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INHS Technical Report 2015 (43)

Prepared for the Illinois Department of Natural Resources, Division of Fisheries

Issue Date: 11/20/2016

Sponsor: Division of Fisheries, Illinois Department of Natural Resources,
Grant/Contract No: Federal Aid Project F-123 R-21

Unrestricted; for immediate online release

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July 1, 2014 – June 30, 2015

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submitted to
Division of Fisheries, Illinois Department of Natural Resources
in fulfillment of the reporting requirements of
Federal Aid Project F-123-R 21

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November 2015

This study is conducted under a memorandum of understanding between the Illinois Department of Natural Resources and the Board of Trustees of the University of Illinois. The actual research is performed by the Illinois Natural History Survey, Prairie Research Institute. The project is supported through Federal Aid in Sport Fish Restoration by the U.S. Fish and Wildlife Service, the Illinois Department of Natural Resources, and the Illinois Natural History Survey. The form, content, and data interpretation are the responsibility of the University of Illinois and the Illinois Natural History Survey, and not the Illinois Department of Natural Resources

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INTRODUCTION

Yellow perch (*Perca flavescens*) is an important sport fish throughout much of its range in North America and they have supported commercial fisheries in larger waters, such as the Great Lakes. Its schooling behavior promotes sizable captures in commercial gears such as trap nets and gill nets, and the tendency of yellow perch to congregate nearshore in the spring makes this species accessible to shore anglers. The majority of yellow perch harvested in North America are taken from the Great Lakes; yellow perch provide the one of the most important sport fisheries in the four states bordering Lake Michigan and until 1997 supported large-scale commercial fisheries in three of those states.

Lake Michigan yellow perch have undergone severe fluctuations in abundance during the past several decades. The population in the southern basin increased dramatically in the 1980's (McComish 1986), and the sport and commercial fisheries expanded accordingly. In Illinois waters alone, the estimated annual catch by sport fishermen doubled between 1979 and 1993, from 600,000 to 1.2 million fish (Muench 1981, Brofka and Marsden 1993). Between 1979 and 1989, the commercial harvest in Illinois tripled, in Wisconsin (excluding Green Bay) it increased six-fold, and in Indiana the harvest increased by over an order of magnitude (Brazo 1990, Hess 1990). However, the yellow perch fishery in Illinois waters during the early and mid-1990's was primarily supported by a strong year-class spawned in 1988 (Marsden and Robillard 2004). Few or no young-of-the-year (YOY) yellow perch were found in lake-wide sampling efforts during 1994-1997 (Hess 1998), but significantly greater survival of the 1998 year-class occurred. The 1998 year-class dominated Lake Michigan Biological Station (LMBS) spring adult assessments between 2000 and 2004 (previous segments of F-123-R). During this period, LMBS trawling efforts detected moderate year-class strength during 2002 and 2004. In 2005, the age structure of yellow perch began to shift towards younger fish so that 52% of the catch was age-3 (2002 year-class) and the 1998 year-class (age-7) contributed 37% of the catch. Additionally, age-0 CPUE from trawling assessments during 2005 and 2010 were the highest recorded in Illinois waters since 1988. During 2006-2008, the 2002 and 2003 year-classes dominated LMBS spring adult assessments and sport harvest collections. Then, in 2009 and 2010 LMBS yellow perch samples (fishery independent and sport harvest) were dominated by the 2005 year-class, while the 2002 and 2003 year-classes also contributed significantly to the fishable population (Redman et al. 2011a). While multiple year-classes (typically at age-3, age-4, and age-5) often support the fishery, current yellow perch harvest has become increasingly reliant on the 2010 year-class and harvest has been near record low levels recorded during the late 1990's (previous segments of F-123-R and F-52-R). Current lake wide assessments show that yellow perch abundance remains low, particularly in comparison to abundance observed in the late 1980's and early 1990's (Makauskas and Clapp 2010). Thus, there continues to be concern about the survival and growth of yellow perch and sustainability of the population in Lake Michigan.

