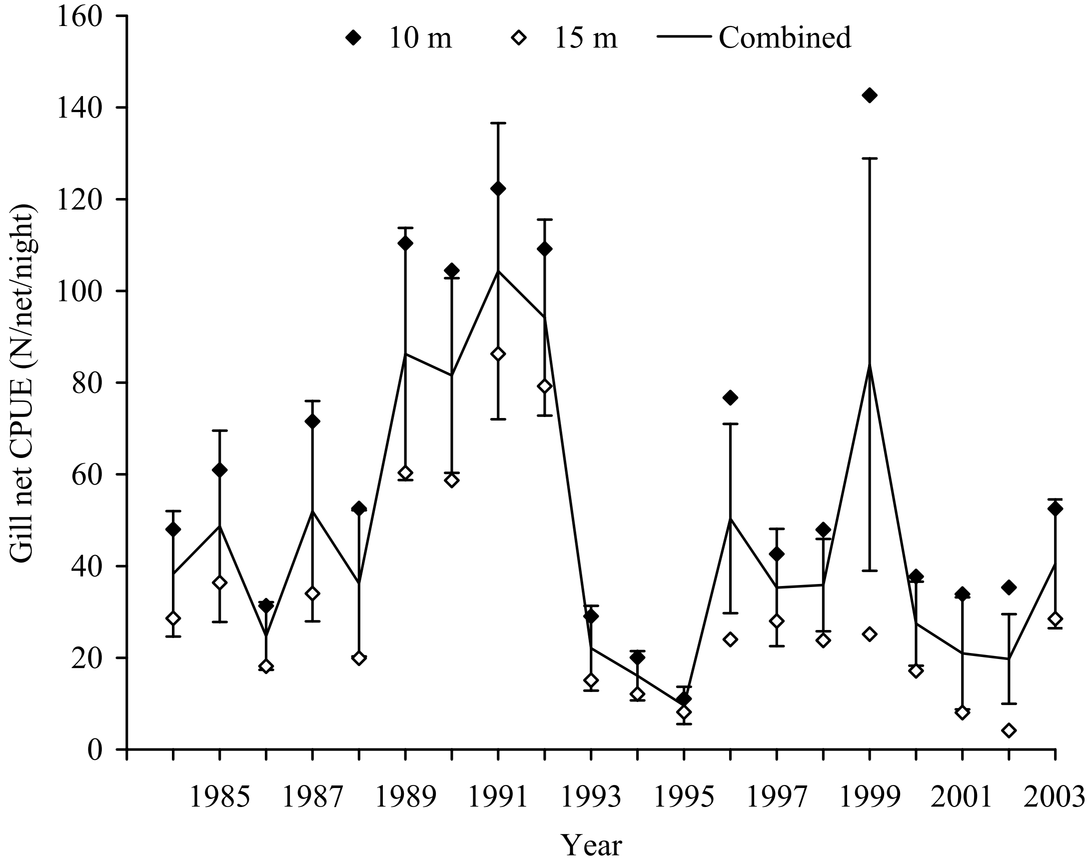

Figure 4-4. Mean annual gill net CPUE of yellow perch at 10 m, 15 m, and combined depths from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. Error bars represent ± 2 SE of combined means.

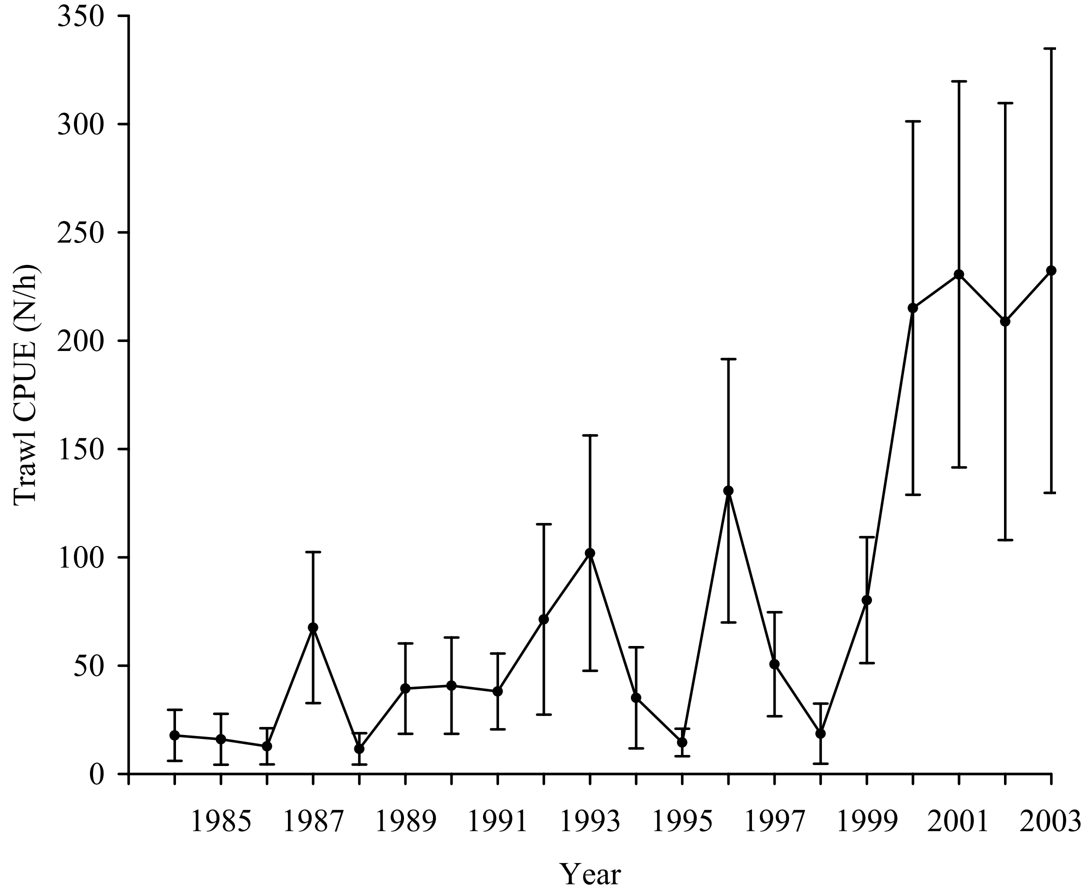

Figure 4-5. Mean annual trawl CPUE of alewives age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2003 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

0.24). 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, personal communication). We will continue to closely monitor alewife abundance due to its impact on yellow perch recruitment (see Job 5).

Mean gill net CPUE decreased in 2003 to its lowest level since 1984 (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. However, catches may increase as the 1998 year class becomes fully vulnerable to the gill nets.

Spottail Shiner

The mean trawl CPUE of spottail shiners in 2003 trended up from 2002 (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 2003 (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 was not significantly different from zero in 2003 (Figure 4-9). Due to high coefficients of variation, the only year in the entire series when CPUE was significantly different than zero was 1994. As with the bloater, the rainbow smelt 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

