Year One 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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Progress Report for 2000-2001

Federal Aid Project F-18-R, Study 11, Year 1

Submitted to:

Indiana Department of Natural Resources

Division of Fish and Wildlife

402 West Washington Street, Room W273

Indianapolis, Indiana 46204-2267

July 2001

PROJECT INFORMATION PAGE

STATE:	Indiana
PROJECT:	Fisheries Research
PROJECT NO.	F-18-R-11
TITLE:	Year One Progress Report: Dynamics and Models of the Yellow Perch in Indiana Waters of Lake Michigan and Near-Shore Fish Community Characteristics
PERIOD COVERED:	July 1, 2000 – June 30, 2001
CONDUCTED BY:	Aquatic Biology and Fisheries Center, Department of Biology, Ball State University, Muncie, Indiana 47306
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FUNDED BY:	Sport Fish Restoration Program and Ball State University

APPROVED BY: ______________________________

Name Date

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Name Date

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Executive Summary

This report represents the first year progress results for the Federal Aid Project F-18-R, Study 11, year 1 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 1984-1999. 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 other near-shore fish species were quantitatively sampled by consistent bottom trawling and gill netting methods at 2-3 index zones in Indiana waters of Lake Michigan from 1984-2000. Relative abundance of yellow perch was extremely low from 1975-1979, increased rapidly to an extremely high level in the mid to late 1980s, then declined rapidly after 1988. By the mid 1990s yellow perch abundance had returned to an extremely low level similar to the late 1970s, and had not significantly increased by 2000. There was 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. Likewise, 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. Dynamics of rainbow smelt *Osmerus mordax* were similar to those of bloaters. As yellow perch, bloaters, and rainbow smelt declined in recent years, not only did abundance of spottail shiners *Notropis hudsonius* increase dramatically, but also newly introduced non-indigenous species began to appear in the catch. Threespine sticklebacks *Gasterosteus aculeatus* were first captured at our index sites in 1993 and became abundant by 1996, but were only caught in low numbers in 1997-2000. The round goby *Neogobius melanostomus* first appeared in the trawl catches in 1998 and became one of the most abundant species in 1999 and 2000. We suspect round gobies may be negatively impacting some indigenous bottom-dwelling species such as sculpins (*Cottus*) and johnny darters *Etheostoma nigrum*, as we have seen a negative relationship in the abundance of gobies and the other two species. However, their potential interaction with yellow perch remains unclear. Another non-indigenous fish species of concern is the white perch *Morone americana*, which first appeared in our catches in 1997 and continued to be caught occasionally through 1999, although none were caught in 2000. If white perch become abundant, they will probably have a negative effect on yellow perch.

Growth rates of the 1983-2000 year classes of yellow perch varied greatly, and were inversely related to population density. 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 density, growth rates of post-1992 cohorts, including the 2000 year class, were unusually high: average females exceeded 200 mm by age 3, and males by age 3 or 4.

Relative abundances of the 1981-1998 yellow perch year classes at age 2 were extremely variable: the strongest year classes were over 800 times more abundant than the weakest year classes. The 1989-1998 year classes were all extremely weak in comparison to the 1983-1986 and 1988 year classes.

Yellow perch length and age structures of the index catches were highly dynamic over the years due to variable recruitment, modal progression, and high total mortality rates. Sex ratios of cohorts were apparently near 50:50 at age 1, but often became skewed at older ages due to sexual differences in total mortality rates. Because females reached exploitable size at a younger age than males, intense exploitation tended to shift the sex ratio in favor of males and truncate the age frequency of females. In addition, maturity of females did not exceed 50% until they reached 180-220 mm, compared to 100-110 mm for males.

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. Abundance of stock-size (≥ 130 mm) yellow perch in 1998-2000 indicated that abundance of quality-size (≥ 200 mm) yellow perch would remain relatively low in 2001-2002. The recruitment models predicted 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. However, the actual strength of the 1998 year class at age 2 was "extremely weak". It also appears the 1999 years class will also fall into this same category as age 1 catches during 2000 were also low. Continued index sampling in 2001 will be necessary to reliably establish the 1999 year class strength, but it appears unlikely the 1999 year class will do much to increase current population densities of the yellow perch in southern Lake Michigan. Recruitment of the 2000 year class to age 2 is likely to be extremely weak as the alewife abundance in 2000 was > 200/hr, exceeding the highest value 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. However, if future alewife abundance is low, the population might rebound relatively quickly as it did in the early 1980s. Although harvest and commercial bycatch tended to suppress abundance of yellow perch age ≥ 2, they generally did not substantially change long-term trends due to the overwhelming effect of alewife abundance. Our modeling predicts 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.

Introduction

This progress report documents completion of all 2000-2001 objectives for Indiana Federal Aid Project F-18-R, Study 11, Year 1 for the period July 1, 2000 to June 30, 2001. Research completed in 2000-2001 has added to the valuable long-term fish population data set begun in the 1970s, contributing to increased understanding of dynamics of the yellow perch *Perca flavescens* and other species including the nonindigenous alewife *Alosa pseudoharengus*, threespine stickleback *Gasterosteus aculeatus*, white perch *Morone americana*, and round goby *Neogobius melanostomus*. Based on interactions with other members of the Great Lakes Fishery Commission's Lake Michigan Yellow Perch Task Group, our data set is the most comprehensive in existence for post-larval yellow perch in Lake Michigan excluding Green Bay. Thus, its significance extends well beyond the borders of Indiana. Results of our long-term population monitoring provide valuable basic information to fisheries researchers, managers, and resource users throughout the Great Lakes region.

The report is organized by project job titles to provide easy access to specific research topics. It is available in both the bound form and a new electronic copy in the Adobe® Acrobat® (.pdf) version. The Acrobat® version is complete with bookmarks and hyperlinks that facilitate navigation among jobs, topics, tables, figures, appendices, and references. Simply point the "hand tool" at a bookmark or hyperlink, then click to jump to the desired location in the document. Click the Back (Previous View) button on the toolbar to return to your previous location. You may need to change the Zoom level to facilitate viewing the pages. The report will be available on a new Ball State University, Aquatic Biology and Fisheries Center web site in the fall of 2001 or by contacting the authors.

Financial support for the project was from the Dingell-Johnson Federal Aid in Sport Fish Restoration Act, with Ball State University providing matching funds.

Acknowledgments

We gratefully acknowledge the strong continued support of the Fisheries Section, Division of Fish and Wildlife, Indiana Department of Natural Resources (IDNR). Thanks are extended to all IDNR staff who have been involved with the project, especially Bill James, Gary Hudson, Randy Lang, John Kubisiak, Brian Breidert, and Janel Palla. Thanks are also due to the staff of the Indiana Division of Fish and Wildlife, Lake Michigan Headquarters for graciously providing launch facilities, storage space, and living quarters during field operations.

We appreciate Ball State University's contribution of equipment, facilities, and matching support funds. We thank all the Ball State staff whom assisted in one way or another with the project, particularly those in the Department of Biology, Office of Academic Research and Sponsored Programs, and Contracts and Grants Office. Zachary J. Willenberg and Jason Doll assisted with field and lab work during 2000.

A special recognition goes to Steven M. Shroyer for the dedicated years of service to Ball State University and the contributions he made towards this project.

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 were the same in 2000 as described in detail by McComish et al. (2000). As in past 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 to established sampling period protocol (Table 1-1). Total night-time trawl effort was 18 h and total gill net effort was 18 net-nights.

Trawl and gill net catches in 2000 were processed and recorded both electronically and on paper as described by McComish et al. (2000). Temperature profiles and secchi readings were recorded manually on paper and entered into computer files by one BSU Aquatic Biology and Fisheries student. All other research data (lengths, weights, numbers, etc.) were recorded using electronic devices and then downloaded into database files. The use of Palm Pilots™ has improved efficiency by reducing the time required and human error associated with transcribing data from hard copy data collection sheets 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 analysis.

Table 1-1. Dates of trawl and gill net sampling at three index sites in Indiana waters of Lake Michigan, IN in 2000. Gill nets were set about 1900 hours on a given date and pulled about 0700 hours the next morning. Horizontal lines separate semimonthly sample periods.

Date	Site	Trawl	10-m Gill Net	15-m Gill Net
6/01/00	M	+	+	+
6/06/00	G	+	+	+
6/07/00	K	+	+	+
6/19/00	M	+	+	+
6/20/00	K		+	+
6/21/00	G	+	+	+
6/22/00	K	+		
7/05/00	G	+		
7/06/00	G		+	+
7/10/00	M	+	+	+
7/11/00	K	+	+	+
7/19/00	M	+	+	+
7/24/00	G	+	+	+
7/25/00	K	+	+	+
8/01/00	K	+	+	+
8/07/00	G	+	+	+
8/08/00	M	+	+	+
8/16/00	M	+	+	+
8/17/00	K	+		
8/22/00	G	+	+	+
8/23/00	K		+	+

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

Methods

Methods of yellow perch age and growth analysis in 2000 were similar to those described by McComish et al. (2000). We continued to age fish using opercles because opercle ages are more precise than scale ages, and opercles can be easily used to back-calculate lengths at annuli (Baker and McComish 1998). However, annular increments were measured differently than in previous years. An image of each opercle was taken using a Panasonic® digital camera (model # WV-CP230) attached to a stereoscopic zoom microscope (10x magnification), captured with Snappy 4.0 video snapshot, and saved using Kodak Imaging for Windows software. A straight-line mark was imposed on each image from the focus to the edge, with cross markings denoting each annulus. The distance from the focus to each annulus was measured using a digitizer, with subsequent values entered into DisBcal 89. 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 690 age ≥1 fish sub-sampled from trawl and gill net catches at sites M, K, and G from June to August 2000. Within the aged sub-sample, 213 (31%) were males and 477 (69%) 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

Males up to age 14 and females up to age 7 were present in the aged sub-sample, with fish older than age 7 rare (Appendices 2-1 and 2-2). As in past years, females grew faster than males, and were significantly larger beginning at age 2 (Figure 2-1). Females and males reached stock size (≥130 mm) by age 2 and 3, respectively. Females reached quality size (≥200 mm) by age 3, and males by age 4.

Mean lengths at last annuli of successive age classes (Figure 2-1) should not be interpreted as absolute growth curves because younger cohorts, especially males, are apparently following different curves when compared to recent cohorts of older fish. For example, in 2000 age 6 males were larger than age 7 males. It is uncertain whether younger cohorts will reach substantially larger asymptotic lengths than older cohorts, or reach similar maximum lengths at younger ages. This question 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 at last annuli of the separate sexes from 1976-1998 show varied trends (Figure 2-2). Only ages 1-4 are used in the display because older ages were not found 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 1995-1999, 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 attained quality size by age 3 in 1976 and 1996-2000, by age 4 in 1977-1979, 1984, and 1995-2000, and beyond age 4 in other years.

Mean lengths of both sexes at ages 2 to 4 varied somewhat in 2000 from their recent peaks (Figure 2-2). Age 3 females reached a mean length that was the highest recorded since the 1970s. Mean lengths of males and females at age 1 have shown a slight increasing trend after 1991, although they have not reached the lengths of the 1970s

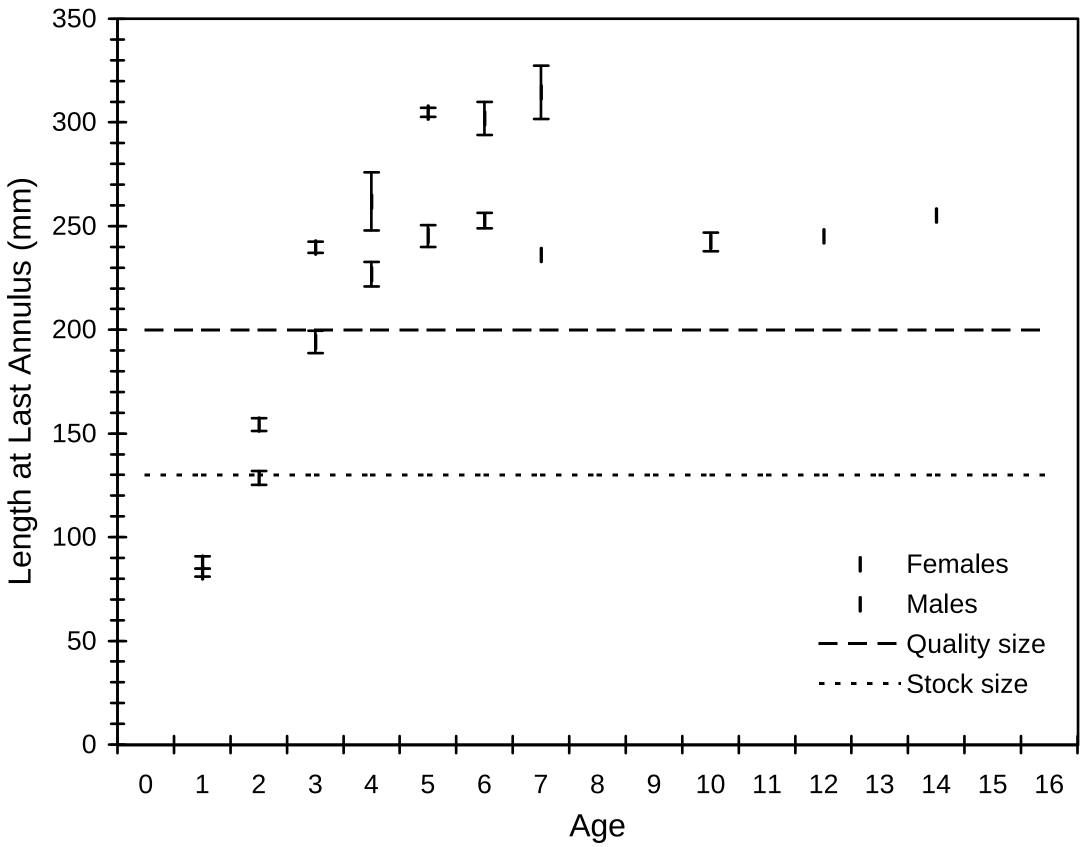

Figure 2-1. Mean back-calculated lengths at last annuli of individual age classes of male and female yellow perch collected from sites M, K and G in Indiana waters of Lake Michigan in 2000. Error bars represent ± 2 SE. Data points without error bars represent only one fish.

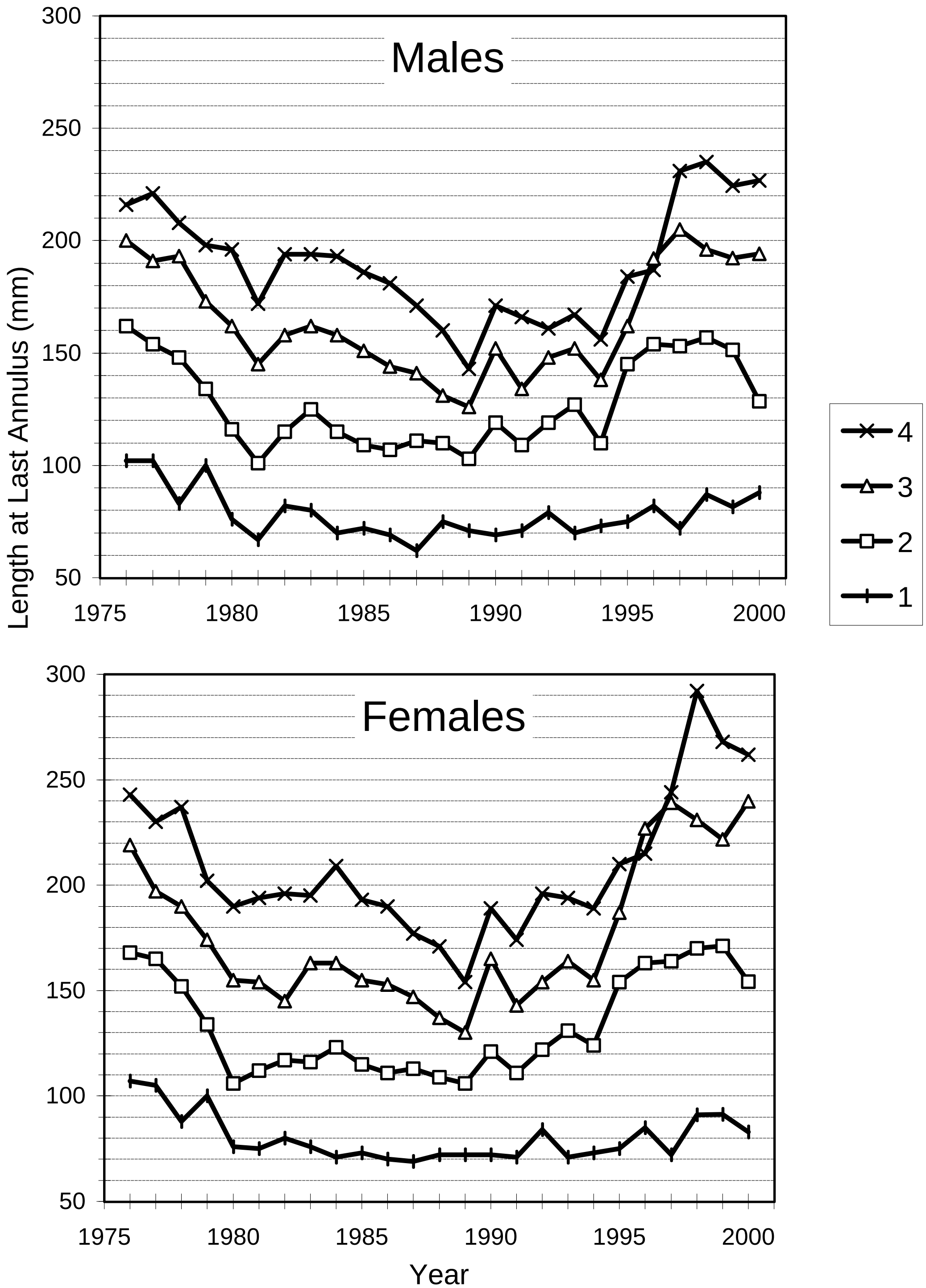

Figure 2-2. Mean back-calculated lengths at last annuli of male and female yellow perch ages 1-4 collected in Indiana waters of Lake Michigan, 1976-2000.

when the density of the yellow perch population was low, *See Job 3*. This suggests growth conditions during the first year of life may be less favorable now than they were in the 1970s, while conditions during the third year may be more favorable.

Growth rates of the 1983-1999 year classes of each sex differed greatly, and recent cohorts were substantially longer at given ages than earlier cohorts (Tables 2-1 and 2-2). Average male length of the 1993-1996 cohorts reached quality size (≥ 200 mm) by age 2, 3, or 4 as compared to age 5 for the 1991-1992 cohorts, age 6 for the 1989-1990 cohorts, and age 7 or 8 for the 1983-1988 cohorts. Trends for female cohorts were similar. Average females of the 1993-1997 cohorts reached quality size (≥ 200 mm) by age 3, compared to age 4 for the 1991-1992 cohorts and age 5 or 6 for earlier cohorts.

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).

Tables 2-3 and 2-4 list von Bertalanffy growth parameters estimated from the data in Tables 2-1 and 2-2. Estimates for the 1992-1996 year classes are provisional because they are based on only 4-8 annuli. Nonetheless, the parameters seem to suggest the 1993-1996

Table 2-1. Mean lengths at annuli 1-9 for male yellow perch collected from sites M, K, and G in Indiana waters of Lake Michigan in 1984-2000. 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	
1992	70	110	162	187	202	213	230		
1993	73	145	192	231	226	240	236		
1994	75	154	205	235	251	253			
1995	82	153	196	224	245				
1996	72	157	192	227					
1997	87	151	194						
1998	82	129							
1999	88								

Table 2-2. Mean lengths at annuli 1-9 for female yellow perch collected from sites M, K, and G in Indiana waters of Lake Michigan in 1984-2000. 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		
1994	75	163	239	292	307	302			
1995	85	164	231	268	305				
1996	72	170	222	262					
1997	91	171	240						
1998	91	154							
1999	83								

Table 2-3. Von Bertalanffy growth parameters and coefficients of determination (R^2) for the 1983-1996 year classes of yellow perch males in Indiana waters of Lake Michigan, fitted to the data in Table 2-1 by the Marquardt-Levenburg method of nonlinear least squares. Estimates for the 1992-1996 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	292	0.206	-0.561	0.980
1992	256	0.320	0.047	0.992
1993	245	0.613	0.445	0.988
1994	269	0.555	0.421	0.998
1995	277	0.438	0.197	0.999
1996	256	0.603	0.480	0.994
Means	255	0.341	-0.136	0.985

Table 2-4. Von Bertalanffy growth parameters and coefficients of determination (R^2) for the 1983-1996 year classes of yellow perch females in Indiana waters of Lake Michigan, fitted to the data in Table 2-2 by the Marquardt-Levenburg method of nonlinear least squares. Estimates for the 1992-1996 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	349	0.372	0.380	0.991
1994	338	0.506	0.536	0.986
1995	396	0.305	0.214	0.999
1996	314	0.505	0.491	0.999
Means	418	0.217	-0.174	0.988

year classes may reach similar ultimate lengths as earlier cohorts, but at younger ages due to substantial increases in *K* from earlier years. Subsequent data will provide additional basis for this observation.