To protect fish stocks, fisheries managers often regulate harvest by implementing size or daily bag limits. However, the ability to successfully set harvest regulations for yellow perch in Lake Michigan is hampered by insufficient information about population size, natural mortality, reproductive potential, and factors affecting the growth and survival of juveniles. The continued decline of the yellow perch population due to reduced survival of larvae to the demersal age-0 stage has prompted researchers to narrow the focus of investigation to spawning behavior and success along with age-0 interactions and survival. Reproductive potential influences the ability of the population to respond to external forces such as overfishing or environmental fluctuations. Thus, accurate estimates of fecundity and knowledge of how reproductive potential varies over the life of yellow perch in Lake Michigan are crucial to the development of appropriate management strategies to ensure the persistence of this species. Fecundity (Brazo et al. 1975) and egg quality (Heyer et al. 2001) have been shown to increase with age in yellow perch. Additionally, marine larvae produced by younger spawners have been shown to experience higher mortality than larvae produced by older, more experienced spawners (O'Farrell and Botsford 2006). Thus, estimates of reproductive potential based on biomass estimates alone risk oversimplifying and overestimating reproductive output. Assessment of pelagic and demersal age-0 yellow perch along with additional juvenile (age-1 and age-2) life stages may permit prediction of future year-class strength. However, variability of larval yellow perch abundance data and age-0 catches is very high, and much remains unknown about the early life history of yellow perch in large lakes. Particularly, how the hydrodynamics of Lake Michigan influence the advection of larval yellow perch from nearshore spawning sites to the offshore pelagic zone as well as eventual settlement into benthic nearshore nursery habitat. The ability to couple physical and biological data will not only enhance our understanding of pelagic age-0 yellow perch feeding behavior, early life-stage movement, and survival rates but also contribute to our ability to monitor year-class strength relative to other years. Characterizing the mechanisms influencing ontogenetic diet and habitat shifts will contribute to our basic understanding of the offshore pelagic stage of age-0 yellow perch in Lake Michigan. Annual assessment of age-0 yellow perch returning to the benthic nearshore areas in the fall, abundance and diet of juvenile (age-1 through age-3) yellow perch, coupled with 20+ years of data collected on yellow perch in Illinois waters of Lake Michigan will help to identify critical bottlenecks that limit survival between early life stages and recruitment to the sport fishery.

Concurrent with the decrease in larval fish recruitment, zooplankton density in southern Lake Michigan has declined, and the assemblage structure has shifted. Nearshore densities of zooplankton in southern Lake Michigan during 1990–2010 were consistently lower than densities in the late 1980s, when yellow perch abundance and harvest were dramatically higher (Dettmers et al. 2003, Clapp and Dettmers 2004, Redman et al. 2011a). Furthermore, zooplankton taxonomic composition in June shifted from abundant cladocerans (about 30% by number) mixed with large-bodied copepods during 1988–1990 to abundant smaller copepods and rotifers, but few cladocerans during 1996-1998. *Daphnia retrocurva* dominated the daphnid community in nearshore waters of southern Lake Michigan during 1972-1984, but declines in abundance occurred following the invasion of *Bythotrephes cederstroemi* in 1986 (Madenjian et al. 2002, Barbiero and Tuchman 2004). Declines in several other Cladocerans species, such as *Eubosmina coregoni*, *Daphnia pulicaria*, and *Leptodora kindti*, have also been attributed to the invasion of this predatory cladoceran (Makarewicz et al. 1995, Barbiero and Tuchman 2004). Additionally, in earlier studies we evaluated how the shift in southern Lake Michigan's zooplankton assemblage influenced growth and survival of larval yellow perch using laboratory experiments (Graeb et al. 2004). One observation made during these experiments was that some yellow perch larvae failed to inflate their swim bladder (Czesny et al. 2005). Swim bladder inflation is usually associated with the nutritional state of fish larvae and can affect survival of these fish to later life stages. Thus, the status and composition of the zooplankton community in both nearshore and offshore waters of Lake Michigan greatly impacts the recruitment success of yellow perch.

To evaluate yellow perch population demographics and identify factors that continue to limit recruitment our objectives were to: 1) Monitor the age and size structure of adult yellow perch on a seasonal basis, 2) estimate the age and, if possible, sex composition of angler-harvested yellow perch, 3) determine the relative abundance of demersal age-0 yellow perch and the availability of their macroinvertebrate and zooplankton prey, 4) monitor the abundance and diet of juvenile yellow perch on a seasonal basis, and 5) collect high resolution substrate data in the nearshore with focus on historical yellow perch spawning grounds. Results of this project will help strengthen management strategies for this important sport fish species. These findings will be incorporated into yellow perch management decisions through multi-agency collaboration, which reflects a changing philosophy in the Great Lakes fisheries from jurisdictional to lake-wide management.