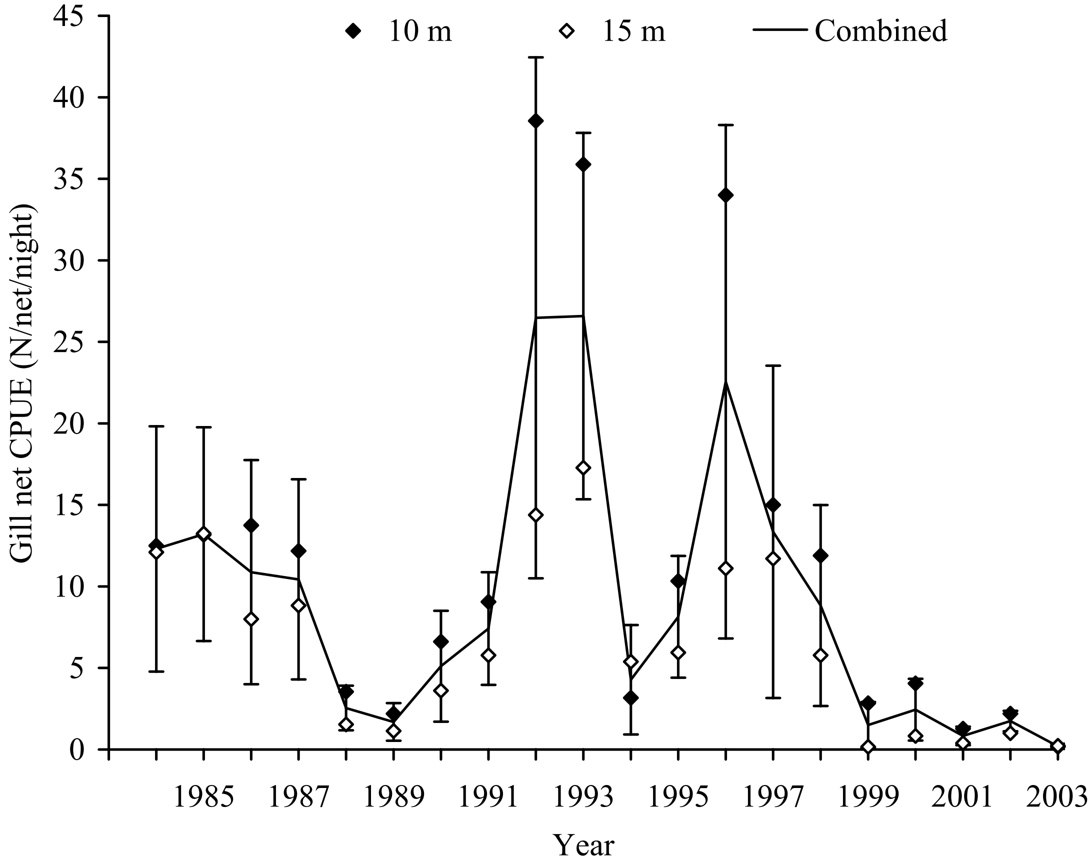

Figure 4-6. Mean annual gill net CPUE of alewives at 10 m, 15 m, and combined depths from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. Error bars represent ± 2 SE of combined means.

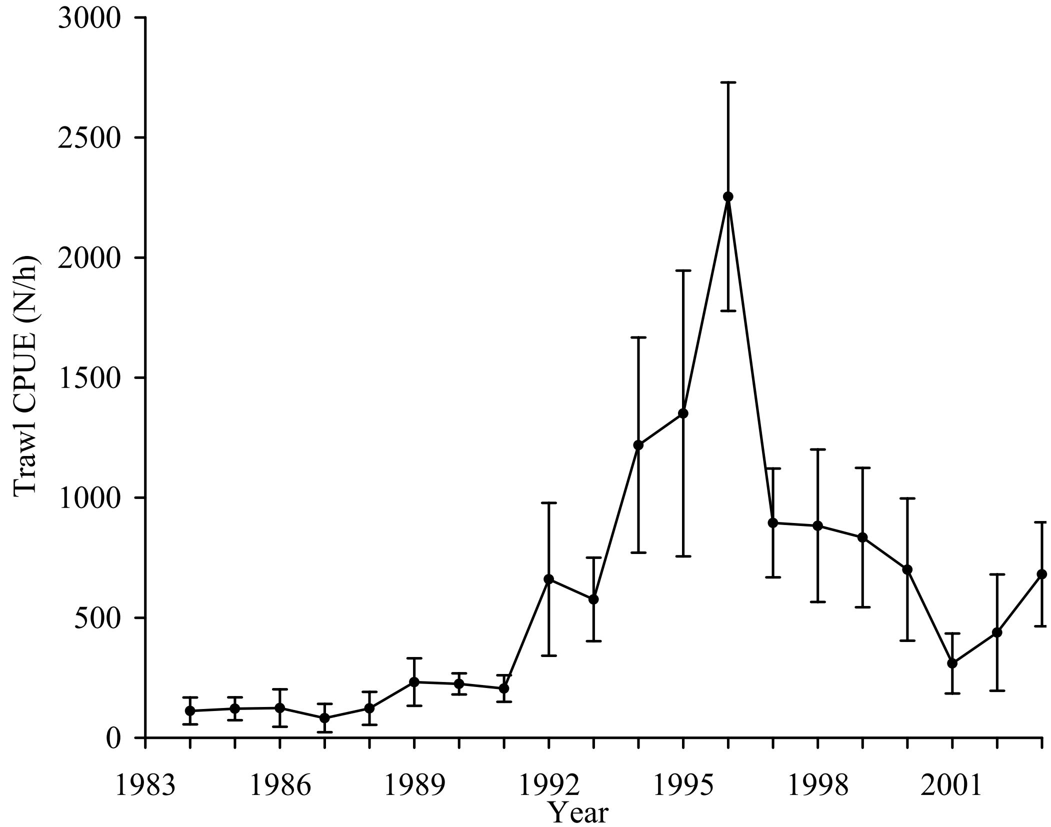

Figure 4-7. Mean annual trawl CPUE of spottail shiners age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2003 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

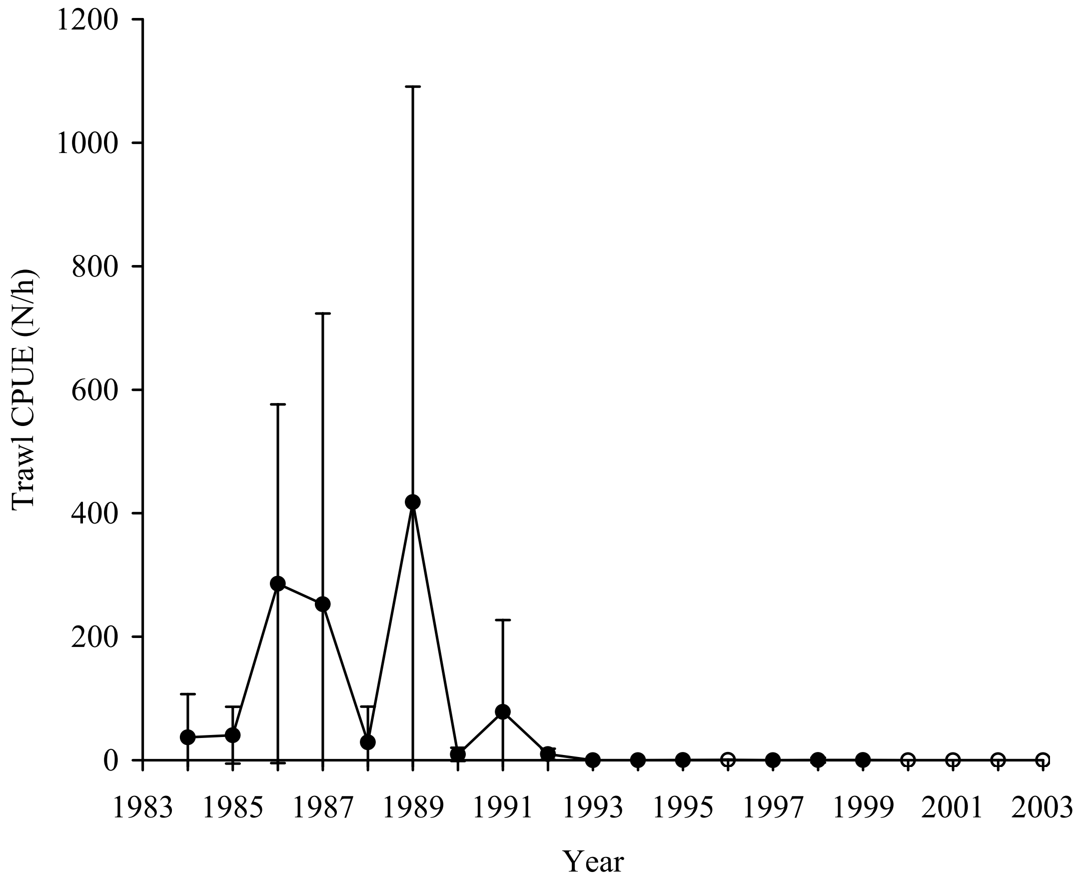

Figure 4-8. Mean annual trawl CPUE of bloaters age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2003 data represent pooled sites M, K, and G. Open circles represent no fish collected and error bars are ± 2 SE.