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 was 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. A standard classification system for yellow perch year class strength was developed based on age-2 CPUEs. Year classes were categorized from extremely weak to extremely strong based on previous work (Shroyer and McComish 1999) using values from the range of observed values for 1981-1998 (Figure 3-1; Appendix 3-1). The 2000 collection data revealed the 1998 year class marked the tenth consecutive extremely weak year class. The 1999 year class was not yet fully vulnerable to the trawl in 2000, but its CPUE at age 1 (3/h), was similar to age 1 fish caught in 1993 and 1997 (Appendix 3-1). The strength of the 2000 year class remains uncertain, but the 2000 age-0 yellow perch CPUE of 0.9/h was one of the lowest recorded since 1975 (Appendix 3-2).

Mortality Rates

Annual total mortality rates (A; Ricker 1975) of yellow perch age ≥1 were estimated using pooled males and females because catch records in most years prior to 1993 did not allow individual sex 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 was about 50-60% for ages 2-6 and about 70% or higher for older ages (Table 3-1). The second method used catch curve analysis (Ricker 1975) of individual

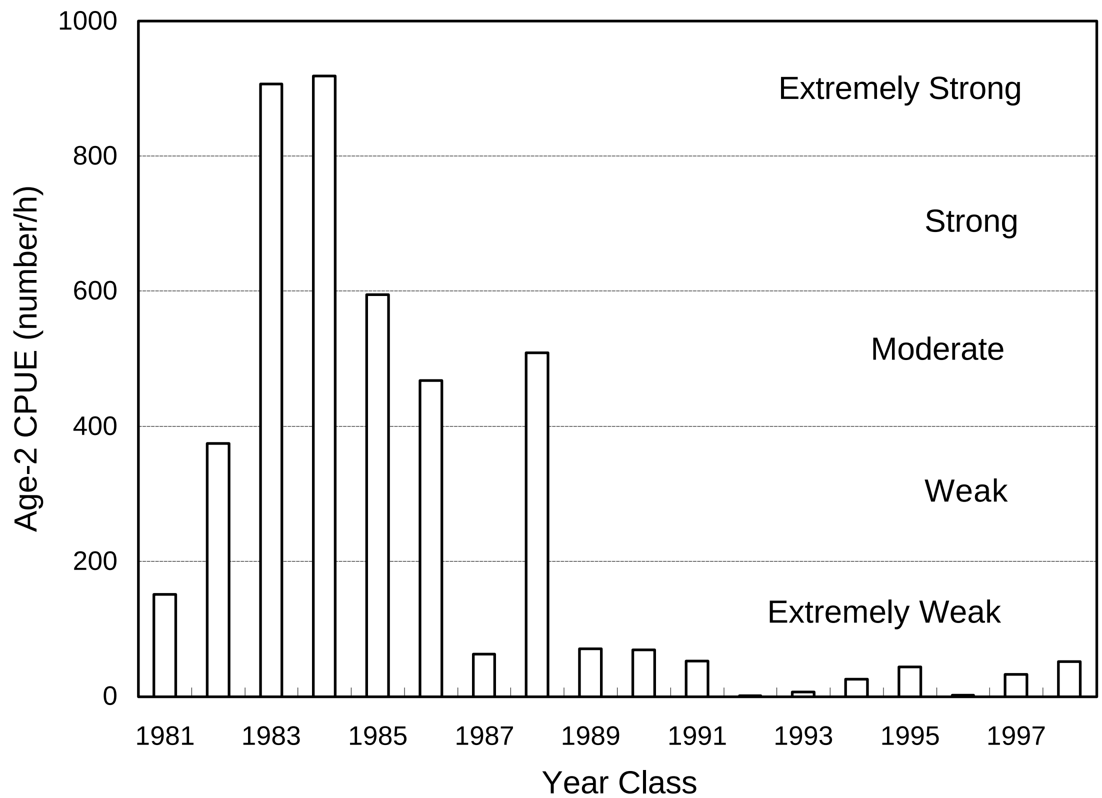

Figure 3-1. Relative strengths of the 1981-1998 year classes of yellow perch in Indiana waters of Lake Michigan based on mean June-August trawl CPUE of age 2 fish at pooled sites M, K, and G.

Table 3-1. Annual total mortality rates (*A*) of the 1980-1997 yellow perch cohorts at sites M, K, and G in Indiana waters of Lake Michigan, based on decreases in 1984-2000 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	Mean	Med.
2-3			4	47	51	14	73		60	39		80		25	85	68		90	53	55
3-4		35	70	34		72	55	7	61		67	31		74	74	27	95		54	61
4-5	69	91	67		79	52	37	54	2	46	79		55	72		94			61	67
5-6	90	56	18	69	55	74	40	30	39	92		92	96	3	97				61	62
6-7				70	86	41	51	73	97	26	86	91							69	73
7-8				95	75	56	68	99		90	84								81	84
8-9				35	82	94	99		83	87	48								76	83
Mean	79	61	40	58	71	58	61	53	57	63	73	73	76	44	85	63	95	90	65	
Med.	79	56	42	58	77	56	55	54	60	67	79	86	76	49	85	68	95	90		67

cohorts over successive years and is probably more accurate for comparing individual cohorts. Catch curve analysis revealed mean *A* of the 1982-1996 cohorts at ages ≥2 ranging from 57-74% (Table 3-2). Estimated overall mean *A* for ages ≥ 2 was approximately 65% when calculated using both methods (Tables 3-1 and 3-2).

We calculated mortality rates for separate sexes of recent cohorts for which sex-specific CPUE was available (Table 3-3). Results reveal major sexual differences in the various components of mortality (instantaneous rate of mortality (*Z*), instantaneous rate of fishing mortality (*F*), instantaneous rate of natural mortality (*M*), conditional rate of fishing mortality (*m*), conditional rate of natural mortality (*n*), expectation of capture by man (*u*), and expectation of natural death (*v*) Ricker (1975)) for the 1991-1996 year classes. Total mortality showed an increasing trend for males, while females tended to fluctuate about means of 1.04 and 0.65 for *Z* and *A*, respectively (Table 3-3). Fishing mortality values (*F*, *m*, and *u*) appeared to show a decreasing trend for females starting with the 1991 year class, while males generally seemed to show an increasing trend (Table 3-4). Instantaneous fishing mortality (*F*) was extremely low for males of the 1993 year class, increased for the 1994 and 1995 cohorts, and dropped sharply for the 1996 cohort. Instantaneous fishing mortality of females decreased dramatically from the 1991 to the 1994 cohorts, nearly doubled for the 1995 year class, then decreased sharply for the 1996 cohort. Natural mortality values (*M*, *n*, and *v*) were higher for males than for females due to lower L_∞ and higher *K* (Tables 2-3 and 2-4). However, trends in natural mortality were somewhat similar for both sexes which is largely explained by density-dependent changes in *K*. Natural mortality increased sharply from the 1991 through 1993 or 1994 cohorts, then decreased for the 1995 cohorts and increased again for 1996.

Table 3-2. Total mortality and survival rates of the 1982-1996 yellow perch cohorts (combined sexes) at sites M, K, and G in Indiana waters of Lake Michigan, based on catch curve analysis of individual cohorts at ages 2-9 in 1984-2000 trawl catches. The nearly-absent 1992 year class has not been captured in sufficient numbers for meaningful analysis. 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
1993	0.83	0.43	0.57	5	0.94
1994	1.23	0.29	0.71	5	0.83
1995	1.34	0.26	0.74	4	0.87
1996	1.11	0.33	0.67	3	0.50
Mean	1.03	0.36	0.64	7	0.87
Median	1.05	0.35	0.65	8	0.87

Table 3-3. Total mortality and survival rates of the 1991-1996 cohorts of male and female yellow perch at sites M, K, and G in Indiana waters of Lake Michigan, based on catch curve analysis of individual cohorts at ages 2-9 in 1993-2000 trawl catches. The nearly-absent 1992 year class has not been captured in sufficient numbers for meaningful analysis. Symbols follow Ricker (1975). The value of *N* is the number of data points (years) in the catch curve.

	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
1993	0.96	0.38	0.62	5	0.91	1.05	0.35	0.65	6	0.87
1994	1.57	0.21	0.79	5	0.81	1.05	0.35	0.65	5	0.77
1995	1.95	0.14	0.86	4	0.83	1.13	0.32	0.68	4	0.85
1996	1.07	0.34	0.66	3	0.39	0.93	0.39	0.61	3	0.47
Mean	1.22	0.32	0.68	5	0.75	1.04	0.35	0.65	5	0.76
Median	1.07	0.34	0.66	5	0.81	1.05	0.35	0.65	5	0.77

Table 3-4. Estimated fishing and natural mortality rates of the 1991-1996 cohorts of male and female yellow perch at sites M, K, and G in Indiana waters of Lake Michigan. 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	0.38	0.41	0.32	0.33	0.26	0.28	0.78	0.25	0.54	0.22	0.49	0.16
1992		0.56		0.43				0.31		0.27		
1993	0.09	0.87	0.08	0.58	0.06	0.56	0.48	0.57	0.38	0.43	0.30	0.35
1994	0.78	0.79	0.54	0.55	0.39	0.40	0.34	0.70	0.29	0.50	0.21	0.44
1995	1.28	0.67	0.72	0.49	0.56	0.30	0.65	0.48	0.48	0.38	0.39	0.29
1996	0.22	0.85	0.19	0.57	0.13	0.52	0.22	0.72	0.19	0.51	0.14	0.47
Mean	0.55	0.69	0.37	0.49	0.28	0.41	0.49	0.50	0.38	0.39	0.31	0.34
Median	0.38	0.73	0.32	0.52	0.26	0.40	0.48	0.53	0.38	0.41	0.30	0.35

Length Frequencies, Sex Ratios, and Age Frequencies

Length frequencies, sex ratios, and age frequencies were calculated as described by McComish et al. (2000). The number of fish of each sex per 10-mm length class was determined for each nightly catch of six pooled 10-minute trawl tows (1 h effort) and each gill net catch. Age composition was calculated using month- and sex-specific age-length keys. The overall June-August age-length tables 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 in 2000 ranged from 60-369 mm (Appendix 3-3). Males ranged from 70-249 mm (Appendix 3-4), and females from 60-369 mm (Appendix 3-5). There was a major peak in the length frequency at 70-169 mm (Figure 3-2), almost exclusively composed of age-2 fish, with over twice as many females as males represented (Appendix 3-3). Sub-stock (age ≥1 and <130 mm) CPUE decreased significantly from 167/h in 1999 to slightly more than 35/h in 2000 and was comprised of primarily age 2 fish (Figures 3-3 and 3-4; Appendix 3-2). Trawl CPUE of stock-size (≥ 130 mm) fish continued to be extremely low with more than 80% being age 2 (Figures 3-5 and 3-6; Appendix 3-2). Quality-size fish (≥ 200 mm) decreased significantly from 1999 to 2000 with fish age 2 and 3 collectively making up over 70% of these fish (Figures 3-7 and 3-8 and Appendix 3-2). The length structure and CPUE in 2000 is clearly dominated by low numbers of very young fish which suggests the population is unlikely to develop a structure similar to the peak density years of mid to late 1980s (Figure 3-9). Proportional stock density (PSD; the percentage of stock-size fish ≥ 200

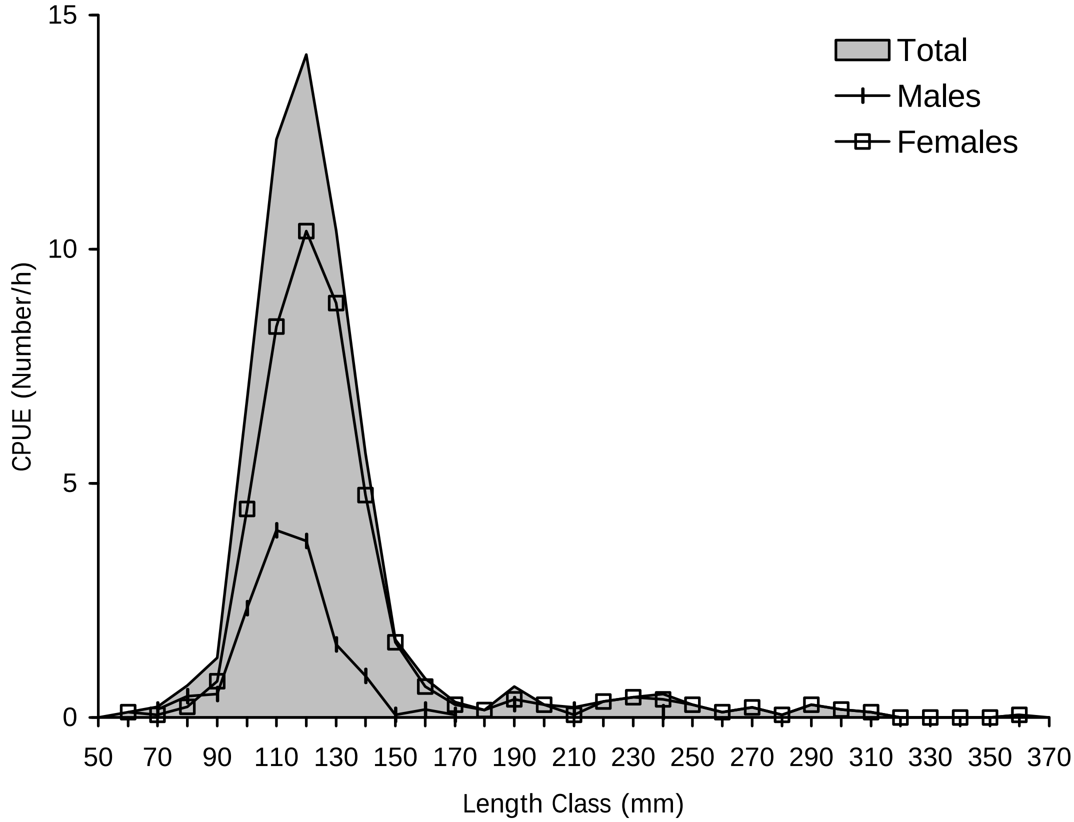

Figure 3-2. Length composition of the trawl catch of yellow perch age ≥1 at sites M, K, and G in Indiana waters of Lake Michigan, June-August 2000.

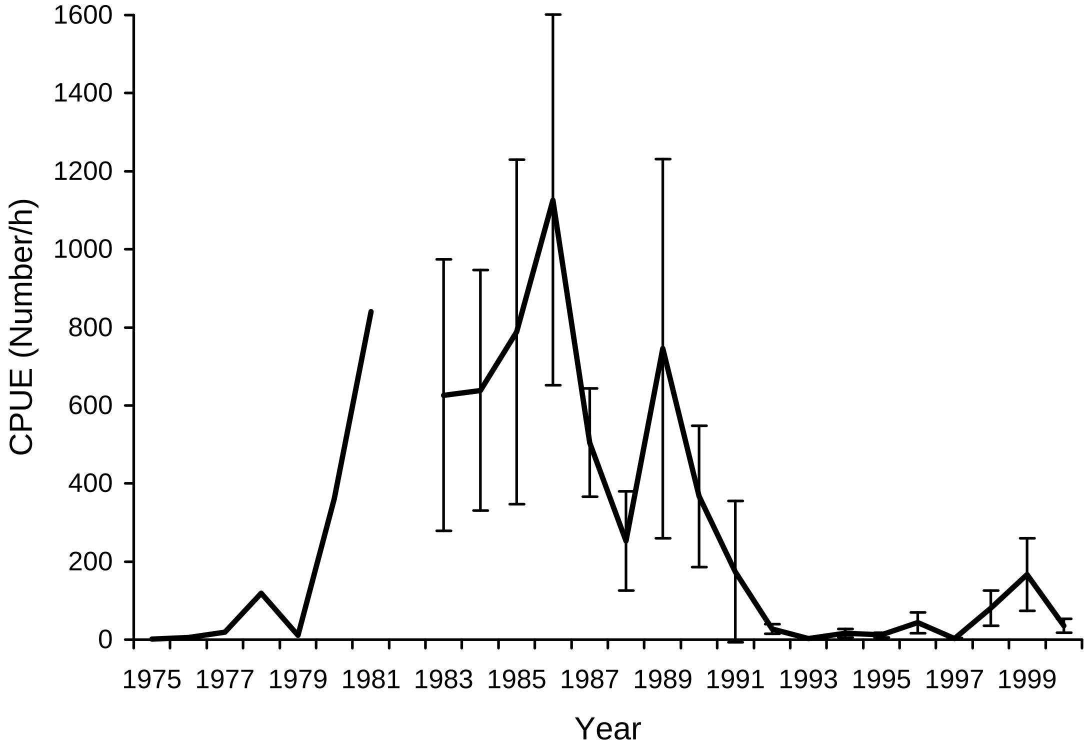

Figure 3-3. Trawl CPUE of sub-stock (age ≥1 and <130 mm) yellow perch in Indiana waters of Lake Michigan for pooled June-August sample periods. No trawling was conducted in 1982. Error bars for 1983-2000 represent ± 2 SE.

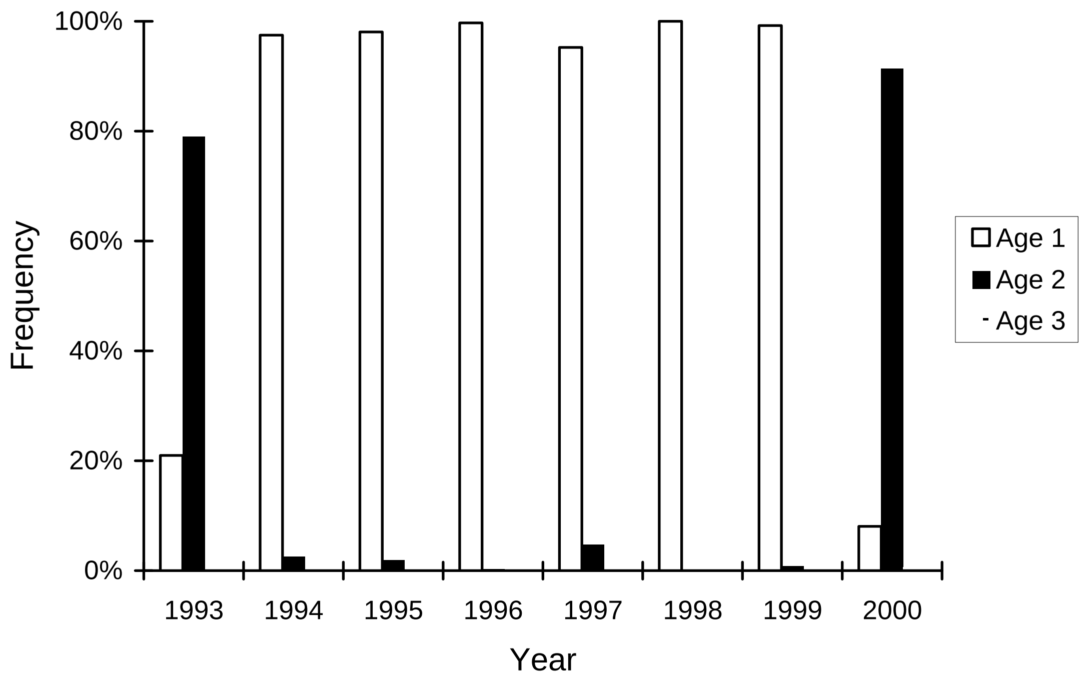

Figure 3-4. Age frequency of the trawl catch of sub-stock (<130 mm and age ≥1) yellow perch at sites M, K and G in Indiana waters of Lake Michigan, 1993-2000.