METHODS

Monitor the adult yellow perch population on a seasonal basis

Adult yellow perch were sampled from May 20th through July 29th, 2014 at Waukegan and Lake Forest, IL. From 2007 through 2012 adult yellow perch were sampled using monofilament gill nets consisting of 100-ft panels of 2.0, 2.5, 3.0, and 3.5-in stretched mesh. To collect a more representative sample of sexually mature yellow perch, an additional 100-ft panel of 1.5-in and 1.0-in stretched mesh was added in 2013 and 2014, respectively. During 2014, nets were set in 10, 15, and 20 meters of water for approximately 24 hours on nine occasions. Because catch per unit effort data (CPUE) is often zero heavy and possesses a high variance to mean ratio, a negative binomial distribution was specified to examine annual variability of CPUE (Power and Moser 1999). Otoliths were removed for age estimation from all adult yellow perch collected and processed via the crack and burn method (Christensen 1964). Final age was assigned as the majority vote of three independent readers.

In 2014, ovaries were taken from one 267 mm gravid female. Fecundity of this fish was approximately 41,385 eggs. We examined annual variability of CPUE to evaluate variation in relative abundance of sexually mature females from 2007 to 2014.

Estimate the age and, if possible, sex composition of angler-harvested yellow perch

Yellow perch regulations changed during the 2014 sampling season to allow harvest of yellow perch during July. In an effort to collect novel biological data amid changing regulations, 66 anal spines were collected from pedestrian anglers at Montrose Harbor and 11 anal spines were collected from a boat angler out of Calumet Harbor during July, 2014. An additional 117 spines were collected from yellow perch harvested at Montrose Harbor, IL from June 18th-30th, 2014. All yellow perch spines were cleaned, sectioned, and mounted for age determination. Fourteen spines were eliminated from age analysis due to damage during the preparation process or $<75\%$ reader agreement ($n = 180$).

Determine the relative abundance of demersal age-0 yellow perch and the availability of their macroinvertebrate and zooplankton prey.

A bottom trawl with a 4.9-m head rope, 38-mm stretch mesh body, and 13-mm mesh cod end was used to sample age-0 yellow perch north of Waukegan Harbor, IL. Daytime bottom trawling was conducted on 12 occasions between August 5th and October 20th, 2014. Sampling occurred at four depth stations (3, 5, 7.5 and 10 m) and water temperature was recorded at each depth station. All fish collected were counted and total length was measured to the nearest 1 mm.

Forty-six replicate zooplankton samples were collected at two historical sites near Waukegan Harbor, IL between May 20th and October 24th, 2014. A 64-µm mesh, 0.5-m diameter plankton net was towed vertically from 0.5 m off the bottom to the surface at 10 m depth sites. Samples were immediately preserved in 10% sugar formalin. In the lab, samples were processed by examining up to three 5-ml subsamples taken from adjusted volumes that provided a count of at least 20 individuals of the most dominant taxa. Zooplankton were enumerated and identified to the lowest taxon possible and measured.

Benthic invertebrates were collected monthly from June through October in 7.5 meters of water at a site north of Waukegan Harbor, IL. A petite ponar grab (with 232 cm^2 sampling area) was used to collect these samples due to poor conditions for SCUBA divers. During each sampling event, two replicate ponar grabs were collected and preserved in 95% ethanol. Back at the laboratory, all samples were sieved through a 363-µm mesh net to remove sand. Organisms were then sorted from the remaining sediment and identified to the lowest taxon possible, typically to genus. Total length (mm) and head capsule width (where applicable) were measured for each individual. All taxa were enumerated and total density estimates were calculated by dividing the total number of organisms counted by the sample area.

Monitor the abundance and diet of juvenile yellow perch on a seasonal basis

Juvenile yellow perch were sampled on 20 occasions from May 22th through October 20th, 2014 using 10-m gill net panels of 6, 8, 10, 12, 16 and 19 mm bar mesh. During each sampling event, nets were fished from two to four hours in 3-10 meters of water at historical sites near Waukegan Harbor, IL; total effort during 2014 was 122.7 hours.