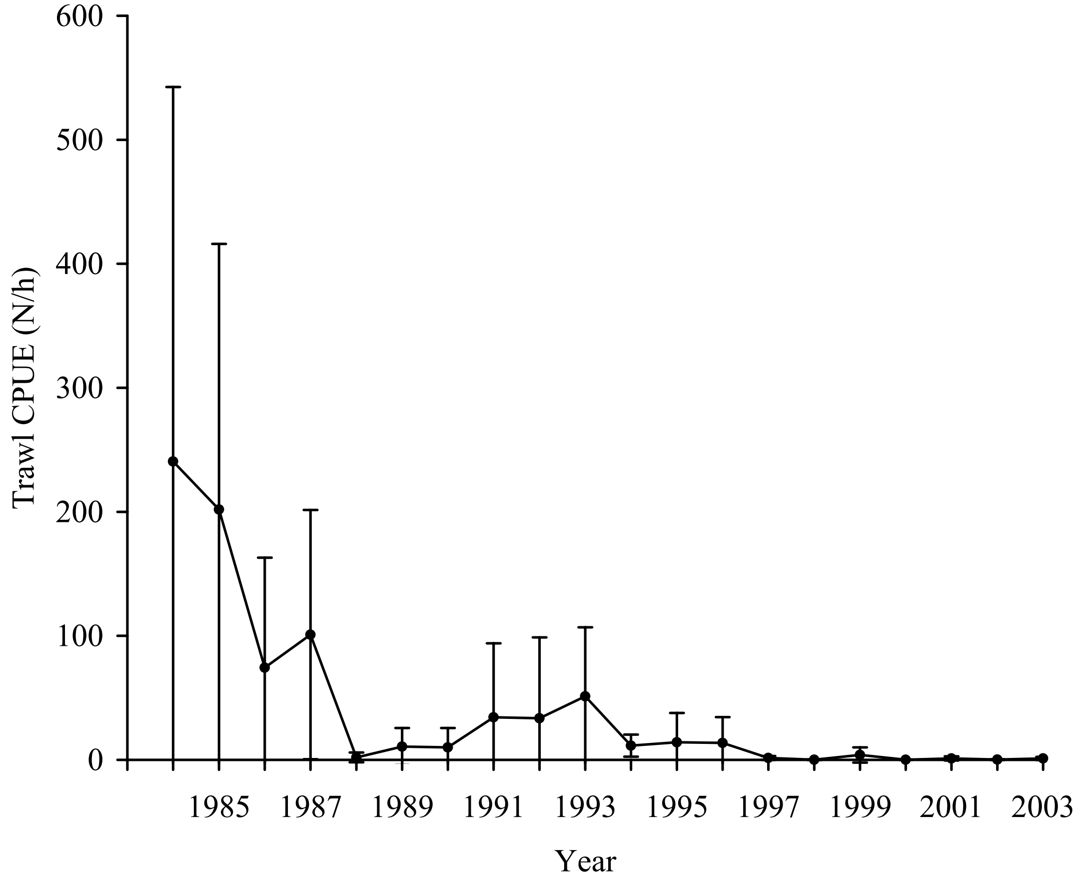

Figure 4-9. Mean annual trawl CPUE of rainbow smelt age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. The 1984 to 1988 data represent pooled sites M and K; the 1989 to 2003 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

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 2003 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 2003 was generally similar to that reported in other years, with the exception of the banded killifish which was caught for the first time in the trawl. We will continue to carefully monitor the species present and be on the lookout for additional nonindigenous species.

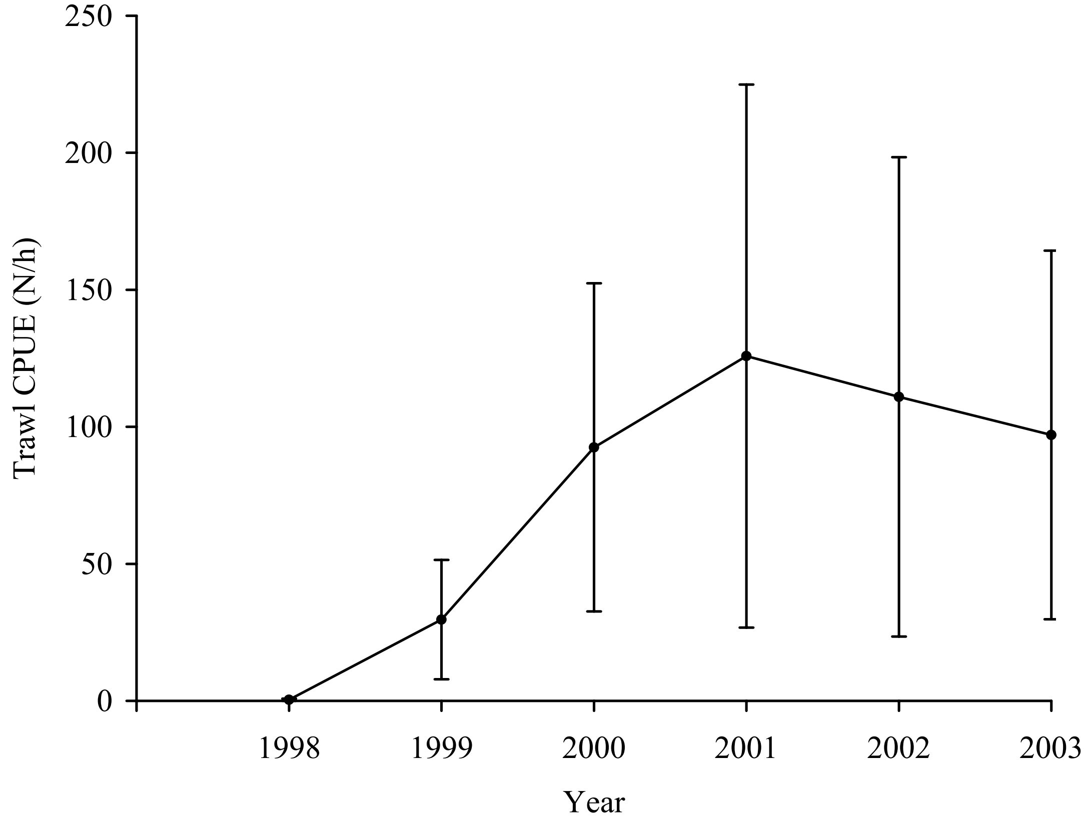

Figure 4-10. Mean annual trawl CPUE of round gobies age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1998 to 2003. Error bars are ± 2 SE.