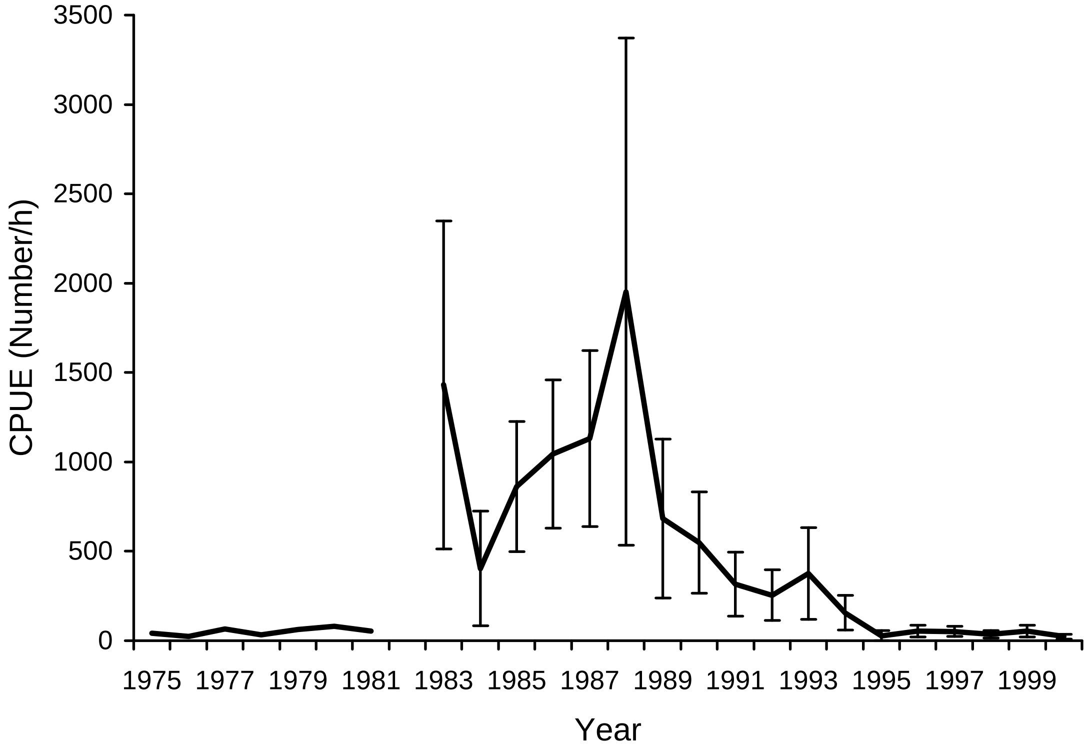

Figure 3-5. Trawl CPUE of stock (≥130 mm) yellow perch in Indiana waters of Lake Michigan for pooled June-August sample periods. No trawling was conducted in 1982. Error bars for 1983-2000 represent ± 2 SE.

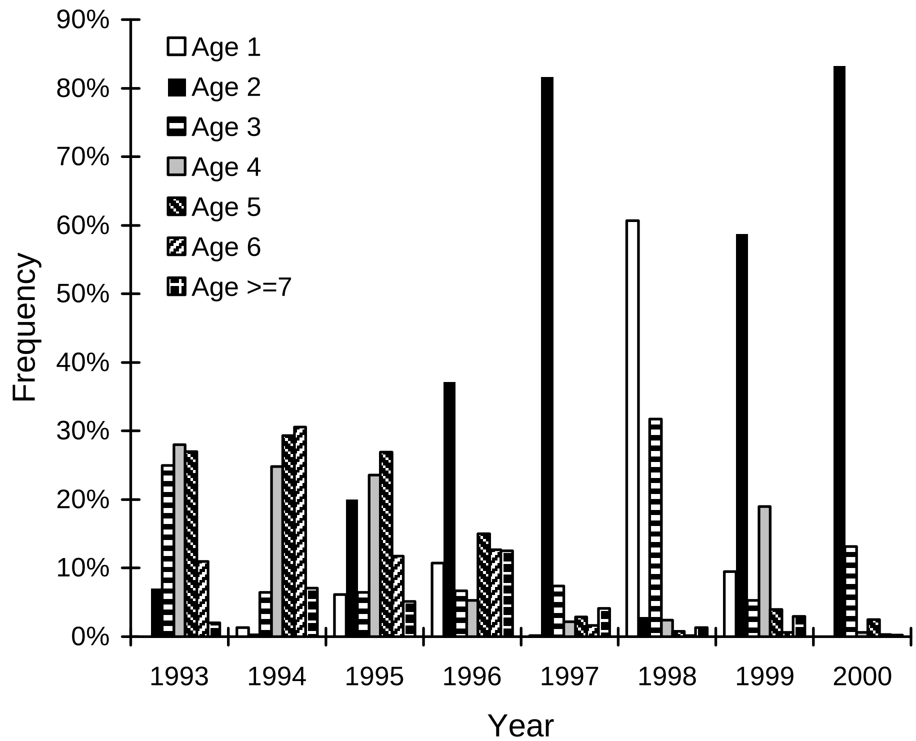

Figure 3-6. Age frequency of the trawl catch of stock (≥ 130 mm) yellow perch at sites M, K, and G in Indiana waters of Lake Michigan, 1993-2000.

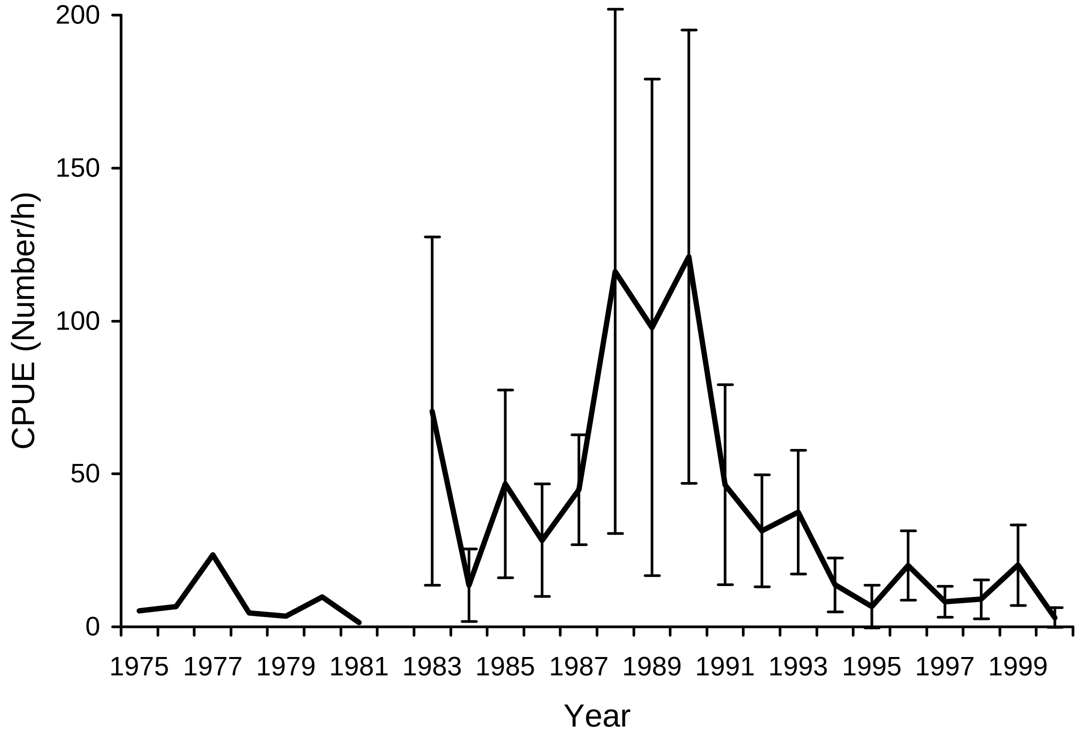

Figure 3-7. Trawl CPUE of quality (≥200 mm) yellow perch in Indiana waters of Lake Michigan for pooled June-August sample periods. No trawling was conducted in 1982. Error bars for 1983-2000 represent ± 2 SE.

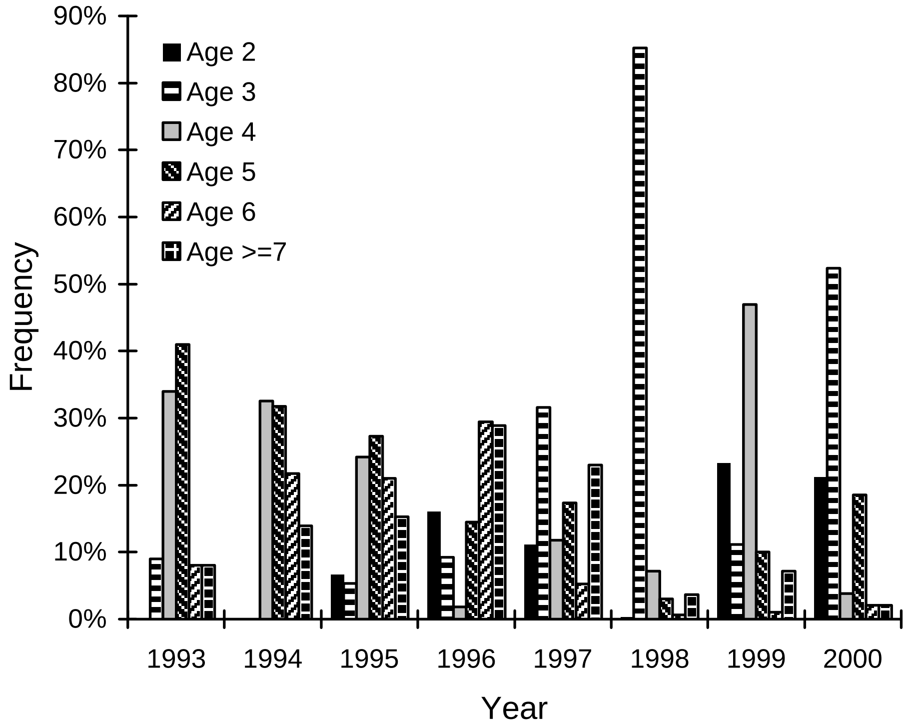

Figure 3-8. Age frequency of the trawl catch of quality (≥ 200 mm) yellow perch at sites M, K, and G in Indiana waters of Lake Michigan, 1993-2000.

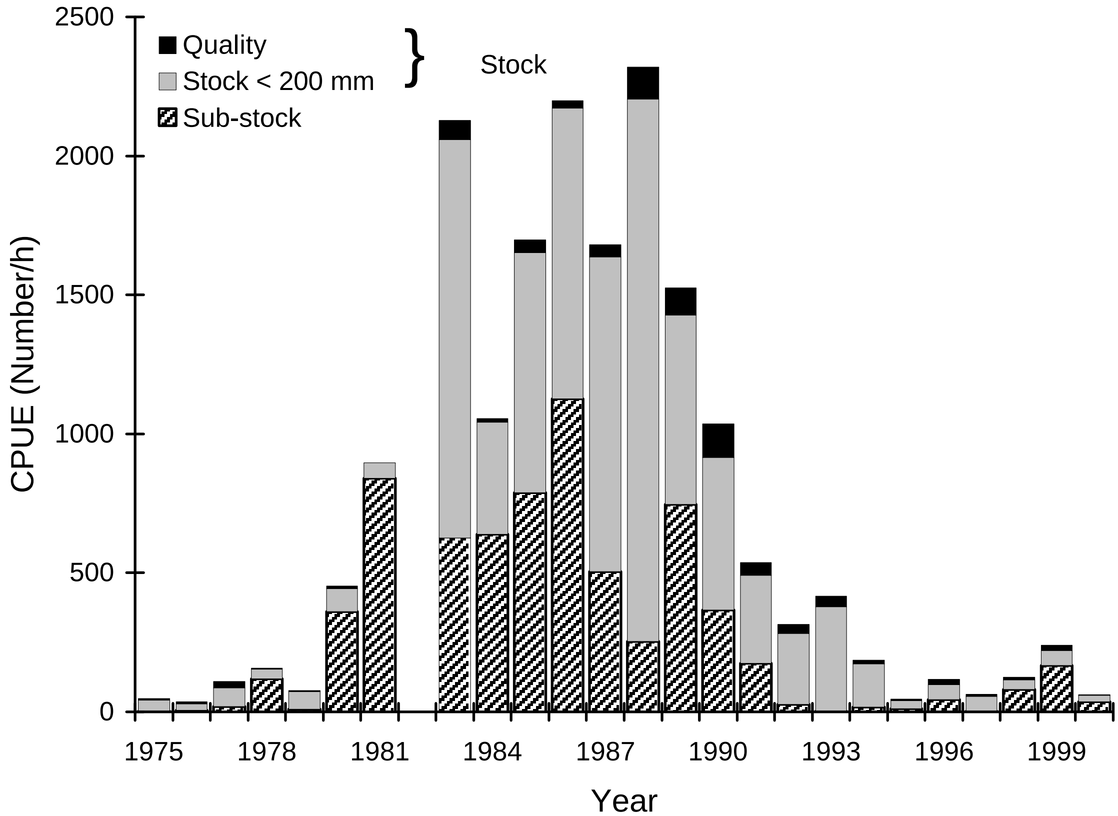

Figure 3-9. Trawl CPUE of sub-stock, stock, and quality yellow perch in Indiana waters of Lake Michigan for pooled June-August sample periods, 1975-2000. No index trawling was conducted in 1982.

mm) approximated the long-term median of 13% in 2000 (Figure 3-10; Appendix 3-2). Figure 3-10 must be interpreted cautiously because PSD of this population in recent years is 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). A trend of increasing females and decreasing males is evident from 1994-2000 for the age ≥1 fish (Figure 3-11). In 2000, the overall sex ratio of fish age ≥1 was 25%:75% male:female (Figure 3-11). The sub-stock composed 61% of the total catch with a sex ratio of 32%:68% male:female (Appendix 3-3; Figure 3-12). Fish of stock size (≥130 mm) made up 39% of the catch, with a sex ratio of 14%:86% male:female (Appendix 3-3; Figure 3-13). Quality-size (≥200 mm) fish were 5% of the total catch (Appendix 3-3). Due largely to sexual difference in growth rates (see ***Job 2***), 91% of quality-size yellow perch and all fish ≥250 mm were females (Figure 3-14; Appendix 3-4 and 3-5).

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 increased from age 1 in 1999 to age 2 in 2000. Concurrent with the increase in age, median length classes of both males and females increased in 2000. Age distributions of the sexes will likely remain similar over the next few years with the continued restrictions on harvest.

Gill Net Catch

Gill nets captured yellow perch ranging in lengths from 100-359 mm in 2000; males from 100-309 mm, and females from 170-359 mm (Appendices 3-6, 3-7 and 3-8).

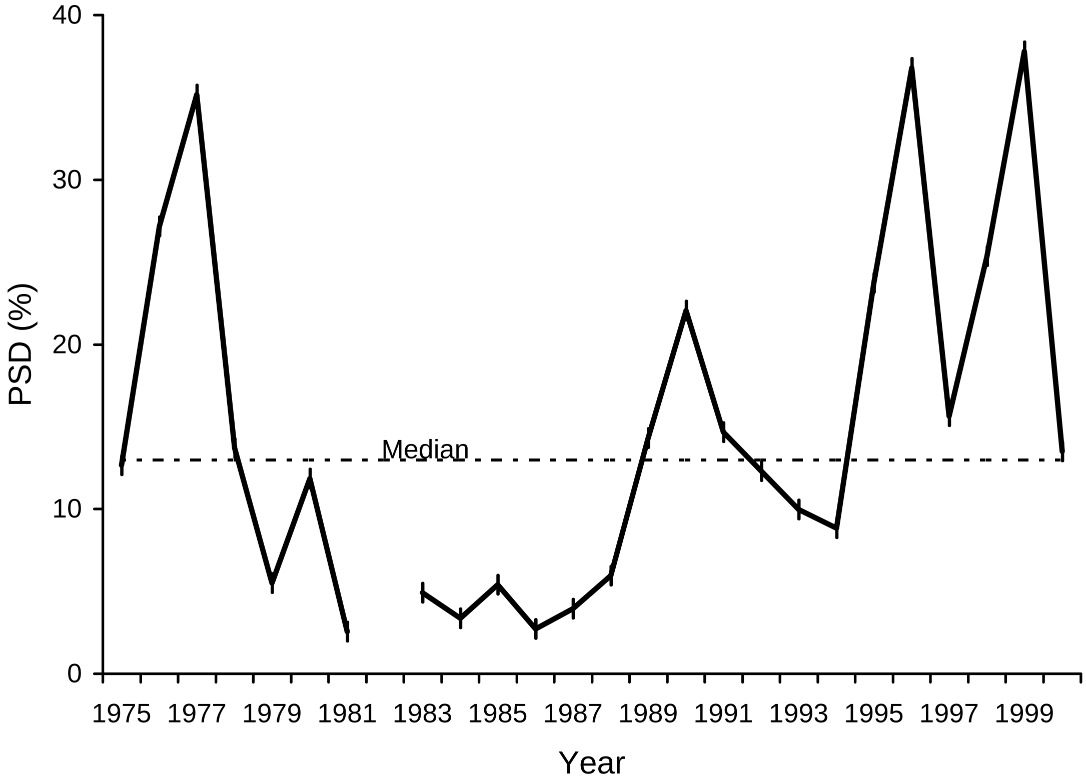

Figure 3-10. Proportional stock density (PSD) of yellow perch in Indiana waters of Lake Michigan for pooled June-August sample periods, 1975-2000. No index trawling was conducted in 1982.

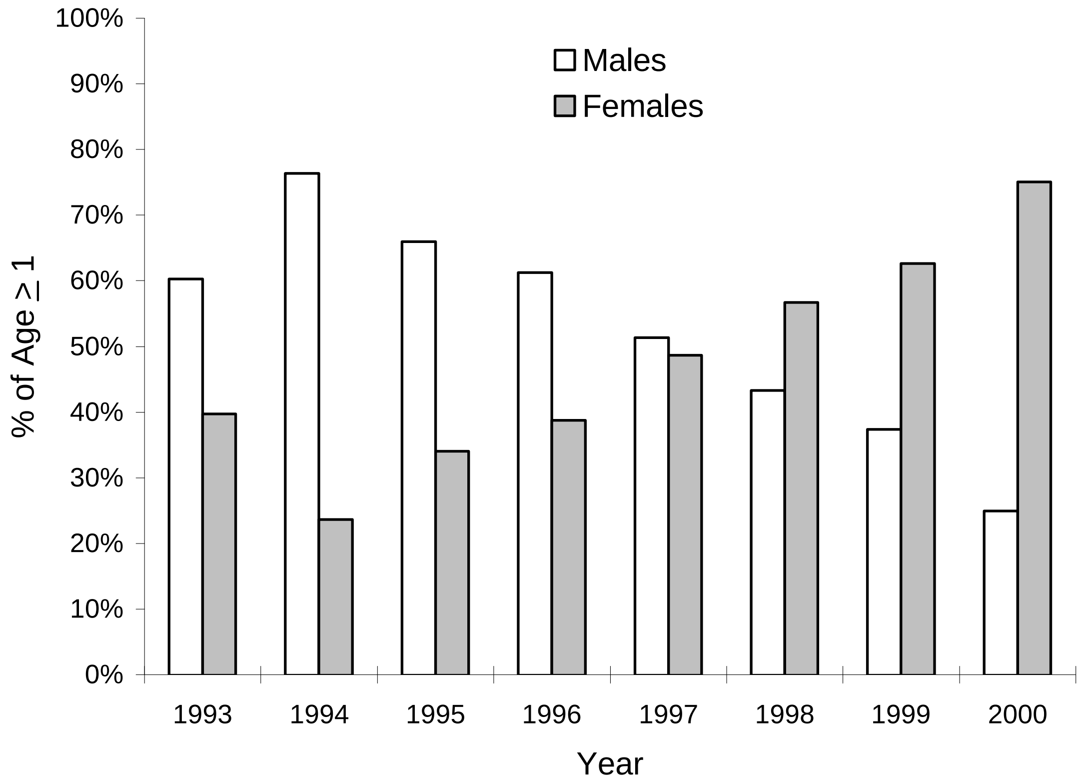

Figure 3-11. Sex ratios of age ≥1 yellow perch in the index trawl catch at sites M, K, and G in Indiana waters of Lake Michigan, 1993-2000.