We examined the diets of 1,896 yellow perch collected at several nearshore sites in Illinois waters of Lake Michigan from 2010-2012 (F-123-R and F-138-R, previous segments) to evaluate the onset of piscivory. Cleithra morphology was used to identify well digested fishes that would previously have been unidentifiable. We also examined the relationship between cleithra length and total fish length for five prey species and applied these relationships to estimate the total length of piscine prey items.

Survey nearshore substrate with a focus on historical yellow perch spawning grounds

An EdgeTech 4125 dual frequency 400/900 kHz side scan sonar was used to map features at the sediment water interface at historical yellow perch spawning grounds in 20 m - 10 m of water during 2014 and 2015. To ensure maximum resolution, range was set between two and three times the water depth and altitude (distance of towfish from seafloor) was maintained at 10% - 15% of the specified range by adjusting the amount of cable out. To facilitate accurate position during post processing, transects were created to ensure overlap of data between 20% and 30%. Chesapeake Technology's SonarWiz was used to post process and mosaic side scan sonar transects. Data was bottom tracked, position was corrected for cable out, and gain was applied to normalize intensity of return across files before importing in to a Geographical Information Systems framework.

RESULTS

Monitor the adult yellow perch population on a seasonal basis

During 2014, spring (May and June) effort was 11 net nights and CPUE (fish/net night) was significantly less than 2007-2011 but not different from 2012 (4.27 ± 8.99 (SD) $p<0.001$; Figure 1). Total effort during July was six net nights and mean CPUE was 3.88 ± 2.85 (SD). A total of 78 yellow perch were collected one of which was lost while retrieving nets. The sex distribution of sampled yellow perch was heavily skewed towards males (74%) with the majority of females (75%) collected after the spawning season during July. A total of 68 otoliths were used for age estimation during 2014; 10 were removed because of reader disagreement or damage while processing. Fish ranged from 2-12 years old with the 2010 (42%) and 2012 (31%) year-classes contributing most to our sampling; mean total length was 171.6 ± 59.09 mm (Figure 2).

Mean CPUE of females during May and June was similar in 2007-2011 ranging from 10-14 fish/net night, but decreased significantly in 2012 and has remained low since (CPUE = 0.45 ± 0.28 fish/net night; $p<0.001$; Figure 3). Over the course of the study, we caught mature females ranging from approximately 156 - 365 mm total length. Fecundity ranged from approximately 6,572 eggs for a 156 mm female to 141,067 eggs for a 336 mm female. Results from previous segments indicate that larger females produced more eggs thus temporal changes in abundance as well as age and size structure of the spawning stock have the potential to impact egg production at the population level in Lake Michigan.

Estimate the age and, if possible, sex composition of angler-harvested yellow perch

Angler harvested yellow perch ranged in age from 2-10 years and 139 - 361 mm in total length (Figure 4). From 2005 to 2013, pedestrian angler harvest was dominated by two or three year-classes beginning when yellow perch recruit to the recreational fishery at age-3 (Figure 5). In contrast, harvest during 2014 relied heavily on the 2010 year-class, as 74% of pedestrian harvested yellow perch were age-4. Mean total length of age-4 yellow perch was 251.8 ± 29.2 mm (SD). Evaluating the sex ratio of angler harvested yellow perch has remained elusive as a result of the invasive procedures necessary for sex determination. However, examining the relationship between length-at-age (age-2 through age-10) of angler harvested yellow perch from 2006-2014 compared to those collected during gill net sampling, indicates that length-at-age of angler harvested fish was similar to female gill net collected fish and only differs significantly at age-2 and age-3 ($p<0.05$; Figure 6). Conversely, male length-at-age was significantly different from that of angler harvested yellow perch during all years (Figure 6).

Determine the relative abundance of demersal age-0 yellow perch and the availability of their macroinvertebrate and zooplankton prey

Total effort during 2014 was approximately 193,999 m^2; a total of nine age-0 yellow perch were collected and CPUE remained near the lowest levels observed since the early 1990's at 4.6 ind/100,000m^2 (Figure 7).