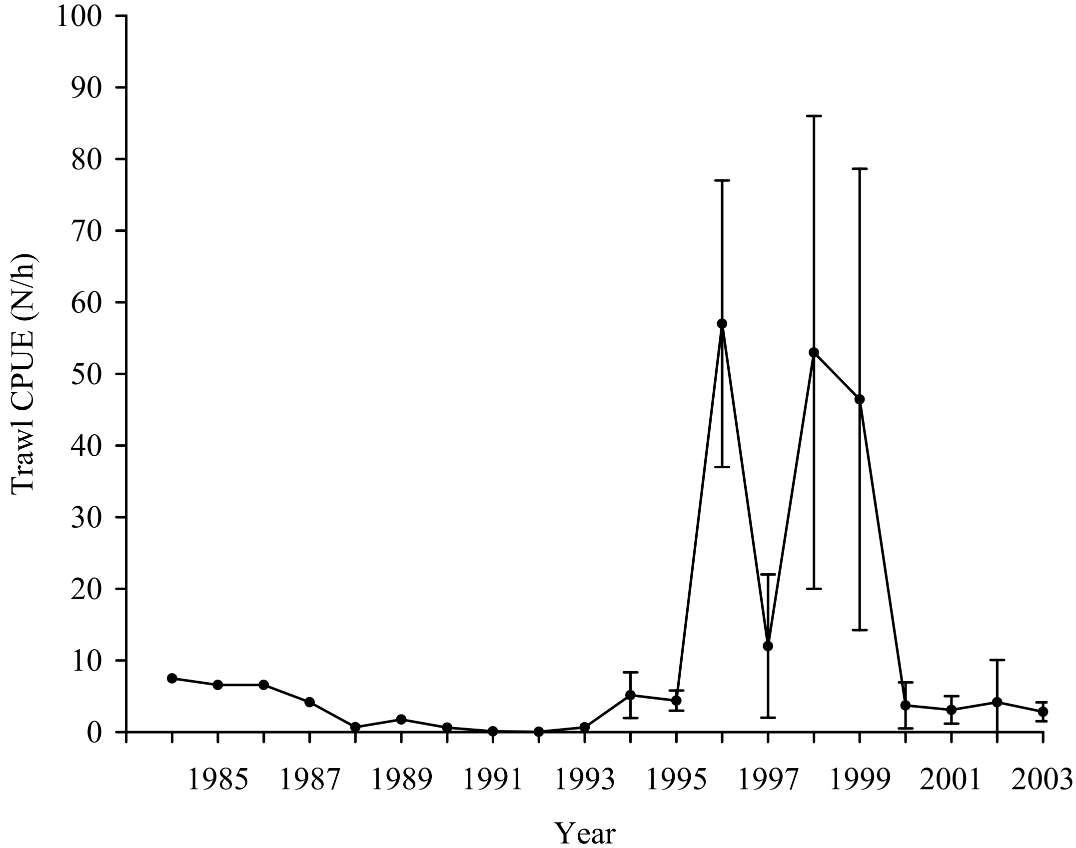

Figure 4-11. Mean annual trawl CPUE of trout-perch age ≥ 1 from pooled sites in Indiana waters of Lake Michigan from 1984 to 2003. The 1984 to1988 data represent pooled sites M and K; the 1989 to 2003 data represent pooled sites M, K, and G. Error bars for 1994 to 2003 are ± 2 SE.

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 stock-size fish in year *t* and quality-size fish in year *t* + 2. This figure differentiates from Figure 4 of Shroyer and McComish (1998) because of the inclusion of *t* = 1995-2001, incorporation of site G beginning with *t* = 1989, and recalculation of stock and quality CPUE for earlier years. The data points for *t* = 1995-2001 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,

$$(2)\ \sqrt{Q_{t+2}} = 3.18 + 0.0044 \bullet S_t \qquad \text{(adjusted } R^2 = 0.62)$$

Model (2) predicts with 95% confidence that quality CPUE will be less than 56 fish/h from 2003 through 2004.

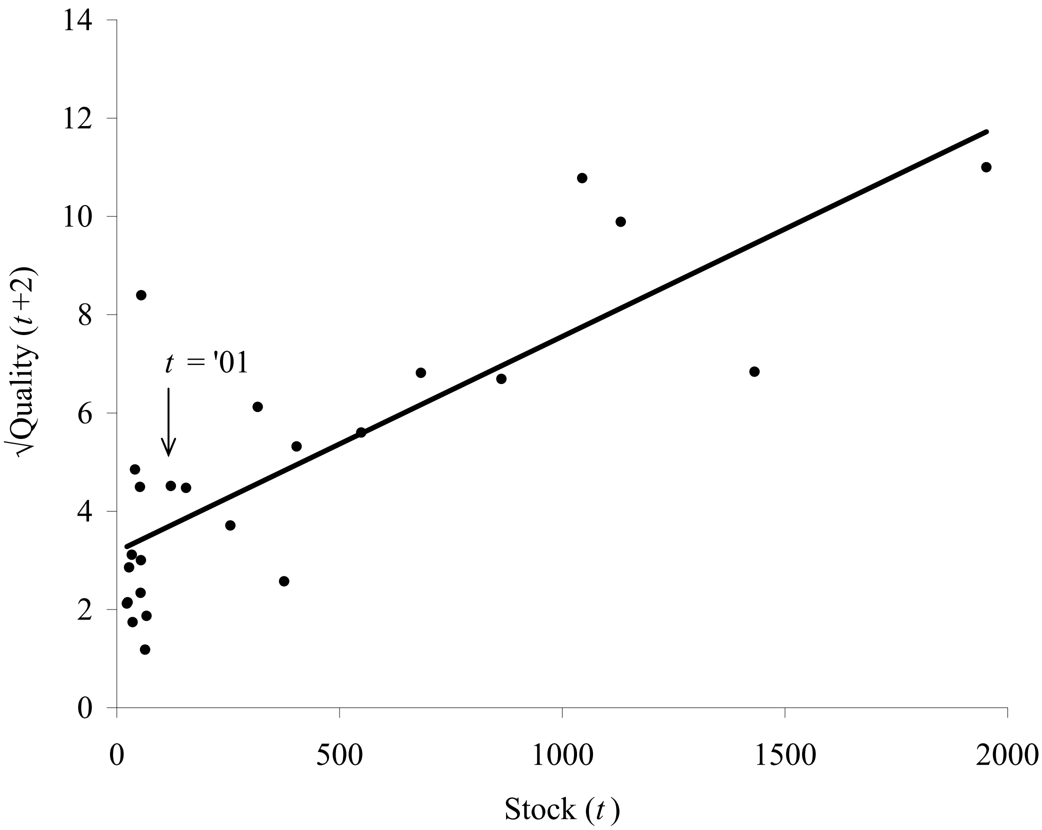

Figure 5-1. Relationship between trawl CPUE (number/h) of stock-size yellow perch in year *t* and the square root of trawl CPUE (number/h) of quality-size yellow perch in year *t* + 2 at sites M, K, and G in Indiana waters of Lake Michigan. *t* = 1975 to 1979, 1981, and 1983 to 2001. Gaps in the time series are due to a lack of index trawl data for *t* = 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 1984-1996 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 $t = 2001$. Although the $t = 2001$ data point stands out slightly from earlier data points, the 95% confidence intervals for the slope and intercept of the updated regression line includes the slope and intercept of model (3), indicating no significant difference. The updated model for pooled sites M, K, and G is:

$$(4)\ \log_e R_{t+2} = 9.71 - (1.60)\ \log_e A_t \qquad (\text{adjusted } R^2 = 0.55)$$

Model (4) predicts with 95% confidence that age-2 CPUE of the 2002 year class in 2004 will be below 73/h. It appears likely yellow perch recruitment for the 2002 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