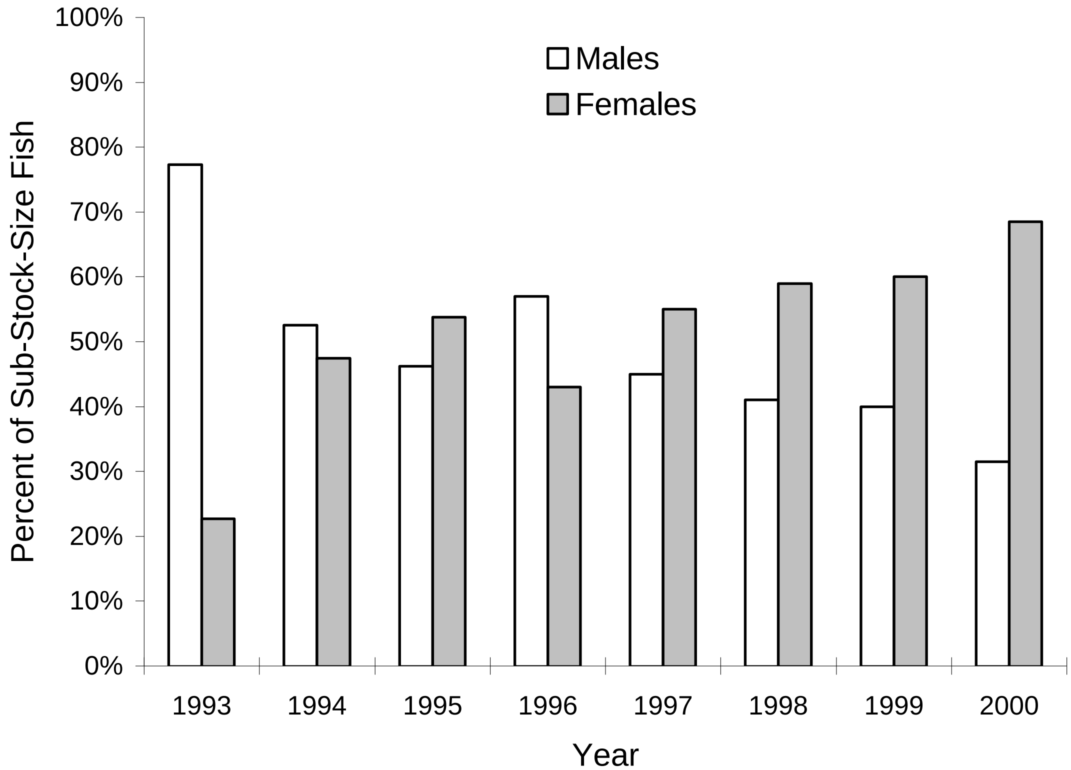

Figure 3-12. Sex ratios of sub-stock-size (age ≥1 and <130 mm) yellow perch in the index trawl catch at sites M, K, and G in Indiana waters of Lake Michigan, 1993-2000.

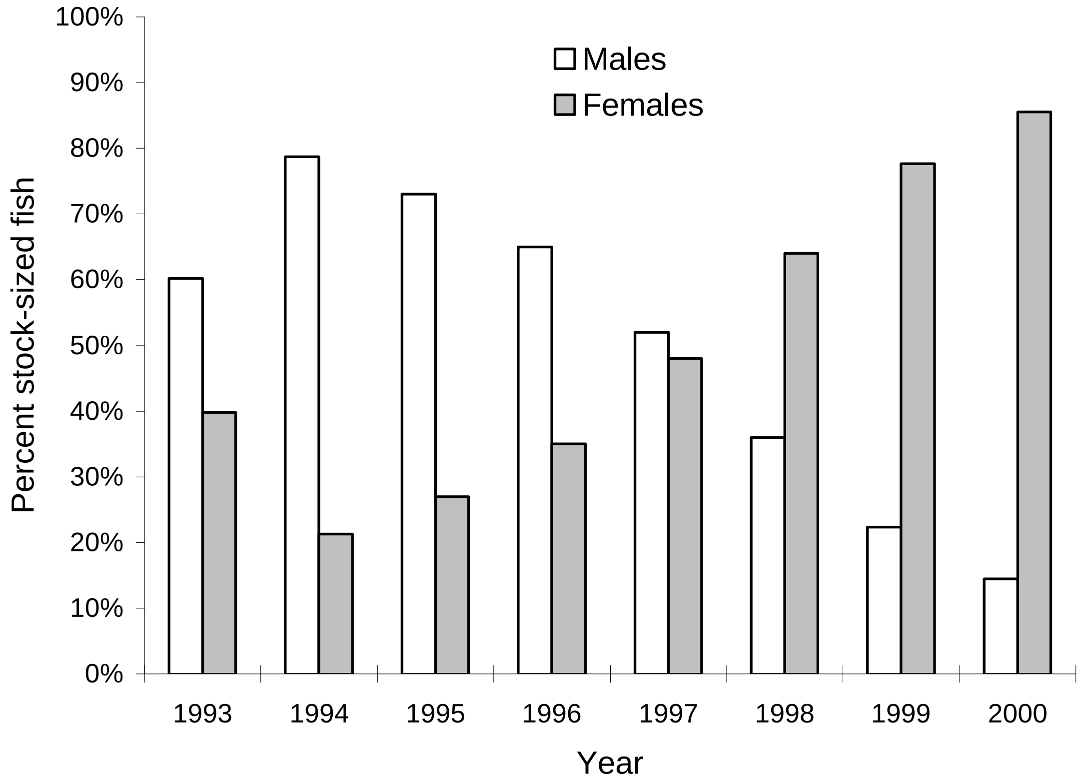

Figure 3-13. Sex ratios of stock-size (≥130 mm) yellow perch in the index trawl catch at sites M, K, and G in Indiana waters of Lake Michigan, 1993-2000.

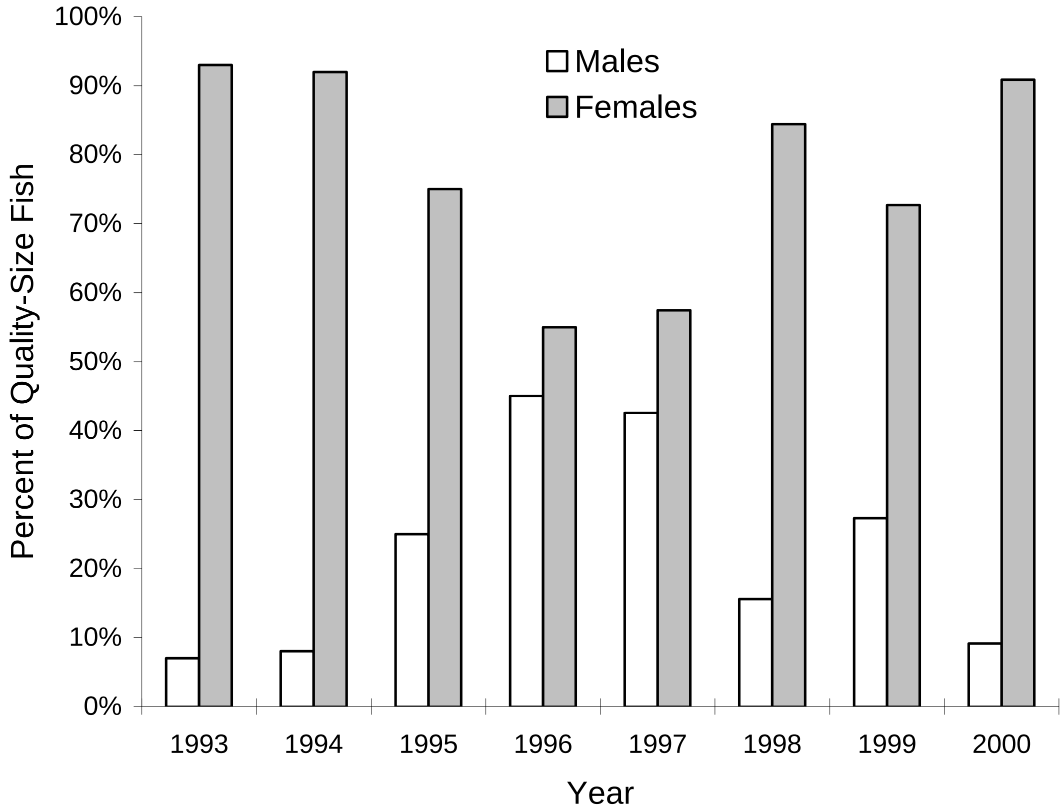

Figure 3-14. Sex ratios of quality-size (≥200 mm) yellow perch in the index trawl catch at sites M, K, and G in Indiana waters of Lake Michigan 1993-2000.

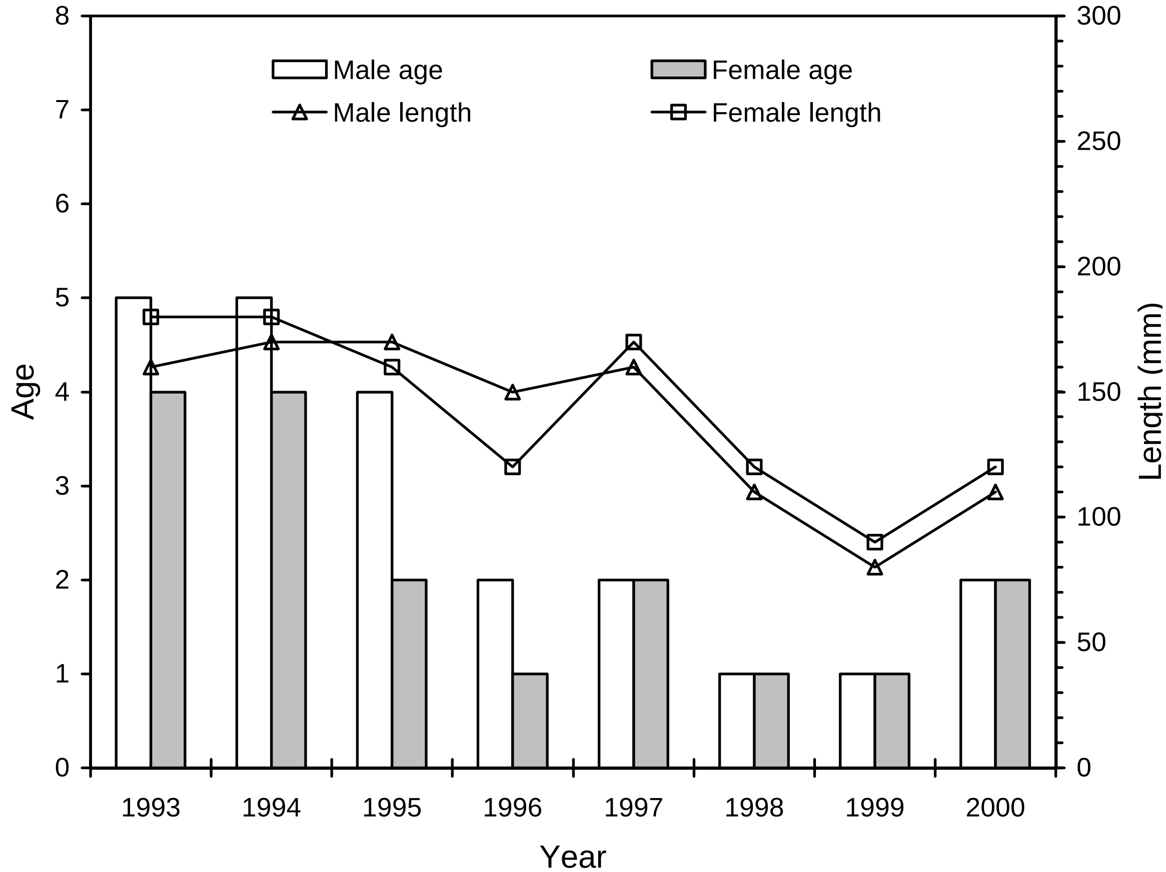

Figure 3-15. Median ages and length classes of male and female yellow perch age ≥ 1 in the trawl catch at sites M, K, and G in Indiana waters of Lake Michigan, June-August 1993-2000.

The length frequency in 2000 was distinctly bimodal with peaks at 250-259 mm and 300-309 mm (Figure 3-16). The first mode was primarily composed of the 1997-cohort females, while 1995-cohort females dominated the second mode (Appendices 3-6; 3-7; and 3-8).

Sex ratios of gill net catches were somewhat similar to that of trawl catches in 2000. The same trend of increasing percent females and decreasing percent males as noted for the trawl catch is shown but not until after 1997 (Figure 3-17). Females comprised 86% of the total gill net catch in 2000 (Figure 3-17). The sex ratio of the quality-sized component of the total gill net catch was 12% to 88% male and female, respectively (Appendices 3-6; 3-7; and 3-8). Figure 3-18 shows that median ages of the gillnet catches were always older for males than females from 1993-1997 due to the gill nets' selection for fish ≥190 mm. In 2000, both males and females had median ages of three likely due to the substantial influence of the 1997 year class. In addition, the recent increase in growth rates of 3-yr-old males (***Job 2***) made them vulnerable to the gill nets. Median length classes of females increased from 250 to 260 mm from 1999-2000 due to the increase in growth rates, but remained at 220 mm for males over that same period of time (Figure 3-18).

Ages and Lengths at Maturity

In 2000, 42% of males were mature at age 1 and virtually 100% at age 2, while 2% of females were mature at age 2 and 86% at age 3 (Table 3-5). Minimum lengths at ≥ 50% maturity were 90-99 mm for males and 210-219 mm for females (Table 3-6). The 1997 and 1998 female cohorts composed about 83% of females age

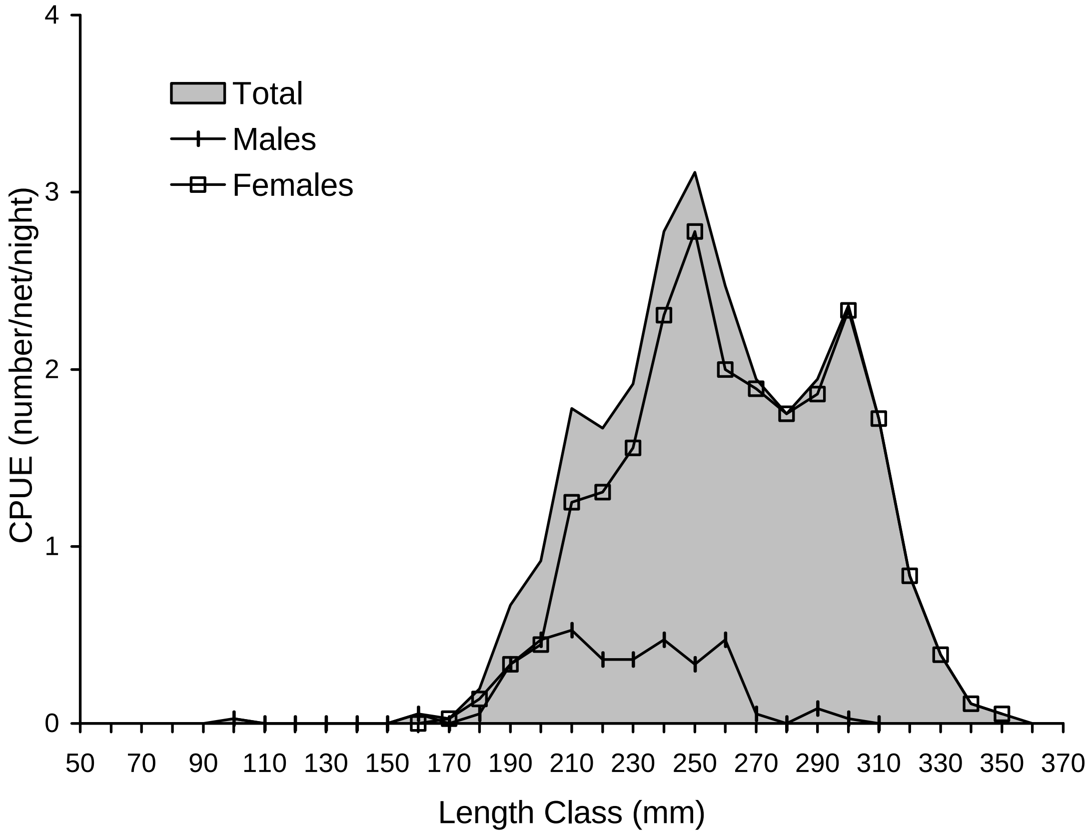

Figure 3-16. Length composition of the pooled 10-m and 15-m gill net catches of yellow perch at sites M, K, and G in Indiana waters of Lake Michigan, June-August 2000.

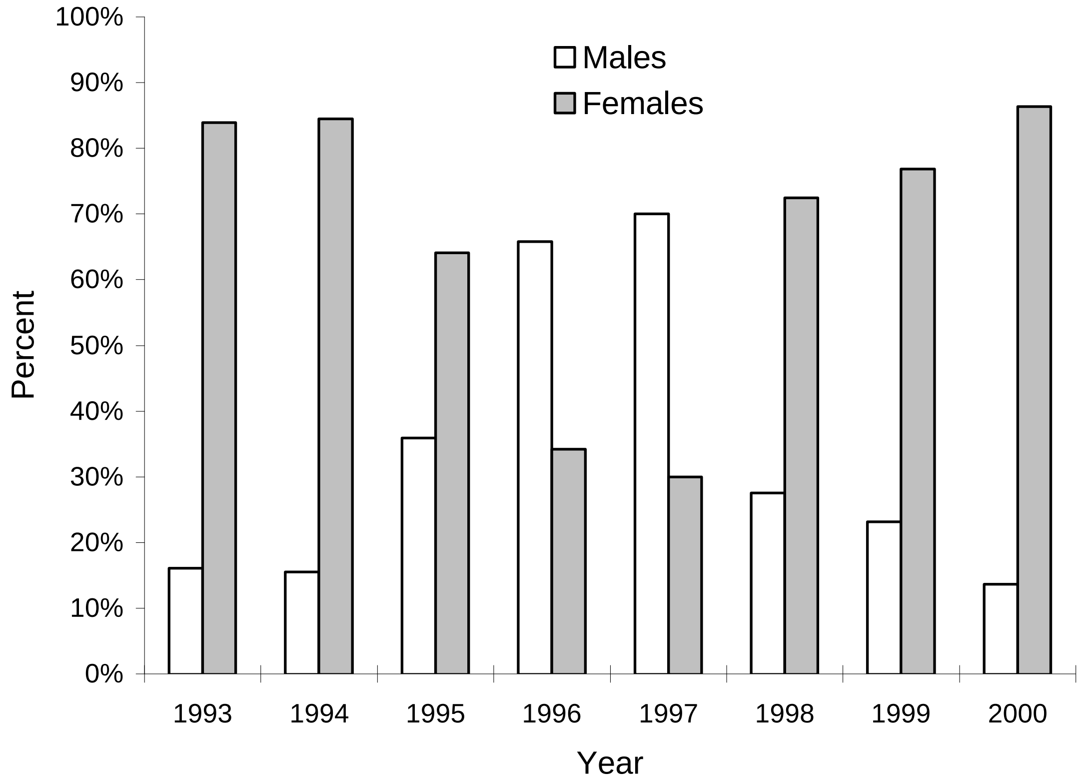

Figure 3-17. Sex ratios of the pooled 10-m and 15-m gill net catches of yellow perch at sites M, K, and G in Indiana waters of Lake Michigan.