Mean June-July zooplankton density (includes rotifers and veligers) in 2014 was 27.5 ind./L (Figure 8), which was similar to 2013 (30.6 ind/L) as the highest recorded densities since

2004. This increase is largely attributable to better detection of rotifers during this sampling period compared to years prior to 2013. Mean June-July (months combined) crustacean zooplankton density was 4.5 ind./L and continues to be well below the critical density of 10 ind./L suggested for effective foraging by larval yellow perch (Bremigan et al. 2003).

Mean zooplankton densities (including rotifers and veligers) ranged from 3.4 ind/L during May to 49.2 ind/L during July (Figure 9). Increases in mean zooplankton density during July, August, and October can be attributed to high densities of veligers that comprised 58%, 76%, and 76% of the total zooplankton densities during these months. Mean monthly crustacean zooplankton density was low throughout the year and peaked at a 8.3 ind./L during July (Figure 9). Copepod nauplii dominated the zooplankton assemblage during May whereas rotifers were the most abundant taxa during June – August (Figure 10). Calanoid copepods and bosmina also contributed significantly to the zooplankton assemblage during this time period. Other cladocerans (e.g. *Polyphemus*, *Ceriodaphnia*, *Leptodora*, *Diaphanosoma*, *Chydoridae*) that were commonly found in samples during 1988-1990 remain either rare or absent in samples.

Based on samples collected via ponar grabs, the overall density of benthic invertebrates near Waukegan, IL ranged from 10,387.93 ind/m^2 during July to 30,574.71 ind/m^2 in October. Mean density increased from July through October and was largely driven by an increase in the density of mollusks. Percent composition of benthic invertebrates consisted of primarily nematods and chironomids during May, June, and July (76%, 79%, and 85% of the total mean monthly density respectively), ostracods and nematods contributed significantly during August (68% of the total mean monthly density) and nematods and mollusks dominated collections during September and October (60% and 83%; Figure 11). Hydracarina were also collected, but in much smaller quantities. Composition of mollusks collected also varied, initially consisting of predominately Sphaeriidae during May (85%), June (73%) and July (69%) August (57%) and shifting to almost entirely pelecypoda mussels in October (89%). Gastropods (freshwater snails) were also present in smaller quantities throughout the sampling season.

Monitor the abundance and diet of juvenile yellow perch on a seasonal basis.

Total effort during 2014 was 122.7 hours during which we captured 64 yellow perch. Seasonal CPUE of yellow perch (all mesh sizes combined) was variable but low ranging from less than one fish/hr during May, June, July, September, and October to 2.2 fish/hr in August (Figure 12). Yellow perch collected in small mesh gill nets ranged from 57-207 mm TL and the length distribution of yellow perch varied by month (Figure 13).

During 2011 and 2014 cleithra were pulled from a subset of yellow perch (n=95), round goby (n=150), alewife (n=199), spottail shiner (n=95), and rainbow smelt (n=25) collected in small mesh gill nets and while bottom trawling to evaluate the relationship between cleithra length and total fish length. A significant relationship between cleithra length and total length was observed for all species ($p<0.05$) and R^2 ranged from 0.96 to 0.99 (Table 1). Diets from 1,896 yellow perch ranging in total length from 50 mm to 213 mm were examined from 2010-2012 to evaluate the onset of piscivory. At least 267 piscine prey items were found within the stomachs of yellow perch with the first evidence of piscivory occurring at 70 mm; in general, the percent of piscivorous yellow perch increased with total length (Figure 14). Of 267 piscine prey items, 166 round goby, 11 yellow perch, eight alewife, one nine-spined stickleback, one sculpin, and 80 unidentifiable fishes were found. Using the described relationships between cleithra total length and total fish length (Table 1) we estimated the total length of piscine prey items found within the diets of juvenile yellow perch (Figure 15). Because the relationship between estimated prey total length and yellow perch total length exhibited a wedge pattern, quantile regression was used to evaluate the relationship at different points (90th, 50th and 10th quantiles) of the relationship. Prey total length increased significantly with yellow perch total length at the 50th (median) and 90th quantiles (slope>0, p<0.05), however the slope at the lower bound 10th quantile was not significantly different from zero (p=0.18) suggesting a continued reliance on small prey items with increasing predator total length (Figure 15). Percent composition of prey items in the diets of yellow perch that were piscivorous and those where no piscine prey were found were remarkably similar indicating a gradual incorporation of piscine prey items rather than an abrupt diet switch (Figure 16).