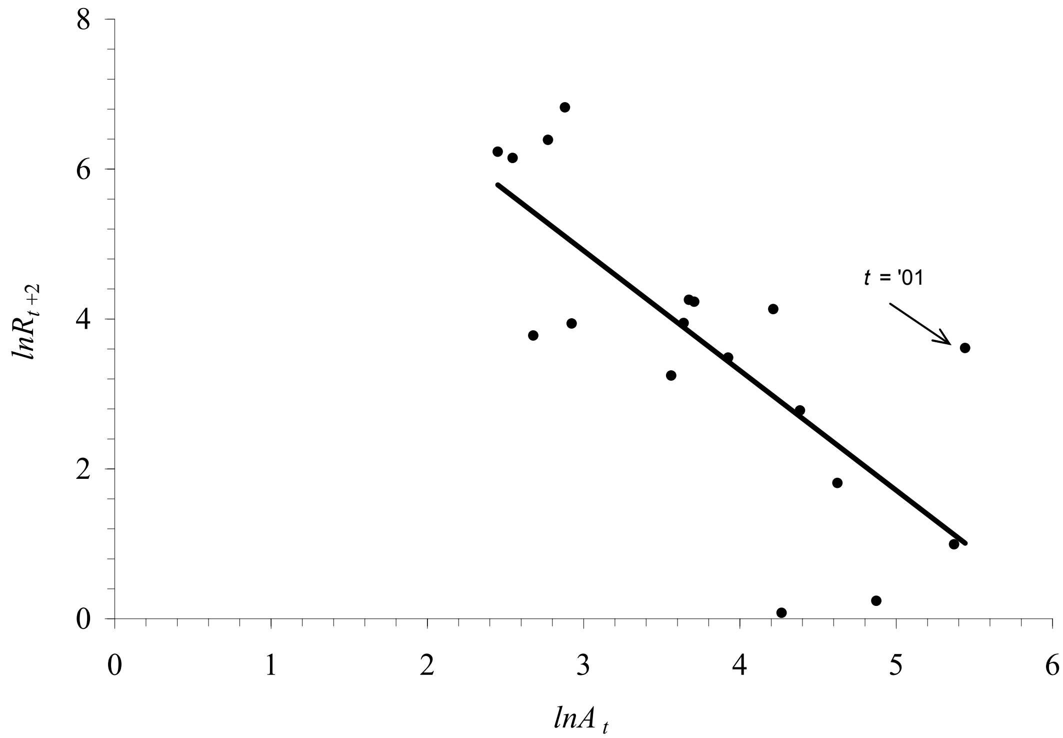

Figure 5-2. Relationship between trawl CPUE (number/h) of age-1 and older alewives in year t (A_t) and trawl CPUE (number/h) of age-2 yellow perch in year $t+2$ (R_{t+2}) at sites M, K, and G in Indiana waters of Lake Michigan. t = 1984 to 2001.

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 which incorporated $t = 2000$. 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 $t =$ 1984-1999 resulted in the model:

$$(5)\ \log_e\left(\frac{R_{t+2}}{S_t}\right) = 6.62 - 0.0186 S_t - 1.42 \log_e A_t$$

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: $A^2 = 0.425$; $P = 0.282$), residual plots did not indicate substantial lack of fit or non-constant variance, and residuals were not significantly autocorrelated (Durbin-Watson statistic = 0.91; $P > 0.05$). Regression statistics for model (5) are listed in Table 5-1. The adjusted R^2 for this model is 0.39, compared to 0.55 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) is convenient for estimating recruitment. It predicts that trawl CPUE of the 2002 year class at age 2 is estimated to be less than 1/h (95% prediction interval: .01/h to 12.3/h). However, it is likely that recruitment of the 2002 year class will be greater than the upper end of the prediction interval based on catch rates of the cohort at age 1

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 = 1984-2001.

Regression Statistics	
Multiple R	0.680
R Square	0.463
Adjusted R Square	0.391
Standard Error	1.517
Observations	18

ANOVA

	df	*SS*	*MS*	*F*	*P*
Regression	2	29.774	14.887	6.461	0.0095
Residual	14	34.561	2.304		
Total	16	64.335			

	Coefficients	*SE*	*t*	*P*	Lower 95% C. I.	*Upper 95% C. I.*
Intercept	6.616	1.726	3.834	0.00163	2.938	10.295
S t	-0.019	0.010	-1.810	0.090	-0.041	0.003
loge$A$ t	-1.425	0.408	-3.496	0.00325	-2.293	-0.556

(see Job 3). 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.

We have recently 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.

We will continue to analyze other biotic and abiotic factors that may help to explain additional variability observed in the alewife/stock/recruitment relationship. For example, we plan to examine the impact that air and water temperature may have on recruitment particularly during the critical spawning period. In addition, fecundity will be looked at as a replacement for stock (all fish 200 mm and larger). This approach would be an improvement by eliminating males as part of the reproductive stock. Not only can we gain insight on how females at differing lengths will impact recruitment but it will help in the management and conservation of valuable spawning stock needed for successful recruitment.

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). We continue to update the model on an annual basis using the most recent available data collected. The model has been modified to represent a type II fishery (Ricker 1975) where natural and fishing mortality occur at the same time. Furthermore, we recalculated natural mortality to differentiate only between the sexes rather than sexes and ages and added within the model a formula annotation for the growth function which mathematically remained unchanged. A mathematical interpretation of the modified 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 we calibrated the model using data starting in 1986. The resulting direct relationship between actual and predicted CPUE is described by the equation, Actual = 1.05 * (Predicted) – 104.14 with an r^2 = 0.87. The updated model provided a slightly stronger relationship than its predecessor.

We continue to update the model on a yearly basis using the data collected from annual sampling. Although we have been successful in the development of the model, we continue to seek ways to improve upon the earlier versions of the model. We are currently investigated the possibility of including sub-models which would establish length frequencies for both males and females of each age class. This may allow a more realistic approach to computing length at age which would allow for variability rather than assuming all fish of a given age and sex are of the same length. Furthermore, this will allow the incorporation of length specific fecundity which might provide for a better understanding of a spawner-per-recruit relationship.

References

Allen, P. J. 2000. A computer simulation model for the yellow perch population in the Indiana waters of Lake Michigan. Master's thesis, Ball State University, Muncie, Indiana.

Allen, P. J., T. E. Lauer, and T. S. McComish. 2002. Dynamics and models of the yellow perch in Indiana waters of Lake Michigan and near-shore fish community characteristics. Report of Ball State University to Division of Fish and Wildlife, Indiana Department of Natural Resources, Indianapolis.

Bagenal, T. B. and E. Braum. 1971. Eggs and early life history. Pages 166-198 in W. E. Ricker, editor. Methods for assessment of fish production in fresh waters. Blackwell Scientific Publications, Oxford and Edinburgh.

Baker, E. A. 1989. A comparative age analysis of yellow perch from Indiana waters of Lake Michigan using scales and opercular bones. Master's thesis, Ball State University, Muncie, Indiana.

Baker, E. A., and T. S. McComish. 1998. Precision of ages determined from scales and opercles for yellow perch *Perca flavescens*. Journal of Great Lakes Research 24:658-665.

Brown, E. H., Jr., and G. W. Eck. 1992. Density-dependent recruitment of the bloater (*Coregonus hoyi*) in Lake Michigan. Polish Archives of Hydrobiology 39:289-297.

Brown, E. H., Jr., R. L. Argyle, R. Payne, and M. E. Holey. 1987. Yield and dynamics of destabilized chub (*Coregonus* spp.) populations in Lakes Michigan and Huron, 1950-84. Canadian Journal of Fisheries and Aquatic Sciences 44 (Supplement 2):371-383.

Cwalinski, T. A. 1996. Simulated forecasting of yellow perch (*Perca flavescens*) relative population density for Indiana waters of Lake Michigan: responses to varying harvest and alewife density. Master's thesis. Ball State University, Muncie, Indiana.

Doll, J. C. 2003. A Windows application to compute back-calculations of fish body lengths using Visual Basic 6.0. Master's thesis. Ball State University, Muncie, Indiana

Eck, G. W., and L. Wells. 1987. Recent changes in Lake Michigan's fish community and their probable causes, with emphasis on the role of the alewife (*Alosa pseudoharengus*). Canadian Journal of Fisheries and Aquatic Sciences 44 (Supplement 2):53-60.

Emery, L. 1985. Review of fish species introduced into the Great Lakes, 1819-1974. Great Lakes Fishery Commission Technical Report 45.

Francis, J. T., S. R. Robillard, and J. E. Marsden. 1996. Yellow perch management in Lake Michigan: multi-jurisdictional challenge. Fisheries 21(2):18-20.

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

Jansen, W. A. 1996. Plasticity in maturity and fecundity of yellow perch, *Perca flavescens* (Mitchill): comparisons of stunted and normal-growing populations. Annales Zoologici Fennici 33:403-415.

Jude, D. J., J. Janssen, and G. Crawford. 1995. Ecology, distribution, and impact of the newly introduced round and tubenose gobies in the biota of the St. Clair and Detroit rivers. Pages 447-460 in Munawar, M., T. Edsall, and J. Leach, editors. The Lake Huron ecosystem: ecology, fisheries, and management. Ecovision.