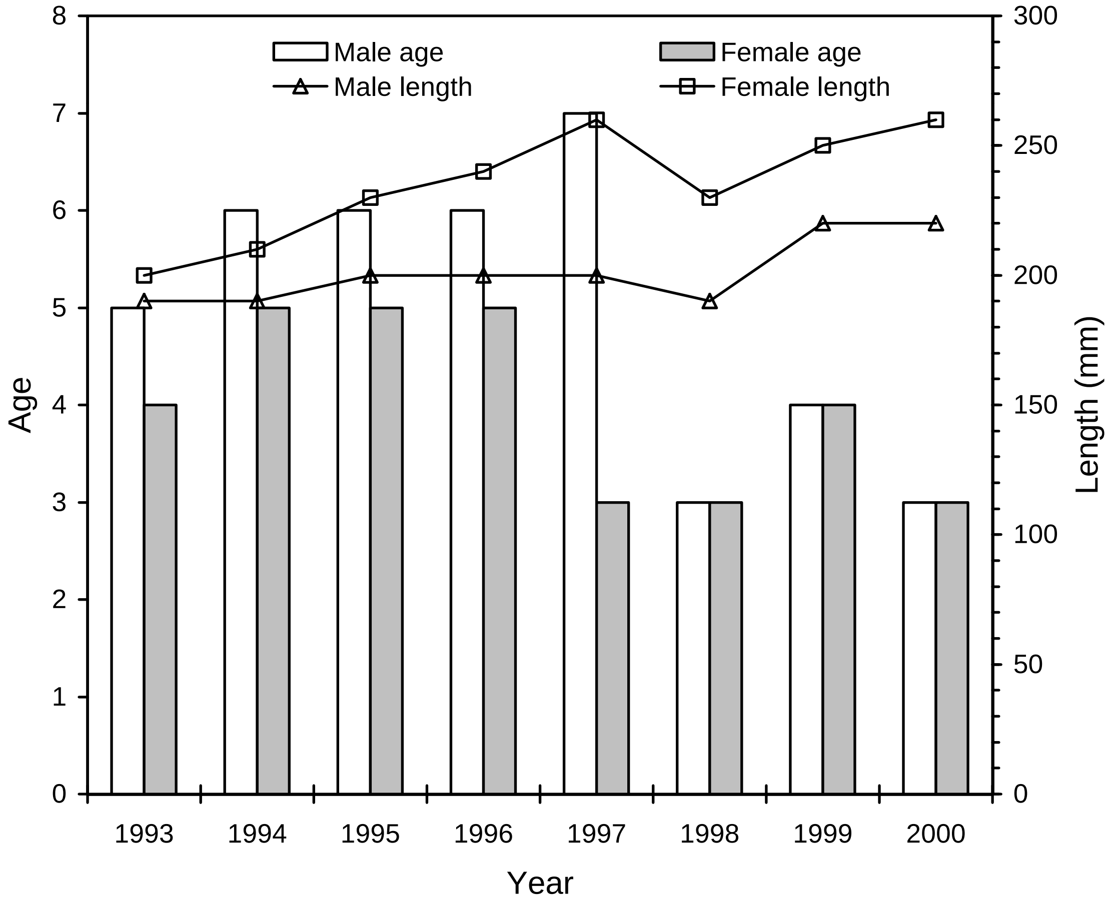

Figure 3-18. Median ages and length classes of male and female yellow perch in the pooled 10-m and 15-m gill net catch at sites M, K, and G in Indiana waters of Lake Michigan, June-August 1993-2000.

Table 3-5. Percent maturity by age for yellow perch in the June, 2000 pooled trawl and gill net catches at sites M, K, and G in Indiana waters of Lake Michigan. Gonads of mature fish were either ripe or recently spent.

	Males			Females		
Age	*N*	Immature	Mature	*N*	Immature	Mature
1	22	68%	42%	10	100%	0%
2	27	0%	100%	273	98%	2%
3	43	0%	100%	176	14%	86%
4	7	0%	100%	2	0%	100%
5	6	0%	100%	74	0%	100%
6	5	0%	100%	12	0%	100%
7	1	0%	100%	2	0%	100%
8						
9						
10	2	0%	100%			
11						
12	1	0%	100%			

Table 3-6. Percent maturity by length class for yellow perch in the June, 2000 pooled trawl and gill net catches at sites M, K, and G in Indiana waters of Lake Michigan. Gonads of mature fish were either ripe or recently spent.

Length class (mm)	Males			Females		
	N	Immature	Mature	*N*	Immature	Mature
50				1	100%	0%
60				2	100%	0%
70	3	100%	0%	1	100%	0%
80	8	100%	0%	4	100%	0%
90	6	33%	67%	10	100%	0%
100	10	0%	100%	40	100%	0%
110	5	0%	100%	68	100%	0%
120	6	0%	100%	67	100%	0%
130	9	0%	100%	40	100%	0%
140	5	0%	100%	25	96%	4%
150	1	0%	100%	11	100%	0%
160	2	0%	100%	6	83%	17%
170						
180	2	0%	100%			
190	10	0%	100%	9	78%	22%
200	11	0%	100%	7	57%	43%
210	17	0%	100%	19	32%	68%
220	6	0%	100%	31	26%	74%
230	6	0%	100%	17	6%	94%
240	2	0%	100%	19	11%	89%
250	2	0%	100%	31	0%	100%
260	1	0%	100%	23	0%	100%
270	1	0%	100%	18	0%	100%
280				14	0%	100%
290	1	0%	100%	26	0%	100%
300				33	0%	100%
310				17	0%	100%
320				6	0%	100%
330				2	0%	100%
340				1	0%	100%
350				1	0%	100%
360						

≥ 2, and thus will largely be responsible for production of future year classes. The majority of the 1998-cohort females should spawn for the first time in 2001.

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 include those major findings, but focus on changes and additions since 1999.

Catch Composition

Trawl Catch of Age ≥1

A total of 12 non-salmonine fish species or genera represented by individuals age ≥ 1 were collected by trawling at sites M, K, and G during 2000 (Appendix 4-1). Spottail shiners were the most abundant species numerically with annual CPUE averaging 700 fish/h, which accounted for 65% of all fish captured. Alewife was the next most abundant fish at 20% of the total, with a mean CPUE of 215 fish/h. Other major fish species sampled included the round goby at 9% (93 fish/h), and yellow perch at 5% (58 fish/h) of the total catch. The trout-perch *Percopsis omiscomaycus*, and longnose sucker *Catostomus catostomus* were present at lesser densities, but exceeded 1.0 fish/h for at least one site. Additional non-salmonine species caught incidentally (CPUE < 1.0 fish/h) were: johnny darter *Etheostoma nigrum*, rainbow smelt *Osmerus mordax*, white sucker *Catostomus commersoni*, freshwater drum *Aplodinotus grunniens*, gizzard shad *Dorosoma cepedianum*, and ninespine stickleback *Pungitius pungitius*.

Among-Site Differences in Trawl Catch

Differences among sites in occurrence and CPUE of some species were observed in 2000 (Figure 4-1). Site M produced the highest CPUE of spottail shiners, while

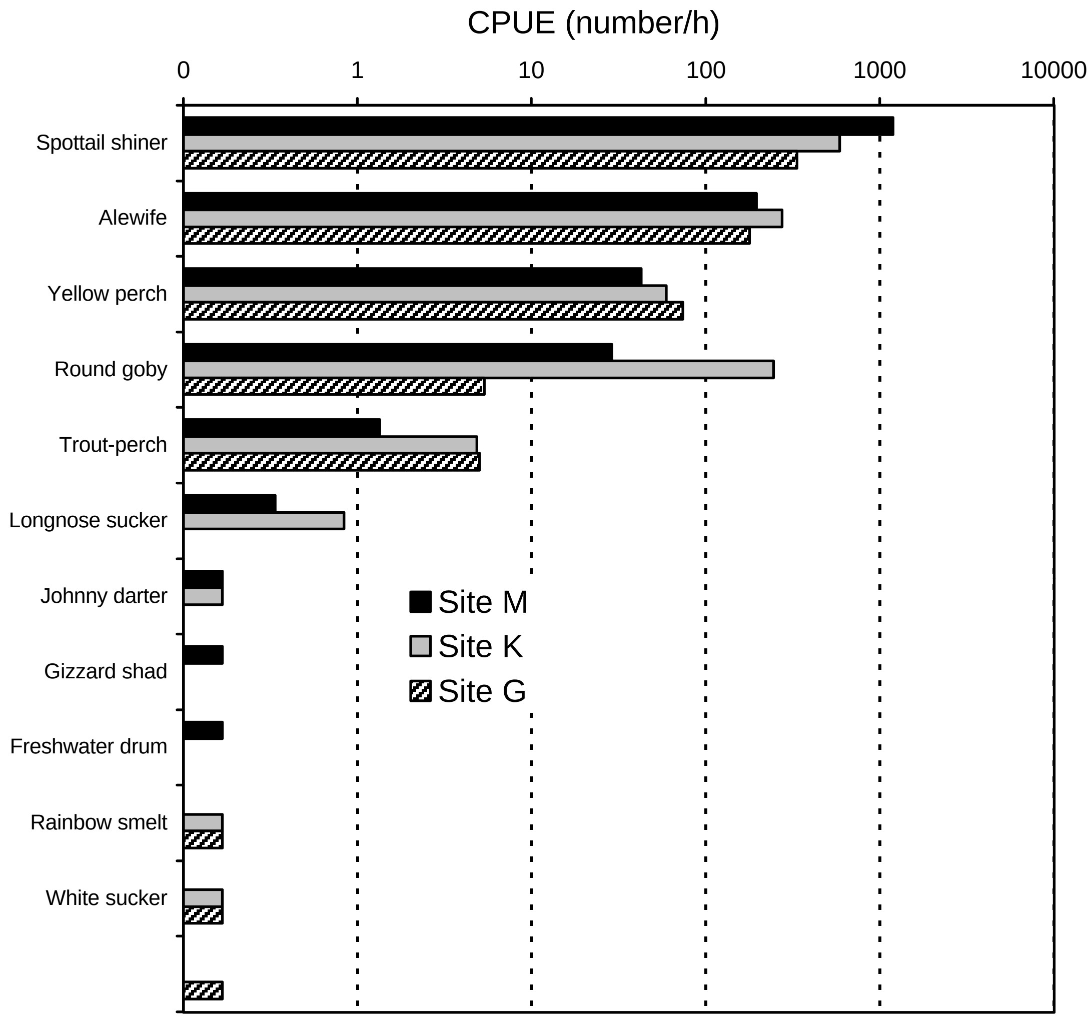

Figure 4-1. Summary of species composition of the trawl catch of non-salmonine fishes at sites M, K, and G in Indiana waters of Lake Michigan for 2000.

freshwater drum and gizzard shad were caught exclusively at this site. The catch rates for alewife, round gobies and longnose sucker were highest at site K. At site G, yellow perch and trout perch were caught in the highest numbers, and ninespine sticklebacks were only caught at this site, while spottail shiners, alewives, and round gobies were caught in lowest numbers.

Trawl Catch of Age 0

Age-0 fishes may not be 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 was 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, but the total June-August effort has been included in reported values of CPUE. Therefore, CPUE during the last half of the sample season would be approximately twice the 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, and spottail shiner 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 is listed in Appendix 3-2. Data for other species were not tabulated because of their limited value in meeting the objectives of this study.

Gill Net Catch

Fourteen different species were caught in gill nets at sites M, K and G in 2000 (Appendix 4-2). The composition of the gill net catch included several species 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 and alewives dominated the catch and accounted for over 93% of the catch at all sites in 2000. The only other species composing ≥1% of the catch was the white sucker (4%). Species caught incidentally (< 1% of CPUE) were longnose sucker, chinook salmon, gizzard shad, round goby, brown trout *Salmo trutta,* coho salmon *Oncorhynchus kisutch*, freshwater drum, lake trout *Salvelinus namaycush*, channel catfish *Ictalurus punctatus*, rock bass *Ambloplites rupestris*, and steelhead trout *Oncorhynchus mykiss*.

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 1984-2000 are summarized (Figure 4-2). Spottail shiners continued to dominate the catch in 2000. Alewife abundance increased substantially to the highest CPUE noted since 1984, and yellow perch decreased to levels similar to the residual numbers seen in 1995 and 1997. Bloaters and rainbow smelt were virtually absent.

Yellow Perch

The relative abundance of the 2000 trawl catch of age ≥1 fish at pooled sites M, K, and G remained at an extremely low level similar to 1994-1999 and 1975-1979 densities (Figure 4-3). The decline in yellow perch abundance after 1988, discussed under ***Job 3***, continued to be due to drastically reduced recruitment and high mortality.

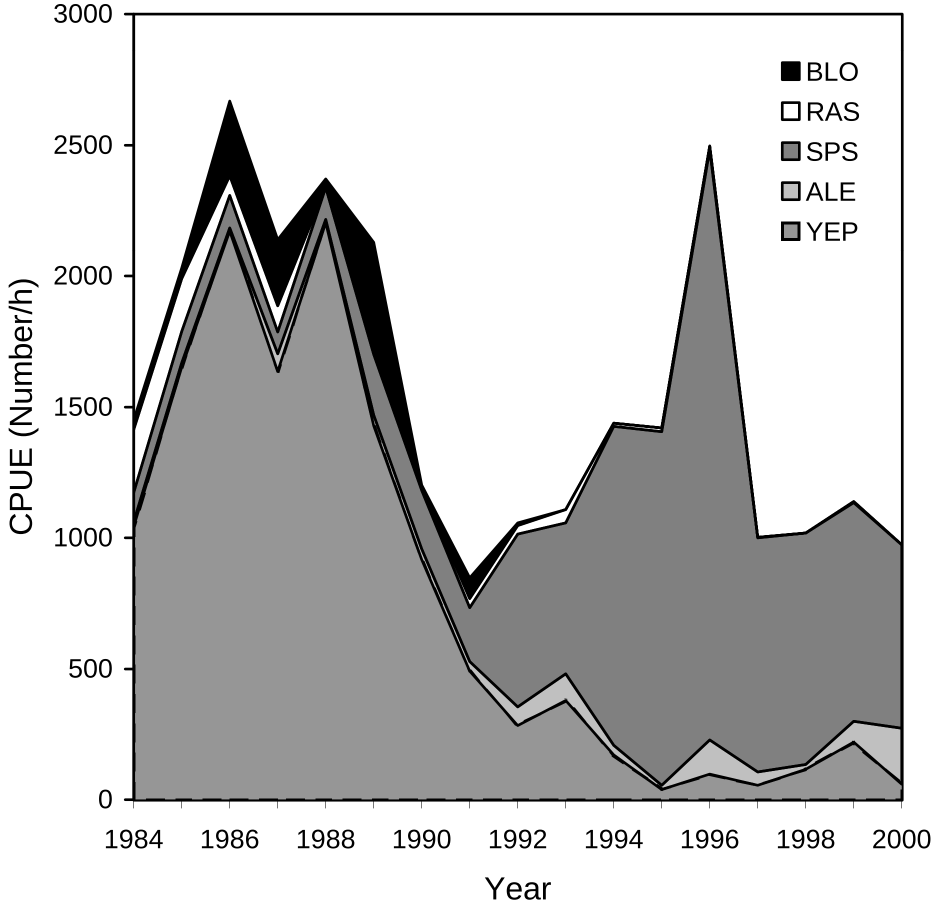

Figure 4-2. Mean annual June-August trawl CPUE (excluding age 0) of five historically abundant species at sites M, K, and G. Abbreviations: YEP = yellow perch, ALE = alewife, SPS = spottail shiner, RAS = rainbow smelt, BLO = bloater.

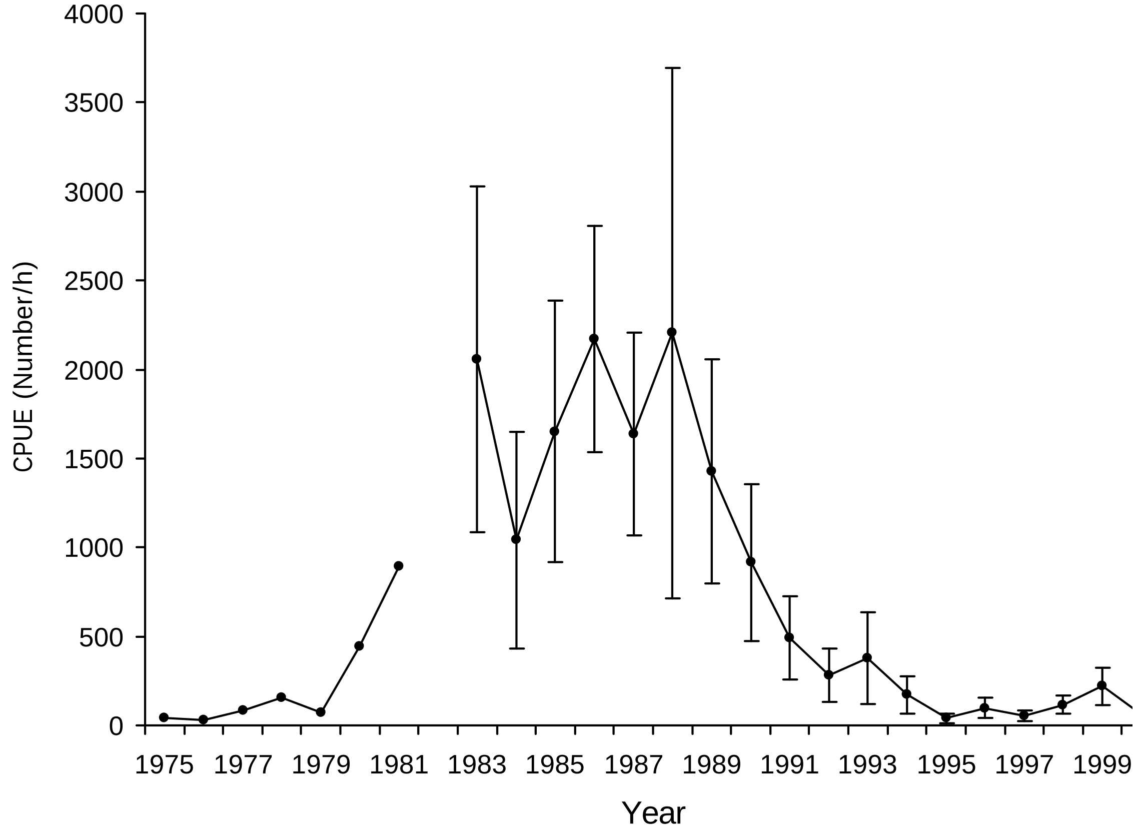

Figure 4-3. Mean trawl CPUE of yellow perch age ≥ 1 for pooled June-August sample periods in Indiana waters of Lake Michigan. Only site K was sampled from 1975-1983; 1984-1988 data represent pooled sites M and K; and 1989-2000 data represent pooled sites M, K, and G. No trawling was conducted in 1982. Error bars for 1983-2000 are ± 2 SE.

Another supporting view of the trend in yellow perch abundance is 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 1984-2000 (Figure 4-4). Trends in gill net CPUE were similar at both depths, but catches were somewhat higher at 10 m and the 2000 gill net CPUE declined significantly from 1999. Due to the selective bias of the gill nets for larger fish, gill net CPUE data are not as representative as trawl CPUE for estimating overall population abundance. Moreover, yellow perch gill net CPUE interpretation must be done with concurrent insights to the dynamics of sex ratios and growth rates, as discussed under ***Job 3***.

Alewife

Alewife trawl CPUE increased 168% from 1999 to 2000, reaching the highest level recorded since 1984 and significantly different from all previous years except 1991 and 1996 (Figure 4-5). Gill net CPUE increased slightly in 2000 but was not significantly different from recent years (Figure 4-6). However, 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. The high abundance of alewives found in June-August 2000 trawl sample was probably the most important factor determining the near absence of age-0 yellow perch in the trawl catch (***See Job 5***).

Spottail Shiner

The trawl CPUE of spottail shiners in 2000 was not significantly different from that found in 1997-1999 (Figure 4-7). However, levels continue to be significantly reduced from the peak abundance in 1996 and may be on a slow downward trend.

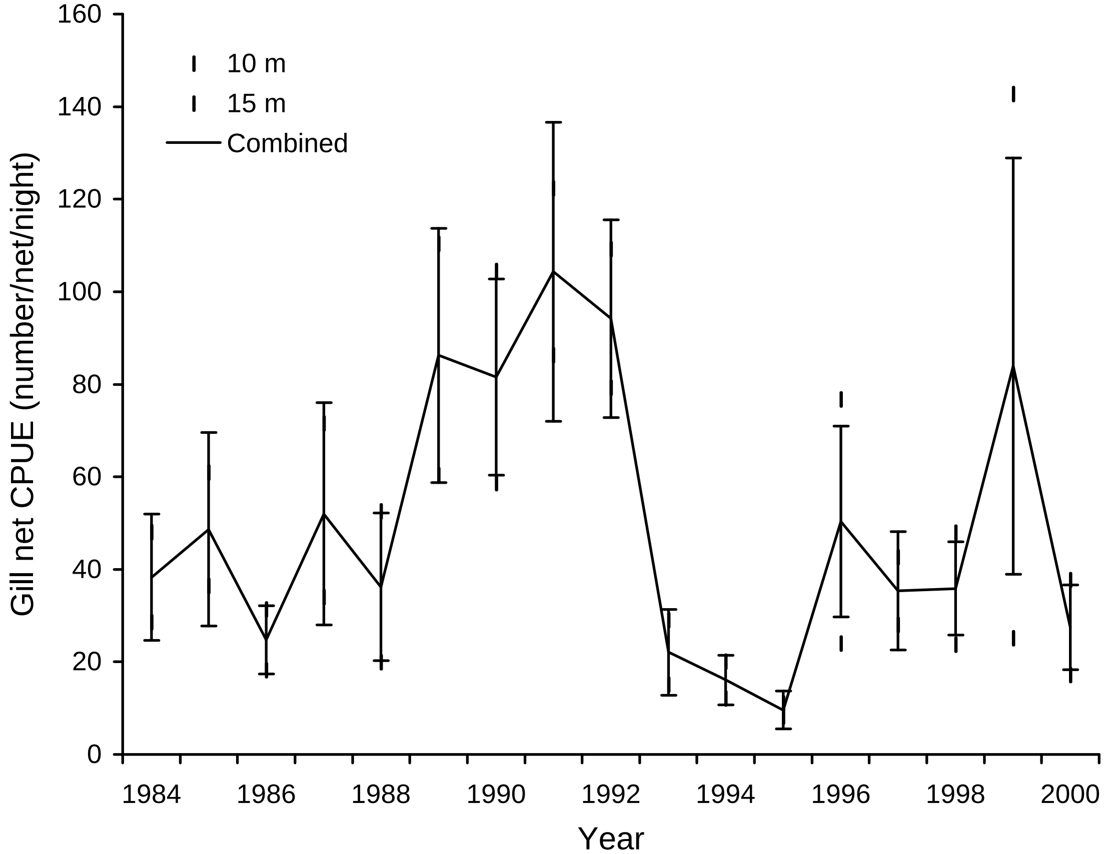

Figure 4-4. Mean annual June-August gill net CPUE of yellow perch at pooled sites M, K, and G in Indiana waters of Lake Michigan at 10 m, 15 m and combined depths, 1984-2000. Error bars represent ± 2 SE of combined means.

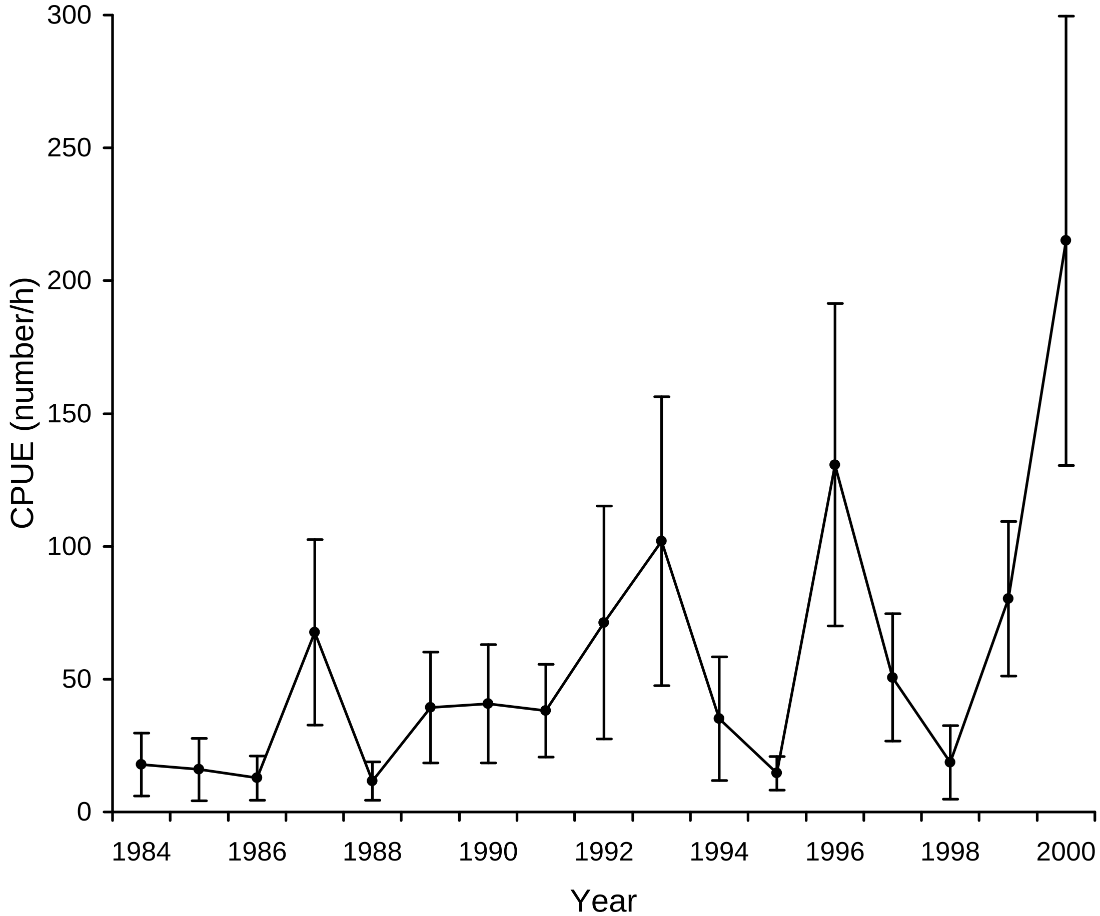

Figure 4-5. Mean trawl CPUE of alewives age ≥ 1 for pooled June-August sample periods in Indiana waters of Lake Michigan. The 1984-1988 data represent pooled sites M and K; the 1989-2000 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

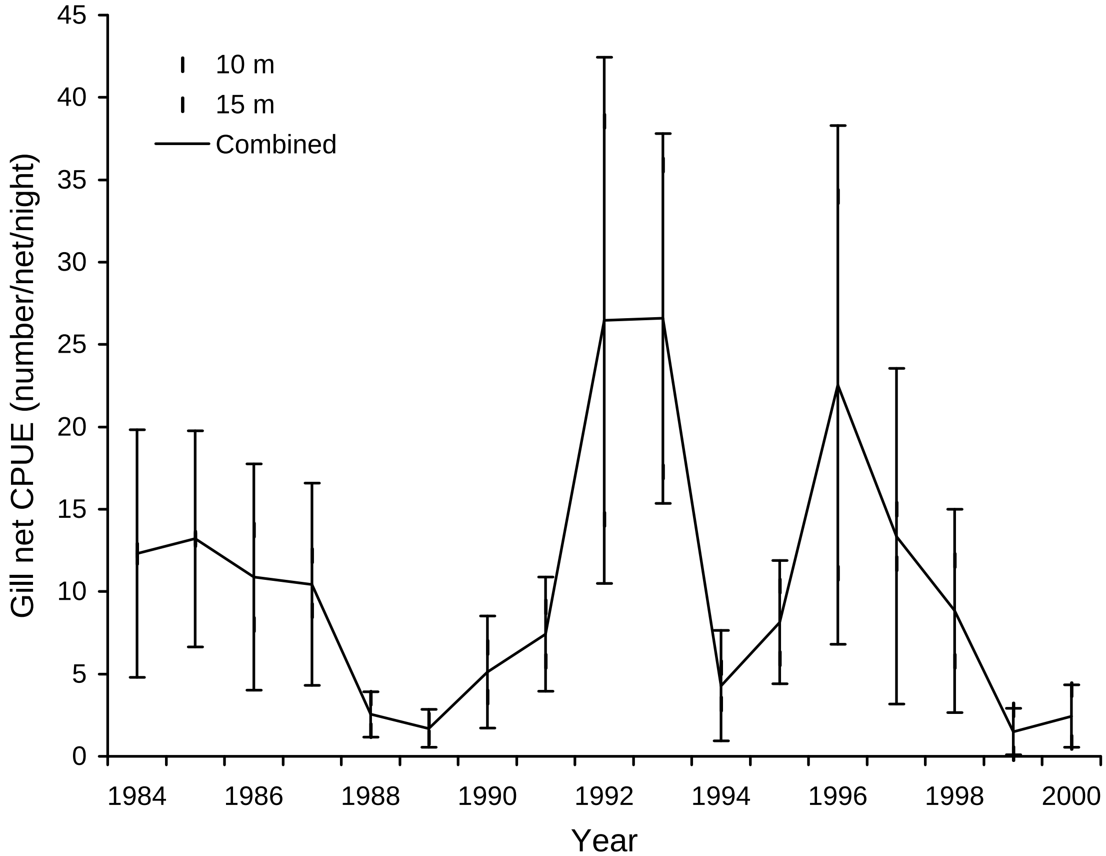

Figure 4-6. Mean annual June-August gill net CPUE of alewives at pooled sites M, K, and G in Indiana waters of Lake Michigan at 10 m, 15 m and combined depths. Error bars represent ± 2 SE of combined means.

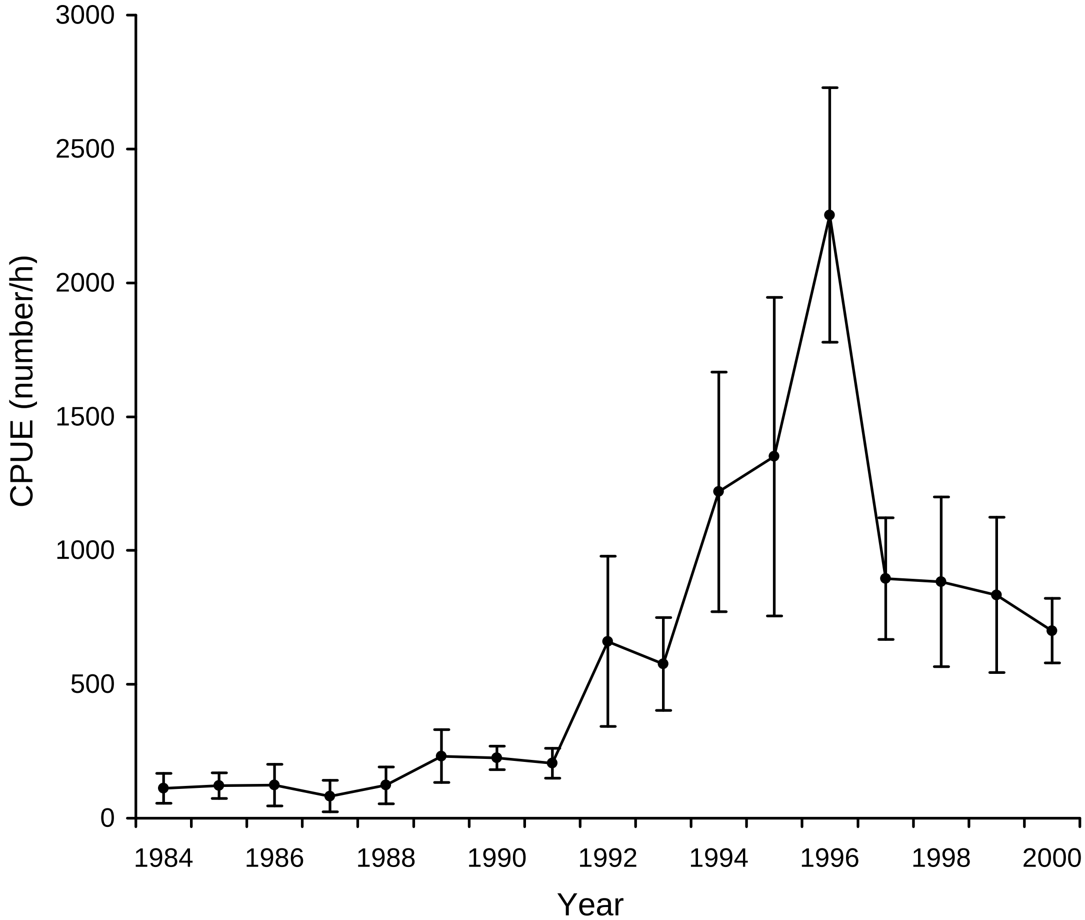

Figure 4-7. Mean trawl CPUE of spottail shiners age ≥ 1 for pooled June-August sample periods in Indiana waters of Lake Michigan. The 1984-1988 data represent pooled sites M and K; the 1989-2000 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

Bloater

The bloater trawl CPUE at pooled sites M, K and G was zero in 2000 (Figure 4-8). Bloater has 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 2000 (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 suppressed probably due largely to continued alewife effects (Smith 1970; Emery 1985)

Round Goby

The round goby was first captured in the trawl in 1998, has undergone a sharp increase in abundance to 92 fish/h by 2000 (Figure 4-10). Round gobies are known to negatively impact indigenous sculpin *Cottus* sp. (Jude et al. 1995), and may be responsible for the decline of this sympatric species (McComish et al. 2000). The significance of the non-indigenous goby to the fish community is not fully understood at this time. However, close attention will be paid to this fish and its potential impacts.

Trout-Perch

Trawl CPUE of trout-perch decreased sharply in 2000 to a level found in years prior to 1996 (Figure 4-11). It is unclear why trout-perch CPUE has recently shown such

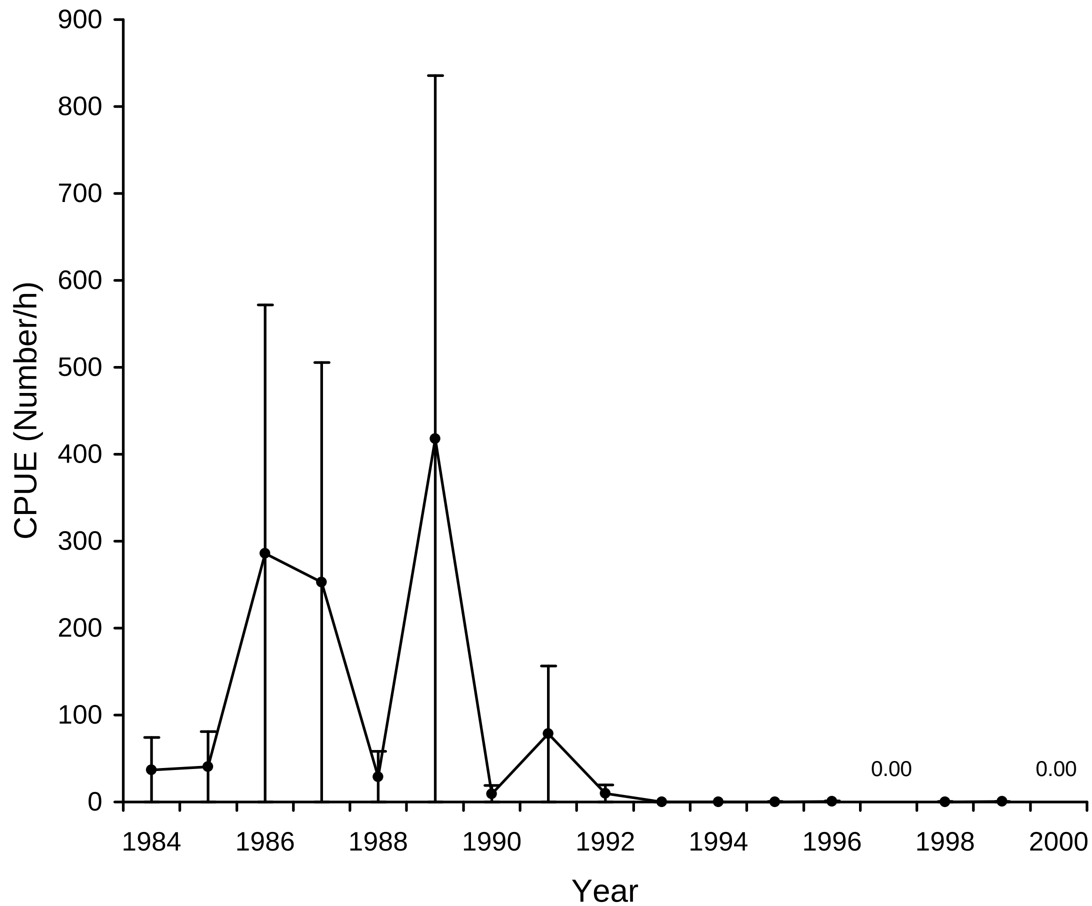

Figure 4-8. Mean trawl CPUE of bloaters age ≥ 1 for pooled June-August sample periods in Indiana waters of Lake Michigan. The 1984-1988 data represent pooled sites M and K; the 1989-2000 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

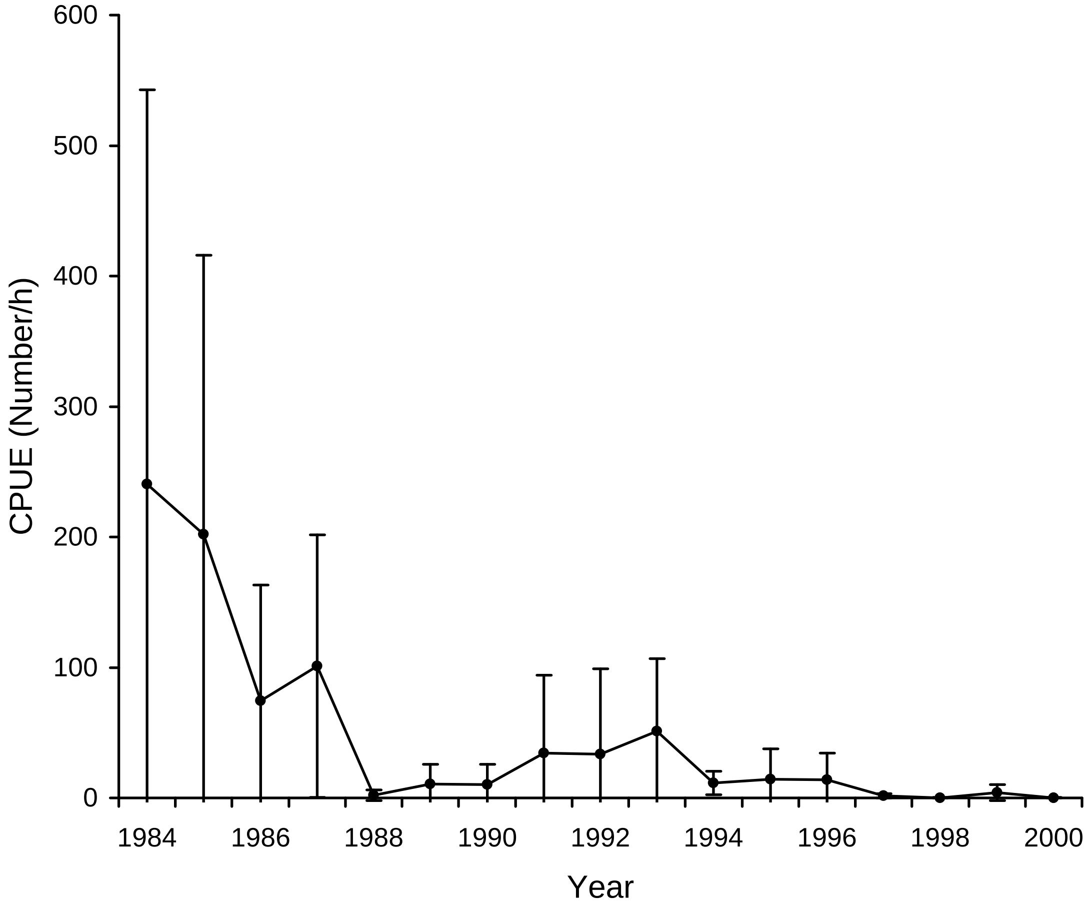

Figure 4-9. Mean trawl CPUE of rainbow smelt age ≥ 1 for pooled June-August sample periods in Indiana waters of Lake Michigan. The 1984-1988 data represent pooled sites M and K; the 1989-2000 data represent pooled sites M, K, and G. Error bars are ± 2 SE.