Lauer, T. E., P. J. Allen, and T. S. McComish. 2004. Changes in mottled sculpin and johnny darter trawl catches after the appearance of round goby in the Indiana waters of Lake Michigan. Transactions of the American Fisheries Society 133:185-189.

McComish, T. S., and S. M. Shroyer. 1996. Characteristics of the near-shore non-salmonine fish community in Indiana waters of Lake Michigan, with emphasis on yellow perch. Final project report of Ball State University to Division of Fish and Wildlife, Indiana Department of Natural Resources, Indianapolis.

McComish, T. S., S. M. Shroyer, and T. E. Lauer. 2000. Population characteristics and models of the yellow perch in Indiana waters of Lake Michigan and the community dynamics of major near-shore fish species. Final project report of Ball State University to Division of Fish and Wildlife, Indiana Department of Natural Resources, Indianapolis.

Nikolskii, G. V. 1969. Theory of fish population dynamics as a biological background for rational exploitation and management of fishery resources (translated from Russian by J. E. S. Bradley). Oliver and Boyd, London.

Nalepa, T. F., D. J. Hartson, D. L. Fanslow, G. A. Lang, and S. J. Lozano. 1998. Declines in benthic macroinvertebrate populations in southern Lake Michigan, 1980 – 1993. Canadian Journal of Fisheries and Aquatic Science 55:2402-2413.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Conseil International pour l'Exploration de la Mer. Rapports et Proces-Verbaux des Reunions 39(2):175-192.

Pothoven, S.A., T.F. Nalepa, and S.B. Brandt. 2000. Age-0 and age-1 yellow perch diet in southeastern Lake Michigan. Journal of Great Lakes Research 26:235-239.

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

Sapp, S. A. 1999. Population trends of major near-shore fish species in Indiana waters of Lake Michigan. Master's thesis. Ball State University, Muncie, Indiana.

Shroyer, S. M., and T. S. McComish. 1998. Forecasting abundance of quality-size yellow perch in Indiana waters of Lake Michigan. North American Journal of Fisheries Management 18:19-24.

Shroyer, S. M, and T. S. McComish. 2000. Relationship between alewife abundance and yellow perch recruitment in southern Lake Michigan. North American Journal of Fisheries Management 20:208-213.

Smith, S. H. 1970. Species interaction of the alewife in the Great Lakes. Transactions of the American Fisheries Society 99:745-765.

Treasurer, J. W. 1981. Some aspects of the reproductive biology of perch (*Perca fluviatilis* L.) fecundity, maturation and spawning behaviour. Fish Biology 18:729-740.

Truemper, H. A. 2003. Food habits and prey size-selection of yellow perch in extreme southern Lake Michigan, with emphasis on the prey: round goby. Master's thesis. Ball State University, Muncie, Indiana.

Tsai, C. and G. R. Gibson. 1971. Fecundity of the yellow perch, (*Perca flavescens*) Mitchill, in the Patuxent River, Maryland. Chesapeake Science 12:270-284.

Weimer, M., and M. Sowinski. 1999. Diet of the round goby (*Neogobius melanostomus*) in Lake Erie. Dreissena 10:7-12.

Wells, L. 1977. Changes in yellow perch (*Perca flavescens*) populations of Lake Michigan, 1954-75. Journal of the Fisheries Research Board of Canada 34:1821-1829.

Wells, L., and A. L. McLain. 1973. Lake Michigan: man's effects on native fish stocks and other biota. Great Lakes Fishery Commission Technical Report 20.

Appendix

Appendix 2-1. Mean back-calculated total lengths (mm) of male yellow perch from pooled sites in Indiana waters of Lake Michigan in 2003.

Year			Total length (mm) at annulus															
class	Age	*N*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2002	1	66	68															
2001	2	50	75	116														
2000	3	11	76	113	138													
1999	4	20	74	112	142	157												
1998	5	152	80	125	156	176	190											
1997	6	37	86	147	181	203	220	232										
1996	7	16	80	129	159	179	195	210	221									
1995	8	12	83	133	166	189	206	225	234	243								
1994	9	6	87	140	173	192	204	222	233	242	250							
1993	10	3	72	121	156	179	194	212	225	236	249	257						
1992	11	1	107	161	189	203	220	227	240	246	251	256	260					
1991	12	0																
1990	13	2	87	129	163	180	192	200	215	228	234	242	247	251	254			
All Classes			78	126	159	180	197	224	227	240	247	251	251					
N		376	376	310	260	249	229	77	40	24	12	6	3	2	2			

Appendix 2-2. Mean back-calculated total lengths (mm) of female yellow perch from pooled sites in Indiana waters of Lake Michigan in 2003.

Year			Total length (mm) at annulus															
class	Age	*N*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2002	1	77	71															
2001	2	83	76	123														
2000	3	27	80	129	155													
1999	4	33	83	128	166	196												
1998	5	311	84	135	177	205	232											
1997	6	73	87	148	202	233	261	284										
1996	7	25	84	146	196	228	257	274	290									
1995	8	24	86	149	203	236	268	287	301	313								
1994	9	6	79	149	203	243	265	289	302	314	322							
All Classes			82	136	181	212	241	283	296	313	322							
N		659	659	582	499	472	439	128	55	30	6							

Appendix 2-3. Standard errors (SE) of mean back-calculated total lengths (mm) of male yellow perch from pooled sites in Indiana waters of Lake Michigan in 2003.

Year			Total length (mm) at annulus															
class	Age	*N*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2002	1	66	1.1															
2001	2	50	1.4	2.1														
2000	3	11	4.6	5.7	6.1													
1999	4	20	3.0	5.4	5.5	5.3												
1998	5	152	1.4	2.3	2.7	2.8	3.2											
1997	6	37	2.5	4.3	5.5	5.9	6.6	6.9										
1996	7	16	5.0	7.5	8.2	7.3	7.5	8.8	9.8									
1995	8	12	5.5	8.1	8.7	9.2	9.6	10.0	10.5	10.5								
1994	9	6	5.2	10.6	12.8	16.3	16.9	15.7	16.3	16.6	16.1							
1993	10	3	5.9	17.4	18.2	11.0	7.9	10.4	5.6	7.3	3.2	1.5						
1992	11	1																
1991	12	0																
1990	13	2	0.6	10.3	9.1	7.2	8.9	9.1	9.2	5.5	4.1	1.1	0.9	1.5	2.2			
All Classes			0.8	1.6	2.1	2.2	2.6	4.3	5.5	6.5	7.9	3.2	4.4	1.5	2.2			
N		376	376	310	260	249	229	77	40	24	12	6	3	2	2			

Appendix 2-4. Standard errors (SE) of mean back-calculated total lengths (mm) of female yellow perch from pooled sites in Indiana waters of Lake Michigan in 2003.

Year			Total length (mm) at annulus															
class	Age	*N*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2002	1	77	1.3															
2001	2	83	0.9	1.7														
2000	3	27	1.5	4.4	7.4													
1999	4	33	3.3	5.0	5.6	8.1												
1998	5	311	0.9	1.8	2.2	2.5	2.8											
1997	6	73	1.6	2.7	4.3	4.6	4.9	4.7										
1996	7	25	2.9	5.8	7.8	8.7	10.7	10.5	10.2									
1995	8	24	3.3	4.8	6.7	7.8	8.8	8.7	8.6	8.2								
1994	9	6	7.4	11.1	21.7	25.0	26.1	25.7	21.9	20.6	19.4							
All Classes			0.6	1.2	1.8	2.1	2.4	3.9	6.3	7.6	19.4							
N		659	659	582	499	472	439	128	55	30	6							

Appendix 3-1. Mean annual trawl CPUE (number/h) of both sexes of yellow perch age ≥1 in Indiana waters of Lake Michigan, by year class and year of capture. Data for 1984-1988 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
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

Appendix 3-2. Mean annual trawl CPUE (number/h) for various components of the yellow perch population in Indiana waters of Lake Michigan from 1975 to 2003. Data from 1975 to 1983 are for site K only; 1984 to 1988 data are pooled sites M and K; 1989 to 2003 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	38
2000	59	30	1	1	58	30	36	18	23	13	3.0	3	13
2001	138	84	4	4	134	85	13	9	121	76	5.5	3	4
2002	105	51	142	157	104	51	34	31	71	31	4.5	2	6
2003	474	226	133	161	341	207	199	126	142	99	20.4	11	14

Appendix 3-3. Mean annual trawl CPUE (number/h) of both sexes of yellow perch age ≥1 by length class and age from pooled sites in Indiana waters of Lake Michigan in 2003.

Length class	Age																	
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
50	4.78																4.78	1.4	1.4
60	40.90																40.90	12.0	13.4
70	69.46																69.46	20.4	34
80	49.63																49.63	14.6	48
90	18.11	1.14															19.26	5.7	54
100	2.00	1.41															3.41	1.0	55
110	0.11	2.47															2.58	0.8	56
120		8.03	1.09														9.12	2.7	58
130		8.81	1.43	2.06	0.81												13.11	3.9	62
140		9.66	3.61	1.01	5.31		0.95										20.55	6.0	68
150		4.23	4.76	5.84	8.62	0.28											23.73	7.0	75
160		0.98	0.98	5.42	16.17	0.37	0.06										23.97	7.0	82
170			1.32	2.97	11.03	0.27	0.26	0.26									16.11	4.7	87
180		0.33	0.33	0.94	12.36	0.20			0.19								14.35	4.2	91
190			0.05	0.31	8.72	0.05		0.18									9.32	2.7	94
200				0.55	5.45	0.38	0.02	0.03									6.43	1.9	96
210			0.17	0.17	2.52	0.29	0.06	0.18									3.38	1.0	97
220				0.07	2.55	0.14	0.25										3.01	0.9	98
230			0.05		0.84	0.23	0.05										1.17	0.3	98
240			0.03	0.02	0.53	0.09	0.02	0.02									0.71	0.2	98
250				0.01	0.36	0.17	0.05	0.02	0.02								0.67	0.2	99
260			0.01	0.01	0.18	0.02	0.02		0.01	0.04							0.28	0.1	99
270					0.28	0.05											0.33	0.1	99
280				0.01	0.64	0.21	0.01	0.01									0.89	0.3	99
290				0.07	0.32	0.20	0.01										0.61	0.2	99
300				0.02	0.32	0.15	0.03	0.08	0.02								0.61	0.2	99
310					0.24	0.06	0.11	0.04									0.45	0.13	99
320					0.25	0.23	0.00	0.01									0.50	0.15	100
330					0.17	0.21	0.11	0.28									0.78	0.23	100
340					0.05	0.10	0.02	0.06									0.22	0.1	100
350					0.04	0.04			0.08								0.17	0.05	100
360								0.06									0.06	0.02	100
370									0.06								0.06	0.02	100
Total	184.98	37.07	13.82	19.49	77.79	3.73	2.03	1.24	0.37	0.04		0.00					340.6		
%	54.3	10.9	4.1	5.7	22.8	1.1	0.6	0.36	0.11	0.01		0.00							
Cum%	54	65	69	75	98	99	100	100	100	100		100							

Appendix 3-4. Mean annual trawl CPUE (number/h) of male yellow perch age ≥1 by length class and age from pooled sites in Indiana waters of Lake Michigan in 2003.

Length class (mm)	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
50	2.43																2.43	1.7	2
60	19.42																19.42	13.7	15
70	29.46																29.46	20.8	36
80	24.72																24.72	17.5	54
90	5.89	1.14															7.03	5.0	59
100	0.74	1.00															1.74	1.2	60
110		1.00															1.00	0.7	61
120		4.41	0.61														5.02	3.5	64
130		4.23	0.18	2.06	0.81												7.28	5.1	69
140		3.06	0.95	0.95	5.24		0.95										11.14	7.9	77
150			1.65	3.56	6.86	0.28											12.34	8.7	86
160		0.37		2.07	8.19	0.37											11.00	7.8	94
170				0.79	1.84	0.27	0.26	0.26									3.42	2.4	96
180				0.19	2.56	0.20			0.19								3.15	2.2	98
190			0.05	0.05	0.51	0.05	0.00	0.18									0.83	0.6	99
200				0.01	0.21	0.05	0.02	0.03									0.32	0.2	99
210					0.19	0.04	0.06										0.29	0.2	99
220																			99
230					0.21	0.18											0.39	0.3	100
240					0.06												0.06	0.04	100
250					0.04	0.02	0.02	0.02	0.02				0.03				0.17	0.1	100
260					0.06		0.01			0.04							0.11	0.1	100
270																			100
280					0.12	0.13	0.01	0.01									0.28	0.2	100
290					0.03	0.01	0.01										0.06	0.04	100
300																			
310																			
320																			
330																			
340																			
350																			
360																			
370																			
Total	82.66	15.20	3.44	9.68	26.94	1.60	1.35	0.51	0.21	0.04			0.03				141.7		
%	58.4	10.7	2.4	6.8	19.0	1.1	1.0	0.4	0.1	0.03			0.02						
Cum%	58	69	72	78	97	98	99	100	100	100			100						100

Appendix 3-5. Mean annual trawl CPUE (number/h) of female yellow perch age ≥1 by length class and age from pooled sites in Indiana waters of Lake Michigan in 2003.

Length class	Age																		
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
50	2.35																2.35	1.2	1.2
60	21.48																21.48	10.8	12.0
70	39.99																40.0	20.1	32
80	24.91																24.9	12.5	45
90	12.23																12.2	6.1	51
100	1.25	0.42															1.7	0.8	52
110	0.11	1.47															1.6	0.8	52
120		3.62	0.47														4.1	2.1	54
130		4.58	1.25														5.8	2.9	57
140		6.61	2.66	0.07	0.07												9.4	4.7	62
150		4.23	3.12	2.28	1.76												11.4	5.7	68
160		0.61	0.98	3.35	7.98		0.06										13.0	6.5	74
170			1.32	2.18	9.19												12.7	6.4	81
180		0.33	0.33	0.75	9.80												11.2	5.6	86
190				0.26	8.22												8.5	4.3	91
200				0.53	5.24	0.33											6.1	3.1	94
210			0.17	0.17	2.32	0.26		0.18									3.1	1.6	95
220				0.07	2.55	0.14	0.25										3.0	1.5	97
230			0.05	0.00	0.63	0.05	0.05										0.8	0.4	97
240			0.03	0.02	0.48	0.09	0.02	0.02									0.7	0.3	97
250				0.01	0.32	0.14	0.02										0.5	0.3	98
260			0.01	0.01	0.12	0.02	0.01		0.01								0.2	0.1	98
270					0.28	0.05											0.3	0.2	98
280				0.01	0.52	0.08											0.6	0.3	98
290				0.07	0.30	0.19											0.6	0.3	99
300				0.02	0.32	0.15	0.03	0.08	0.02								0.6	0.3	99
310					0.24	0.06	0.11	0.04									0.4	0.2	99
320					0.25	0.23		0.01									0.5	0.3	99
330					0.17	0.21	0.11	0.28									0.8	0.4	100
350					0.04	0.04			0.08								0.2	0.1	100
360								0.06									0.1	0.03	100
370									0.06								0.1	0.03	100
Total	102.3	21.9	10.4	9.8	50.8	2.1	0.7	0.73	0.16								198.9	100	
%	51.4	11.0	5.2	4.9	25.6	1.07	0.34	0.37	0.08										
Cum%	51	62	68	73	98	99	100	100	100										100

Appendix 3-6. Mean annual gill net CPUE (number/net/night) of both sexes of yellow perch by length class and age from pooled sites in Indiana waters of Lake Michigan in 2003.