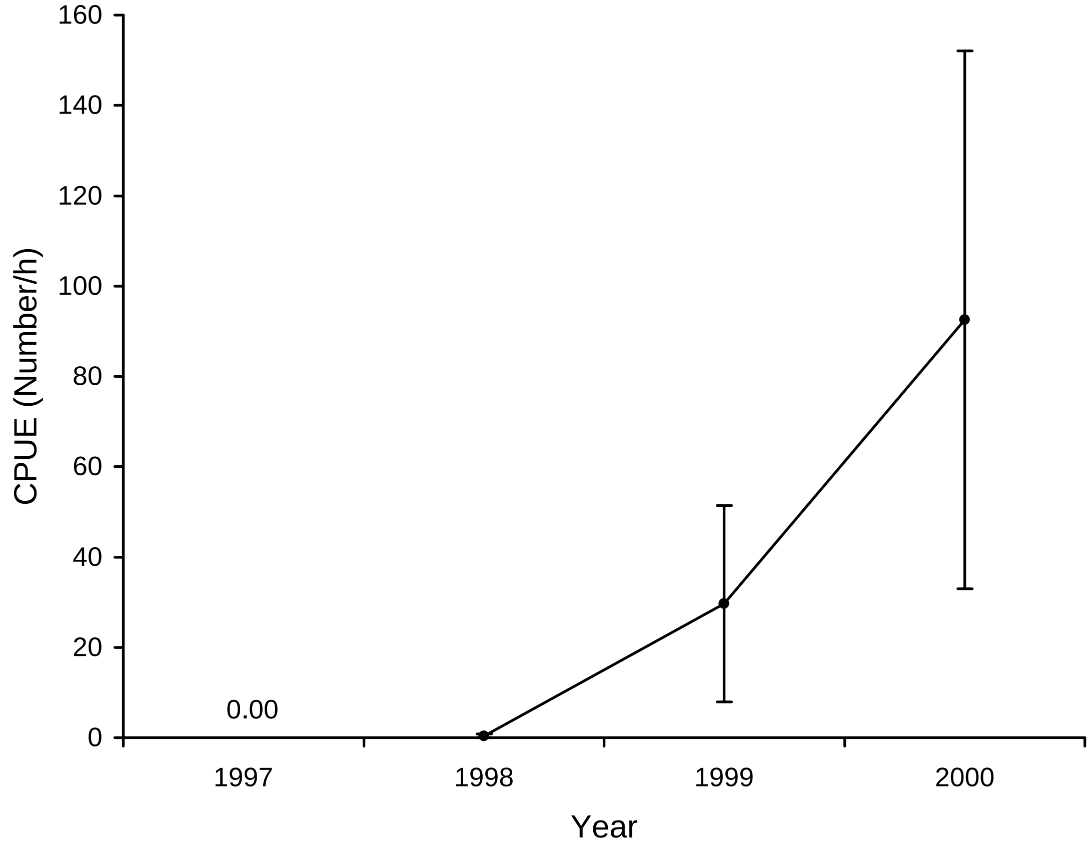

Figure 4-10. Mean trawl CPUE of round gobies for pooled June-August sample periods in Indiana waters of Lake Michigan. The data represent pooled sites M, K, and G. Error bars are ± 2 SE.

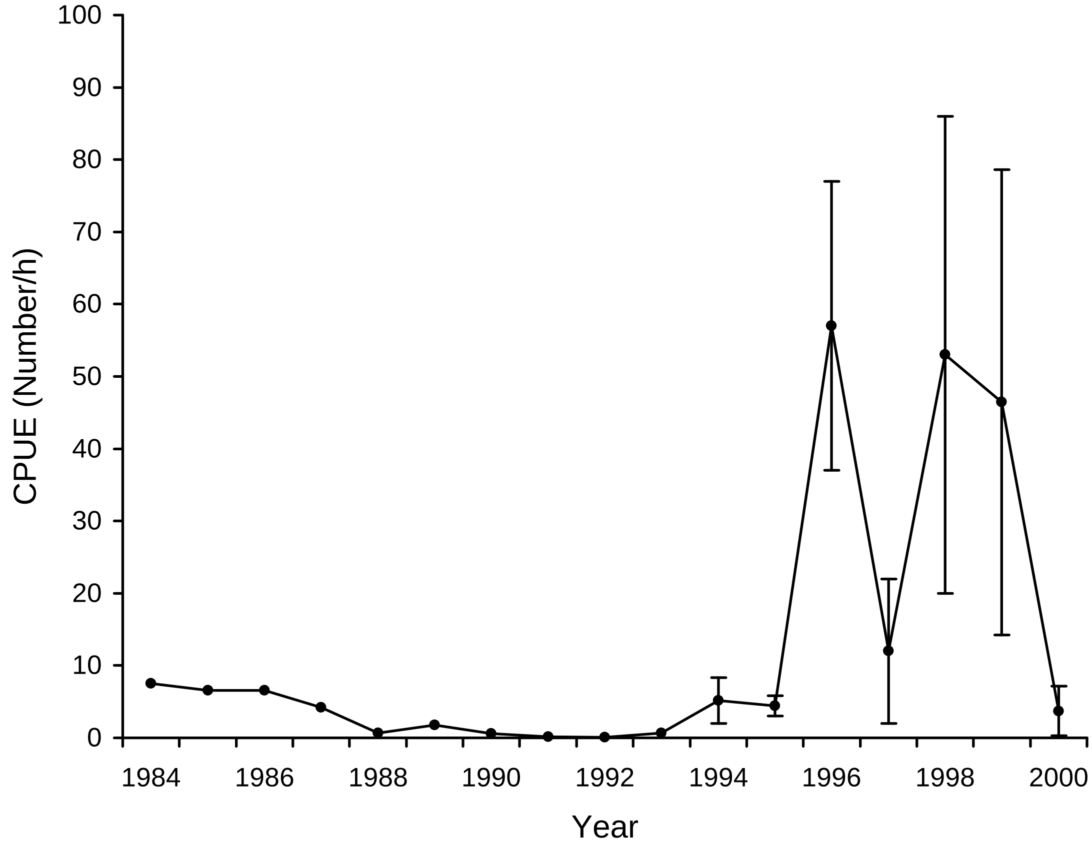

Figure 4-11. Mean trawl CPUE of trout-perch for pooled June-August sample periods in Indiana waters of Lake Michigan. The 1984-1988 data represent pooled sites M and K; the 1989-2000 data represent pooled sites M, K, and G. Error bars for 1994-2000 are ± 2 SE.

wide fluctuations. Currently, no apparent correlation between CPUE of trout-perch and yellow perch or alewives exist (Sapp 1999).

Johnny Darter

Johnny darter trawl CPUE in 2000 was near zero, which was preceded by three years of declining abundance from its highest catch recorded in 1996 (Figure 4-12). This decline may be the result of an interaction between johnny darters and the recent increased abundance of round gobies, as both are benthic species.

Threespine Stickleback

The threespine stickleback, a nonindigenous species (Stedman and Bowen 1985), was captured at our index sites for the first time in 1993, represented by one specimen from site M (McComish et al. 1994). Thereafter the CPUE increased exponentially each year to a peak of 187 fish/h in 1996. The following year, the CPUE plummeted to < 5 fish/h and was below 1 fish/h in 1999 and zero in 2000. Threespine sticklebacks have been caught almost exclusively when bottom temperatures at 5 m have been < 20 C, so they may move offshore as the nearshore water warms. Unusually warm 5-m bottom temperatures in June-August 1998-2000 may have contributed to the extremely low or zero CPUE in those years. It may also be, however, that the population has collapsed and the fish were absent in the catch for that reason. Consequently, the current population abundance of the threespine stickleback in Indiana waters is uncertain.

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

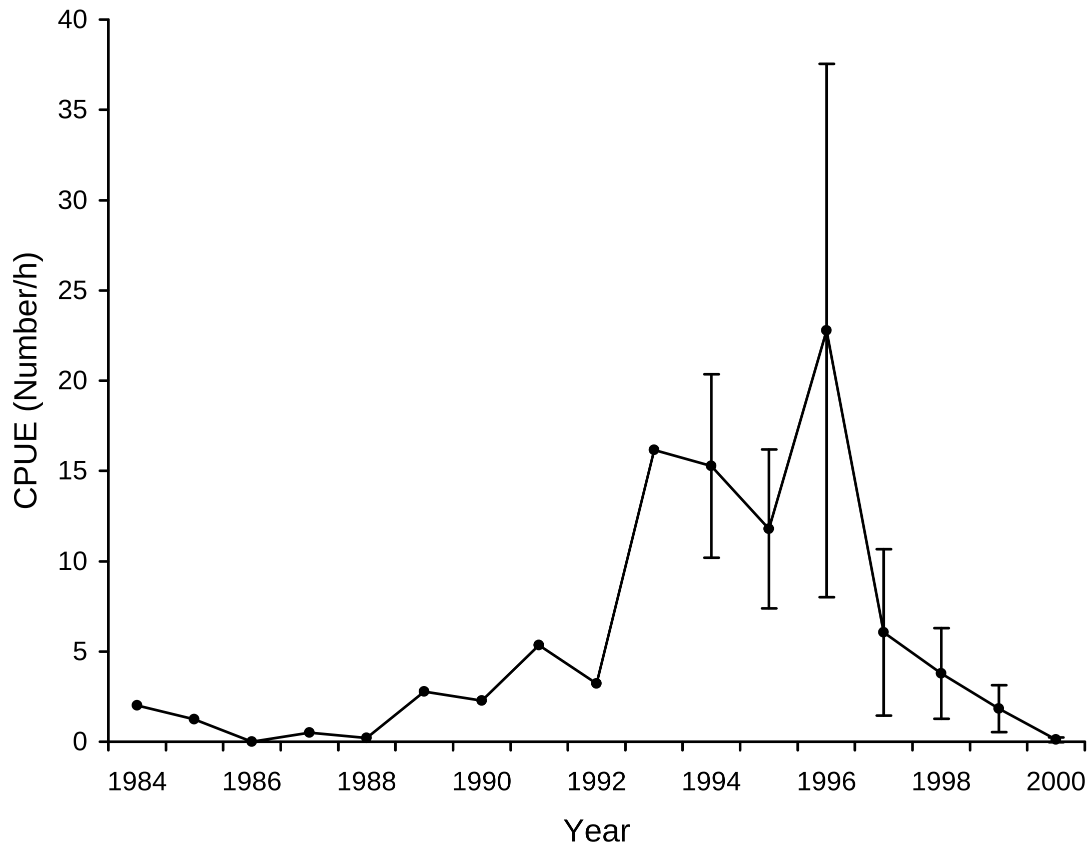

Figure 4-12. Mean trawl CPUE of johnny darters for pooled June-August sample periods in Indiana waters of Lake Michigan. The 1984-1988 data represent pooled sites M and K; the 1989-2000 data represent pooled sites M, K, and G. Error bars for 1994-2000 are ± 2 SE.

composition of the incidental catch in 2000 was generally similar to that reported in other years, with the exception of the new nonindigenous species already noted. White perch *Morone americana*, recently reported by McComish et al. (2000), was not captured at the three Indiana sample sites in 2000. We will continue to carefully monitor the species present and be on the lookout for nonindigenous species.

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

<u>Forecasting Quality Sized Yellow Perch CPUE</u>

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 $t + 2$. Differences from Figure 4 of Shroyer and McComish (1998) are due to inclusion of t = 1995-1998, incorporation of site G beginning with t = 1989, and recalculation of stock and quality CPUE for earlier years. The data points for t = 1995-1998 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,

$$(2)\ \sqrt{Q_{t+2}} = 3.29 + 0.00427 \bullet S_t$$

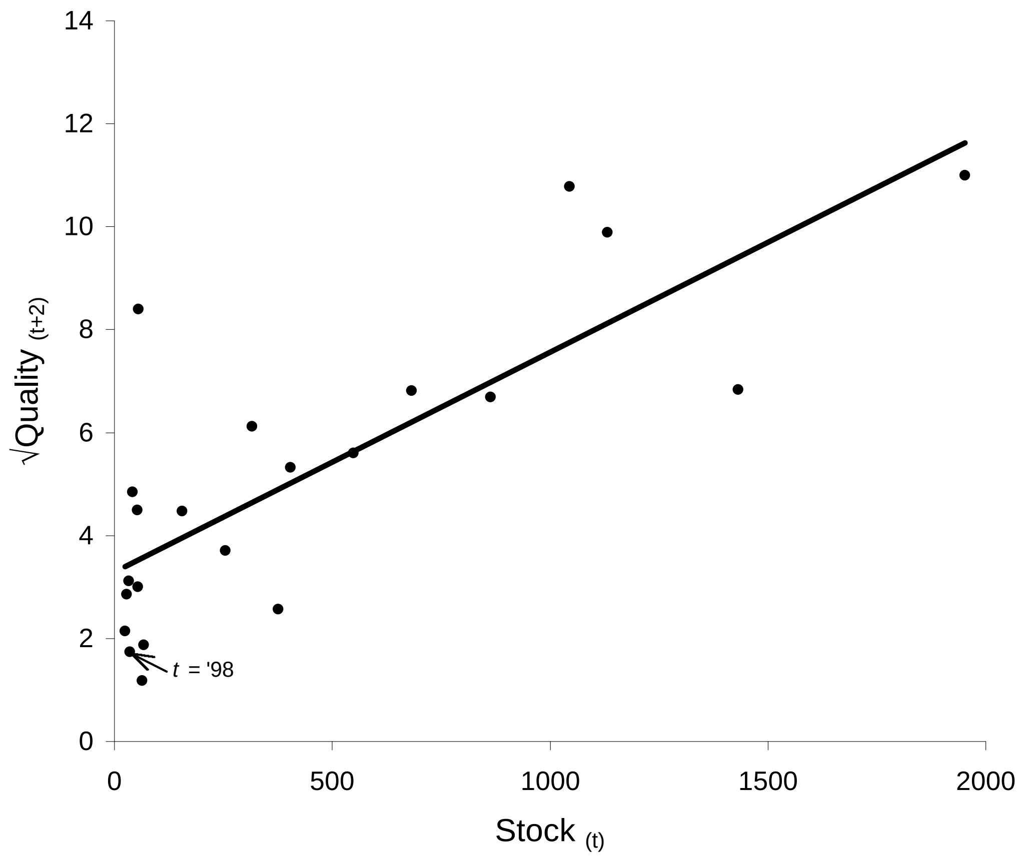

Figure 5-1. Relationship between trawl CPUE (number/h) of stock-size yellow perch in year *t* and the square root of trawl CPUE (number/h) of quality-size yellow perch in year *t* + 2 at sites M, K, and G in Indiana waters of Lake Michigan, for *t* = 1975-1979, 1981, and 1983-1998. Gaps in the time series 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).

Model (2) predicts with 95% confidence that quality CPUE will be less than 56 fish/h in 2001-2002.

Alewife and Recruitment

Shroyer and McComish (2000) examined the relationship between the abundance of alewives and the recruitment of yellow perch to determine if 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 = 1998. The t = 1998 data point does not stand out from earlier data points, providing no evidence of a change in the relationship between alewife abundance and yellow perch recruitment. The 95% confidence intervals for the slope and intercept of the updated regression line include the slope and intercept of model (3), indicating no significant difference. The updated model for pooled sites M, K, and G is:

$$(4)\ \log_e R_{t+2} = 11.82 - (2.24)\ \log_e A_t$$

Model (4) predicts with 95% confidence that age-2 CPUE of the 1999 year class will be between 0.5/h and 109.8/h. The point estimate of 7.5/h appears reasonable given the

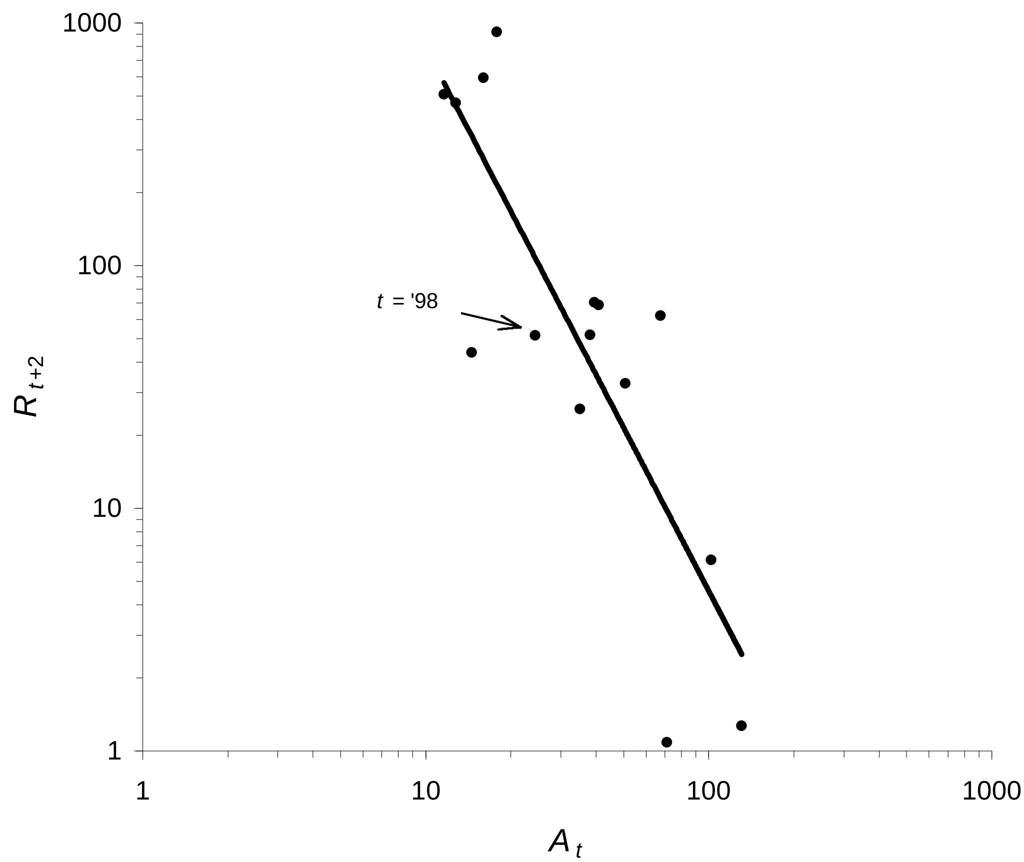

Figure 5-2. Relationship between trawl CPUE (number/h) of age-1 and older alewives in year *t* (A_t) and trawl CPUE (number/h) of age-2 yellow perch in year *t* + 2 (R_{t+2}) at sites M, K, and G in Indiana waters of Lake Michigan, for *t* = 1984-1998. This plot is an update of Figure 1 in Shroyer and McComish (2000).

actual CPUE of 3/h at age 1 (Appendix 3-1). Due to high alewife abundance in 2000 (Figure 4-5), the 95% prediction interval for age-2 CPUE of the 2000 year class ranges from 0.04/h-17.2/h. However, caution should be made in predicting the 2000 year class as alewife densities have been extrapolated beyond the range of values used to create the equation.

<u>Alewife, Stock, and Recruitment</u>

Shroyer and McComish (2000) discussed the possible importance of yellow perch spawning stock abundance to prediction of yellow perch recruitment in years when alewife abundance is low enough to allow the potential for strong recruitment, but they did not include spawning stock abundance in their published model. It is possible to include both spawning stock abundance and alewife abundance in a Ricker type stock-recruitment model. A model of this type first appeared in McComish and Shroyer (1996) and was recently updated in McComish et al. (2000). In this section, we present an update to the most recent edition which incorporated $t = 1998$. 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 at pooled sites M, K, and G for t = 1984-1998 resulted in the equation:

$$(5)\ \log_e\left(\frac{R_{t+2}}{S_t}\right) = \log_e a - bS_t - 2.238 \log_e A_t$$

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

= 0.409; P = 0.303), residual plots did not indicate substantial lack of fit or non-constant variance, and residuals were not significantly autocorrelated (Durbin-Watson statistic = 1.91; P > 0.05). Regression statistics for equation (5) are listed in Table 5-1. The adjusted R^2 for this model is 0.724, compared to 0.679 for model (4) of the previous section. Thus, addition of abundance of quality-size fish resulted in a slight statistical improvement of the recruitment model. The variable S_t is, at best, only marginally significant statistically (Table 5-1). However, there is strong biological justification for inclusion of the stock-recruitment relationship (Hilborn and Walters 1992). Model (5) is more realistic biologically than model (4) of the previous section because it forces recruitment to approach zero as spawning stock approaches zero.