Length class	Age																		
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
50																			
60																			
70																			
80																			
90																			
100																			
110																			
120																			
130																			
140																			
150																			
160			0.003	0.02	0.003												0.03	0.07	0
170																			
180		0.01	0.01	0.10	0.79		0.01		0.01								0.92	2.26	2
190			0.02	0.29	4.14	0.05		0.01									4.50	11.12	13
200				0.61	6.02	0.35	0.05										7.03	17.37	31
210			0.21	0.21	3.59	0.35	0.06	0.16									4.59	11.33	42
220				0.11	3.13	0.26	0.25										3.76	9.27	51
230			0.15	0.04	2.41	0.25	0.15	0.00									3.00	7.41	59
240			0.06	0.07	1.70	0.42	0.19	0.21									2.64	6.5	65
250				0.06	1.45	0.67	0.19	0.04	0.04				0.05				2.50	6.2	72
260			0.07	0.11	1.07	0.16	0.09	0.03	0.10	0.06	0.03						1.72	4.26	76
270					1.27	0.18		0.02	0.03								1.50	3.71	79
280				0.10	1.39	0.37	0.03	0.03									1.92	4.73	84
290				0.24	0.72	0.52	0.02										1.50	3.70	88
300				0.08	0.82	0.31	0.05	0.18	0.03								1.47	3.64	92
310					0.51	0.13	0.25	0.09									0.97	2.40	94
320					0.44	0.53	0.00	0.05	0.03								1.06	2.61	97
330					0.12	0.23	0.15	0.25									0.75	1.85	98
340					0.17	0.08	0.16	0.10									0.50	1.24	100
350					0.04	0.02		0.04	0.01								0.11	0.27	100
360						0.03													
370																			
Total		0.01	0.51	2.04	29.80	4.91	1.64	1.20	0.25	0.06	0.03		0.05				40.5		
%		0.02	1.2	5.0	73.6	12.1	4.1	3.0	0.6	0.2	0.1		0.1						
Cum%		0.02	1	6	80	92	96	99	100	100	100								

Appendix 3-7. Mean annual gill net CPUE (number/net/night) of male yellow perch by length class and age from pooled sites in Indiana waters of Lake Michigan in 2003.

Length class (mm)	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
50																			
60																			
70																			
80																			
90																			
100																			
110																			
120																			
130																			
140																			
150																			
160																			
170																			
180				0.01	0.06		0.01		0.01								0.1	2.59	3
190			0.02	0.02	0.18	0.05		0.01									0.3	8.62	11
200				0.01	0.39	0.07	0.05										0.5	16.38	28
210					0.28	0.07	0.06										0.4	12.93	41
220				0.03	0.06	0.08											0.2	5.17	46
230					0.07	0.06											0.1	4.31	50
240					0.19	0.03	0.06	0.08									0.4	11.21	61
250					0.10	0.08	0.04	0.04	0.04				0.05				0.4	11.20	72
260					0.11		0.02	0.03	0.06	0.06	0.03						0.3	9.50	82
270					0.08	0.07		0.02	0.03								0.2	6.03	88
280					0.04	0.07	0.03	0.03									0.2	5.17	93
290					0.04	0.05	0.02										0.1	3.45	97
300					0.03	0.03											0.1	1.72	98
310																			
320						0.06											0.06	1.72	100
330																			
340																			
350																			

Appendix 3-8. Mean annual gill net CPUE (number/net/night) of female yellow perch by length class and age from pooled sites in Indiana waters of Lake Michigan in 2003.

Length class	Age																		
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
130																			
140																			
150																			
160				0.0216	0.003												0.03	0.1	0.1
170																	0.0	0.0	0.1
180		0.01	0.01	0.09	0.73												0.8	2.2	2
190				0.27	3.96												4.2	11.3	14
200				0.60	5.63	0.28											6.5	17.5	31
210			0.21	0.21	3.31	0.29		0.16									4.2	11.2	42
220				0.09	3.07	0.17	0.25										3.6	9.6	52
230			0.15	0.04	2.34	0.19	0.15										2.9	7.7	60
240			0.06	0.07	1.50	0.39	0.13	0.13									2.3	6.1	66
250				0.06	1.35	0.59	0.14										2.1	5.7	71
260			0.07	0.11	0.97	0.16	0.07		0.04								1.4	3.8	75
270					1.19	0.12											1.3	3.5	79
280				0.10	1.35	0.30											1.8	4.7	83
290				0.24	0.68	0.47											1.4	3.7	87
300				0.08	0.80	0.29	0.05	0.18	0.03								1.4	3.8	91
310					0.51	0.13	0.25	0.09									1.0	2.6	94
320					0.44	0.48		0.05	0.03								1.0	2.7	96
330					0.12	0.23	0.15	0.25									0.8	2.0	98
340					0.17	0.08	0.16	0.10									0.5	1.3	100
350					0.04	0.02		0.04	0.01								0.1	0.30	100
360						0.03											0.03	0.07	100
370																			
Total		0.01	0.5	1.97	28.15	4.20	1.35	0.99	0.12								37		
%		0.02	1.3	5.3	75.5	11.3	3.6	2.6	0.3										
Cum%		0.02	1	7	82	93	97	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 2003. Species are listed by descending abundance (alphabetically in cases of ties) in M, K, and G combined catches. Abbreviations: CPUE = catch per unit effort (number/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	987.5	542.1	51.9	683.3	168.7	49.1	372.2	64.8	47.3	681.0	216.5	50.1
Yellow perch	625.2	477.1	32.9	120.8	115.9	8.7	276.2	297.3	35.1	340.7	206.8	25.1
Alewife	232.3	182.4	12.2	347.3	199.7	25.0	117.3	113.7	14.9	232.3	102.5	17.1
Round goby	48.3	55.7	2.5	233.2	141.9	16.8	9.7	8.7	1.2	97.1	67.3	7.1
Trout-perch	3.3	2.3	0.2	1.5	0.7	0.1	3.7	3.2	0.5	2.8	9.0	0.2
Longnose sucker	1.8	1.9	0.1	3.5	3.4	0.3	1.5	1.6	0.2	2.3	1.4	0.2
White sucker	0.8	0.6	0.04	0.5	0.7	0.04	4.83	5.33	0.61	2.1	1.9	0.2
Rainbow smelt	1.8	3.3	0.10	0.8	1.3	0.06	0.83	1.67	0.11	1.2	1.2	0.1
Brown trout[1]	0.83	1.67	0.04	0.17	0.33	0.01				0.3	0.6	0.02
Banded kilifish	0.33	0.67	0.02							0.1	0.2	0.01
Chinook salmon[1]	0.2	0.3	0.01							0.1	0.1	0.004
Common carp							0.17	0.33	0.02	0.1	0.1	0.004
Ninespine stickleback				0.17	0.33	0.0				0.1	0.1	0.004
Totals	1903		100	1391		100	786		100	1360		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 2003. Species are listed by descending abundance (alphabetically in cases of ties) in M, K, and G combined catches. Abbreviations: CPUE = catch per unit effort (number/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	27.1	12.0	67.1	65.0	35.0	89.3	29.4	13.5	86.9	40.5	14.0	82.9
Longnose sucker	9.3	5.9	23.0	5.7	4.6	7.8	0.8	0.7	2.5	5.1	2.7	10.5
White sucker	2.3	2.5	5.6	1.3	1.1	1.8	2.9	2.8	8.6	2.2	1.3	4.4
Chinook salmon	0.5	0.8	1.2	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.5
Alewife	0.2	0.2	0.4	0.3	0.4	0.3	0.2	0.2	0.5	0.2	0.2	0.4
Coho salmon	0.3	0.4	0.6	0.1	0.2	0.1				0.1	0.1	0.2
Round Goby	0.1	0.2	0.2				0.3	0.4	0.7	0.1	0.1	0.2
Steelhead	0.2	0.33	0.4	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.2
Brown trout	0.3	0.4	0.7							0.1	0.1	0.2
Channel catfish	0.1	0.2	0.2	0.2	0.2	0.2				0.1	0.1	0.2
Lake trout				0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.1	0.1
Lake whitefish	0.2	0.2	0.4							0.1	0.1	0.1
Rainbow smelt	0.1	0.2	0.2							0.03	0.1	0.1
Totals	40.4		100.0	72.8		100.0	33.8		100.0	48.9		100.0