Equation (5) is convenient for estimating recruitment itself. Equation (5) predicts that trawl CPUE of the 1999 year class at age 2 will be 6.5/h (95% prediction interval: 0.48/h-86.1/h). This is not significantly different from the predictions using only alewife abundance, but the 95% prediction interval is substantially narrower. Predicted trawl CPUE of the 2000 year class at age 2 is 0.12/h (95% prediction interval: 0.01/h-2.31/h). Again, the 2000 year class prediction should be taken with caution due to extrapolation of alewife CPUE as described in the previous section.

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

Table 5-1. Summary of the results of the regression of $\log_e(R_{t+2}/S_t)$ versus St and $\log_e A_t$ for sites M, K, and G in Indiana waters of Lake Michigan, t = 1984-1998.

Regression Statistics	
Multiple R	0.874
R Square	0.764
Adjusted R Square	0.724
Standard Error	1.099
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*P*
Regression	2	46.874	23.437	19.397	0.000174
Residual	12	14.499	1.208		
Total	14	61.373			

	Coefficients	*SE*	*t*	*P*	Lower 95% C.I.	Upper 95% C.I.
Intercept	9.4837	1.4628	6.4835	0.0000	6.2967	12.6708
St	-0.0139	0.0077	-1.8126	0.0950	-0.0306	0.0028
lnAt	-2.3594	0.3859	-6.1140	0.0001	-3.2002	-1.5186

detailed description of the model and its application to southern Lake Michigan yellow perch may be found in Allen (2000).

Continued standardized index sampling and data analysis will improve model inputs, leading to a better overall yellow perch population projection.

The equations associated with the input variables, which include growth, recruitment, and mortality were updated to ensure the IYPMs continued effectiveness (see previous section). Attempts are currently under way to improve on the models' ability to predict length at age for males and females at each age class. Originally, the IYPM used population density to predict the fish's length at age. Naturally occurring overlap of ages at various length classes, particularly for older fish, resulted in the model predicting a decrease in female length from age 6 to age 7. Although females by age 6 have historically reached stock size, problems arise when weights of fish are calculated. To improve the model predictability of length at age, fish following age 2 will increase in length for subsequent years based on the historical average increments. This procedure will ensure fish do not decrease in length at older ages and likely will give a more accurate estimate of the fish's length at age. Natural mortality updated in the model will shift from the use of n (Ricker 1975) as a normal distribution to being computed from M (Ricker 1975). The parameter M will be predicted in the model based on the value of the Brody coefficient K (from von Bertalanffy). Pauly (1980) notes the parameters M and K are closely related and initial analysis of our data supports that hypothesis. The Brody coefficient K, will be generated for each age of males and females based on population density. This procedure will likely enhance the effects density-dependence has on yellow perch natural mortality.

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Appendix 2-1. Back-calculated total lengths (mm) of male yellow perch from sites M, K, and G in Indiana waters of Lake Michigan in 2000.

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
1999	1	20	88															
1998	2	91	83	129														
1997	3	53	91	154	194													
1996	4	10	90	166	205	227												
1995	5	24	93	163	201	226	245											
1994	6	10	79	145	184	214	234	253										
1993	7	1	76	170	205	223	227	233	236									
1992	8	0																
1991	9	0																
1990	10	2	62	105	137	156	186	205	217	230	237	243						
1989	11	0																
1988	12	1	84	143	157	177	191	200	204	213	229	236	241	245				
1987	13	0																
1986	14	1	70	127	159	172	177	181	185	193	202	210	218	242	255	266		
All			87	142	194	219	236	237	212	216	226	233	229	243	255	266		
N		213	213	193	102	49	39	15	5	4	4	4	2	2	1	1		

Appendix 2-2. Back-calculated total lengths (mm) of female yellow perch from sites M, K, and G in Indiana waters of Lake Michigan in 2000.

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
1999	1	20	83															
1998	2	192	92	154														
1997	3	149	91	170	240													
1996	4	11	96	169	220	262												
1995	5	86	86	164	222	265	305											
1994	6	14	84	153	205	244	274	302										
1993	7	5	79	136	194	236	269	298	314									
All			90	161	231	261	299	301	314									
N		477	477	457	265	116	105	19	5									

Appendix 3-1. Mean June-August 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
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							0.038	0.071	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	0.051	0.059	0.57	0.27	1.1	0.9	1.6	1.2	4.0	44	1.5			
1998				0.017		0.0082		0.021	0.23	0.034	0.18	0.080	0.067	0.33	1.0	14	1.3	98		
1999					0.073	0.026	0.043	0.012	0.31	0.14	0.094	0.42	0.45	0.32	2.1	10	2.8	33	171	
2000									0.03		0.03				0.06	0.6	0.1	3.2	51	3

Appendix 3-2. Yellow perch catch per unit effort (CPUE; number/h) for various components of the population, from June-August 5-m-depth bottom trawl samples in Indiana waters of Lake Michigan. Data from 1975-1983 are for site K only; 1984-1988 data are pooled sites M and K; 1989-2000 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		5.2		13
1976	31		1.5		29		5.1		24		6.6		27
1977	134		47		86		20		67		24		35
1978	154		1.3		153		119		34		4.6		14
1979	105		31		74		10		63		3.5		5.5
1980	598		155		443		361		82		10		12
1981	896		1.2		895		840		55		1.4		2.5
1982													
1983	2550	1258	492	590	2058	973	626	347	1432	917	71	57	4.9
1984	1207	603	164	206	1042	609	639	308	404	321	14	12	3.4
1985	2641	1706	989	1596	1652	733	788	441	863	364	47	31	5.4
1986	2559	873	387	392	2171	636	1126	475	1045	415	28	18	2.7
1987	1703	574	67	80	1636	568	504	138	1132	492	45	18	4.0
1988	2216	1493	12	14	2204	1491	252	127	1952	1418	116	86	6.0
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	174	181	316	178	46	33	15
1992	284	150	0.83	1.0	283	150	28	13	255	143	31	18	12
1993	386	256	7.7	10	378	258	2.4	1.3	376	257	37	20	10
1994	179	102	6.8	5.5	172	103	17	11	156	97	14	8.8	8.8
1995	50	33	10	14	40	29	12	6.5	28	28	6.6	7.0	24
1996	98	57	0.61	0.76	98	56	43	27	54	33	20	11	37
1997	67	36	12	11	55	29	2.9	1.8	52	28	8.2	5.1	16
1998	1070	836	954	849	116	52	80	45	36	21	9.0	6.3	25
1999	224	102.3	3.8	4.4	220	103.5	167	93.009	53	33	20	13.16	38
2000	59.3	29.5	0.9	0.7	58.4	30	35.6	17.9	22.7	13.3	3.0	3.3	13

Appendix 3-3. Mean June-August trawl CPUE (number/h) of both sexes of yellow perch age ≥1, by length class and age, at sites M, K, and G in Indiana waters of Lake Michigan in 2000.

Length class	Age																		
(mm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
50																			
60	0.11																0.11	0.2	0.2
70	0.23																0.23	0.4	1
80	0.68																0.68	1.2	2
90	0.80	0.48															1.28	2.2	4
100	0.56	6.22															6.78	11.6	16
110	0.50	11.69	0.15														12.34	21.2	37
120		14.10	0.06														14.15	24.3	61
130		9.89	0.51														10.40	17.8	79
140		5.11	0.54														5.64	9.7	89
150		1.60	0.06														1.66	2.8	91
160		0.83															0.83	1.4	93
170		0.27	0.05														0.33	0.6	93
180		0.13	0.01	0.02													0.16	0.3	94
190		0.45	0.22														0.66	1.1	95
200		0.21	0.07														0.28	0.5	95
210		0.10	0.06	0.06	0.01												0.22	0.4	96
220		0.01	0.33														0.34	0.6	96
230		0.08	0.35														0.44	0.8	97
240		0.10	0.29	0.01	0.03	0.01				0.03		0.03					0.50	0.9	98
250		0.11	0.16		0.01												0.28	0.5	98
260			0.07	0.01	0.02												0.11	0.2	98
270		0.02	0.15		0.05												0.22	0.4	99
280			0.03		0.01	0.01											0.06	0.1	99
290			0.06		0.20	0.01											0.27	0.5	99
300			0.02	0.02	0.10	0.02											0.17	0.3	100
310				0.01	0.09	0.01											0.11	0.2	100
320																			
330																			
340																			
350																			
360					0.05												0.05	0.1	100
370																			
Total	2.88	51.41	3.20	0.14	0.56	0.06				0.03		0.03					58		
%	5	88	5.5	0.2	1.0	0.11				0.048		0.0476							
Cum%	5	93	99	99	100	100				100		100							

Appendix 3-4. Mean June-August trawl CPUE (number/h) of male yellow perch age ≥1, by length class and age, at sites M, K, and G in Indiana waters of Lake Michigan in 2000.

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	0.17																0.17	1.2	1
80	0.45																0.45	3.1	4
90	0.45	0.06															0.50	3.5	8
100	0.23	2.10															2.33	16.1	24
110	0.06	3.78	0.15														3.99	27.5	51
120		3.71	0.06														3.77	26.0	77
130		1.05	0.51														1.56	10.7	88
140		0.78	0.11														0.89	6.2	94
150		0.06															0.06	0.4	95
160		0.17															0.17	1.2	96
170		0.05															0.05	0.4	96
180																	0.00	0.0	96
190		0.15	0.13														0.28	1.9	98
200																	0.00	0.0	98
210		0.07	0.04	0.05	0.01												0.17	1.2	99
220																	0.00	0.0	99
230																	0.00	0.0	99
240			0.01	0.01	0.03	0.01				0.03		0.03					0.11	0.8	100
250																			
260																			
Total	1.36	11.98	1.02	0.06	0.03					0.03		0.03					14.50		
%	9.4	82.6	7.0	0.4	0.2					0.2		0.2							
Cum%	9	92	99	99	100					100		100							

Appendix 3-5. Mean June-August trawl CPUE (number/h) of female yellow perch age ≥1, by length class and age, at sites M, K, and G in Indiana waters of Lake Michigan in 2000.

Length class (mm)	Age 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	%	Cum%
50																			
60	0.11																0.11	0.3	0.3
70	0.06																0.06	0.1	0.4
80	0.22																0.22	0.5	0.9
90	0.35	0.43															0.78	1.8	2.7
100	0.33	4.12															4.45	10.2	12.8
110	0.44	7.91															8.35	19.1	31.9
120		10.39															10.39	23.7	55.6
130		8.84															8.84	20.2	75.8
140		4.33	0.42														4.75	10.8	86.6
150		1.54	0.06														1.61	3.7	90.3
160		0.67															0.67	1.5	91.8
170		0.22	0.05														0.27	0.6	92.4
180		0.13	0.01	0.02													0.16	0.4	92.8
190		0.30	0.09														0.39	0.9	93.7
200		0.21	0.07														0.28	0.6	94.3
210		0.03	0.02	0.01													0.05	0.1	94.5
220		0.01	0.33														0.34	0.8	95.2
230		0.08	0.35														0.44	1.0	96.2
240		0.10	0.28	0.01													0.39	0.9	97.1
250		0.11	0.16		0.01												0.28	0.6	97.7
260			0.07	0.01	0.02												0.11	0.2	98.0
270		0.02	0.15		0.05												0.22	0.5	98.5
280			0.03		0.01	0.01	0.006										0.06	0.1	98.6
290			0.06		0.20	0.01											0.27	0.6	99.2
300			0.02	0.02	0.10	0.02											0.17	0.4	99.6
310				0.01	0.09	0.01											0.11	0.3	99.9
320																			
330																			
340																			
350																			
360					0.054												0.05	0.1	100
370																			
Total	1.52	39.43	2.18	0.08	0.53	0.06	0.01										43.81		
%	3.5	90.0	5.0	0.2	1.2	0.13	0.01												
Cum%	3.5	93.5	98.5	98.7	99.9	100	100												

Appendix 3-6. Mean June-August 10-m and 15-m gill net CPUE (number/net/night) of both sexes of yellow perch, by length class and age, at sites M, K, and G in Indiana waters of Lake Michigan in 2000.

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	0.01	0.02															0.03	0.10	0
110																			
120																			
130																			
140																			
150																			
160	0.00	0.06															0.06	0.21	0
170		0.03															0.03	0.10	0
180		0.11	0.08	0.01													0.19	0.73	1
190		0.21	0.46														0.67	2.49	4
200		0.39	0.45	0.04	0.03												0.92	3.43	7
210		0.49	1.06	0.18	0.05												1.78	6.65	14
220	0.00	0.31	1.20	0.06	0.10												1.67	6.24	20
230		0.38	1.25	0.07	0.14	0.03	0.03			0.03							1.92	7.17	27
240		0.91	1.44	0.17	0.18	0.05				0.01		0.01					2.78	10.4	38
250		0.94	1.82		0.21	0.14											3.11	11.6	49
260		0.20	1.74	0.17	0.28	0.06								0.03			2.47	9.25	58
270		0.30	1.19		0.24	0.21											1.94	7.28	66
280			1.02	0.04	0.56	0.04											1.75	6.55	72
290			0.69		1.10	0.15											1.94	7.28	80
300			0.16	0.12	1.97	0.12											2.36	8.83	88
310			0.21	0.19	1.23	0.09											1.72	6.44	95
320					0.78	0.03	0.03										0.83	3.12	98
330					0.31	0.08											0.39	1.46	99
340					0.08		0.03										0.11	0.42	100
350						0.03	0.03										0.06	0.21	100
360																			
370																			
Total	0.01	4.33	12.8	1.05	7.26	1.02	0.20			0.04		0.01		0.03			27		
%	0.05	16.2	47.8	3.92	27.2	3.82	0.74			0.16		0.05		0.10					
Cum%	0.05	16	64	68	95	99	100			100		100		100					

Appendix 3-7. Mean June-August 10-m and 15-m gill net CPUE (number/net/night) of male yellow perch, by length class and age, at sites M, K, and G in Indiana waters of Lake Michigan in 2000.

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	0.01	0.02															0.03	0.76	1
110																			
120																			
130																			
140																			
150																			
160		0.06															0.06	1.53	2
170																			
180			0.06														0.06	1.53	4
190		0.06	0.28														0.33	9.16	13
200		0.08	0.32	0.04	0.03												0.47	13.0	26
210		0.04	0.32	0.12	0.05												0.53	14.5	40
220		0.07	0.13	0.06	0.10												0.36	9.9	50
230			0.11	0.03	0.14	0.03	0.03			0.03							0.36	9.9	60
240			0.15	0.07	0.18	0.05				0.01		0.01					0.47	13.0	73
250			0.06	0.00	0.14	0.14											0.33	9.2	82
260			0.19	0.08	0.11	0.06								0.03			0.47	13.0	95
270					0.03	0.03											0.06	1.5	97
280					0.00												0.00	0.0	97
290					0.08												0.08	2.29	99
300					0.03												0.03	0.76	100
310																			
Total	0.01	0.31	1.62	0.40	0.89	0.30	0.03			0.04		0.01		0.03			4		
%	0.34	8.61	44.38	10.9	24.6	8.11	0.76			1.15		0.38		0.76					
Cum%	0.34	9	53	64	89	97	98			99		99		100					

Appendix 3-8. Mean June-August 10-m and 15-m gill net CPUE (number/net/night) of female yellow perch, by length class and age, at sites M, K, and G in Indiana waters of Lake Michigan in 2000.

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																			
170		0.03															0.03	0.12	0.12
180		0.11	0.02	0.01													0.14	0.60	0.7
190		0.15	0.18														0.33	1.44	2.2
200		0.31	0.13														0.44	1.93	4.1
210		0.46	0.74	0.06													1.25	5.42	9.5
220		0.23	1.07														1.31	5.66	15.2
230		0.38	1.14	0.04													1.56	6.74	21.9
240		0.91	1.29	0.10													2.31	9.99	31.9
250		0.94	1.77		0.07												2.78	12.0	43.9
260		0.20	1.55	0.08	0.17												2.00	8.66	52.6
270		0.30	1.19		0.22	0.19											1.89	8.18	60.8
280			1.02	0.04	0.56	0.04	0.09										1.75	7.58	68.4
290			0.69		1.01	0.15											1.86	8.06	76.4
300			0.16	0.12	1.94	0.12											2.33	10.1	86.5
310			0.21	0.19	1.23	0.09											1.72	7.46	94.0
320					0.78	0.03	0.03										0.83	3.61	97.6
330					0.31	0.08											0.39	1.68	99.3
340					0.08		0.03										0.11	0.48	99.8
350						0.03	0.03										0.06	0.24	100
360																			
370																			
Total		4.02	11.1	0.65	6.37	0.72	0.17										23		
%		17.4	48.3	2.8	27.6	3.1	0.7												
Cum%		17	66	69	96	99	100												

Appendix 4-1. Summary of the species composition of the mean June-August trawl catches of age ≥ 1 fish at sites M, K, and G in Indiana waters of Lake Michigan in 2000. 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	1182.3	744.7	81.4	585.7	151.6	50.1	333.8	112.8	56.0	700.6	119.7	65.4
Alewife	194.2	153.2	13.4	273.3	191.8	23.4	177.7	106.4	29.8	215.1	84.6	20.1
Round goby	28.8	29.7	2.0	243.3	90.2	20.8	5.3	4.1	0.9	92.5	59.6	8.6
Yellow perch	42.5	44.4	2.9	59.2	54.1	5.1	73.3	59.8	12.3	58.3	29.0	5.4
Trout-perch	1.3	1.6	0.1	4.8	5.6	0.4	5.0	8.0	0.8	3.7	3.4	0.3
Chinook salmon[2]	1.5	2.6	0.1	0.2	0.3	0.0				0.56	0.1	0.1
Longnose sucker	0.3	0.4	0.0	0.8	1.7	0.1				0.39	0.7	0.0
Johnny darter	0.2	0.3	0.0	0.2	0.3	0.0				0.11	0.1	0.0
Lake Trout[2]	0.2	0.3	0.0	0.2	0.3	0.0				0.11	0.1	0.0
Rainbow smelt				0.2	0.3	0.0	0.2	0.3	0.0	0.11	0.2	0.0
White sucker				0.2	0.3	0.0	0.2	0.3	0.0	0.11	0.2	0.0
Freshwater drum	0.2	0.3	0.0							0.06	0.0	0.0
Gizzard shad	0.2	0.3	0.0							0.06	0.0	0.0
Ninespine stickleback							0.2	0.3	0.0	0.06	0.1	0.0
Totals	1452	828	100	1168	261	100	596	39	100	1072	558	100

[1]Primarily *C. bairdi*; possibly some *C. cognatus*.

[2]Fingerlings.

Appendix 4-2. Summary of the species composition of the mean June-August gill net catch at sites M, K, and G in Indiana waters of Lake Michigan in 2000. 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	67.0	36.1	89.1	49.3	27.1	85.3	48.3	10.5	82.9	54.89	12.18	86.06
Alewife	5.7	7.6	7.5	4.8	7.8	8.4	4.0	4.5	6.9	4.83	3.28	7.58
White sucker	1.0	0.9	1.3	2.3	2.9	4.0	4.7	3.4	8.0	2.67	1.73	4.18
Longnose sucker				0.5	1.0	0.9	0.3	0.4	0.6	0.28	0.41	0.44
Chinook salmon	0.2	0.3	0.2	0.3	0.7	0.6				0.17	0.26	0.26
Gizzard shad	0.3	0.4	0.4	0.0	0.0	0.0	0.2	0.3	0.3	0.17	0.14	0.26
Round Goby	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.3	0.17	0.18	0.26
Brown trout							0.3	0.7	0.6	0.11	0.26	0.17
Coho salmon	0.2	0.3	0.2	0.2	0.3	0.3				0.11	0.13	0.17
Freshwater drum	0.3	0.7	0.4							0.11	0.09	0.17
Lake trout				0.2	0.3	0.3	0.2	0.3	0.3	0.11	0.18	0.17
Channel catfish	0.2	0.3	0.2							0.06	0.04	0.09
Rock bass							0.2	0.3	0.3	0.06	0.13	0.09
Steelhead	0.2	0.3	0.2							0.06	0.04	0.09
Totals	75.2	35.0	100	57.8	23.9	100	58.3	10.1	100	63.8	10.1	100

[1]May include some lake herring *Coregonus artedi.*