Survey nearshore substrate with a focus on historical yellow perch spawning grounds

A total of 75 transects 2.5 km in length were completed at historical yellow perch spawning grounds near Lake Forest, Illinois during 2014 and 2015 (Figure 17). Approximately 14.4 km^2 of seafloor were mapped. Water depth over the surveyed area ranged from approximately 20 m to 7 m. Sand dominated much of the surveyed area with complex rocky substrate likely suitable for yellow perch spawning isolated to water less than 12 m found in the southwestern portion of our surveyed area.

DISCUSSION

Adult yellow perch

To improve our annual assessment of the adult yellow perch population we targeted fish in deeper waters (10-20 m) with gill nets set during the spring and summer. Despite the addition of a 100-ft panel of 1.0-in stretched mesh in 2014, mean CPUE during May and June was significantly less than 2013, at 4 fish/net night (SD 8.99) but not significantly from 2012, which was the lowest recorded CPUE during LMBS gill net surveys (Figure 1). Catch-per-mesh was recorded in 2014 to facilitate accurate comparisons among years prior to the addition of 1.5-in and 1-in meshes in 2013 and 2014, respectively. Upon removing 1.5-in and 1.0-in meshes, which typically capture age-2 and age-3 yellow perch, CPUE dropped to 0.36 fish/net night (SD 0.67). The 2010 year-class continued to dominate our adult assessment as it accounted for 42% of our total yellow perch catch. Young fish in general (<age-4), which prior to 2013 never comprised greater than 15% of the total catch, constituted 36% of our total adult yellow perch catch during 2014. In conjunction with low relative abundance and a decrease in age structure, the sex ratio of sampled yellow perch was heavily skewed towards males at 74%. While it is clear the addition of smaller gill net panels has altered the age structure and sex ratios of sampled yellow perch, relative abundance of adult yellow perch appears to be at the lowest levels since LMBS gill netting began in 2007. This trend is reflected in lakewide CPUE, which continues to show a long-term decline in the abundance of adult yellow perch which remains well below levels detected in the late 1980’s and early 1990’s.

Investigation of the female spawning stock in southwestern Lake Michigan from 2007-2013 indicated that fecundity increased exponentially with total length; this supports the contention that estimates of population level reproductive potential should account for both size composition of spawners and spawner biomass (F-123-R, previous segments). Female yellow perch relative abundance during May and June was not different from 2012 or 2013 and significantly lower than 2007-2011. Female yellow perch consisted of 11% of all fish sampled during May and June compared to 49% during July (75% of all females) when female CPUE was 1.9 fish/net night ± 2.1 (SD). An increase in the percent of females captured after the spawning season (July and later) was also observed in 2009 and 2013. These results suggest: that female yellow perch may be relatively stationary during the spring spawning season, male yellow perch are comparatively more mobile during the spawning season, females may be congregating in isolated nearshore spawning areas not sampled by our gill nets, or that females become more mobile and move to nearshore areas post spawn. Additional information on the timing and location of spawning as well as the movement of gravid females is required to better assess spawner abundance and reproductive potential. Continued sampling during and beyond the sampling season will allow us to better under understand seasonal movements and demographics of yellow perch.

In an effort to determine the age structure of yellow perch harvested by pedestrian anglers, anal spines were collected from fish at Montrose Harbor during June and July, 2014. Harvested yellow perch ranged from age-2 through age-10; however, over 74% of angler harvest consisted of age-4 (2010 year-class) yellow perch. This was unsurprising given the strength of this year-class from bottom trawl surveys in 2010 (F-123-R) and the relative contribution of this year-class to the fishery as age-3 in 2013. Unfortunately, while the 2010 year-class has almost entirely been supporting the recreational fishery, estimated harvest of yellow perch during 2014 was near record low numbers (F-52-R). During 2014, the 2012 (age-2) year-class contributed substantially to harvest; however, bottom trawl and adult gill net surveys suggest this year-class is in substantially lower abundance than the 2010 year-class. As a result it is likely that angler harvest will remain near or below record low levels until a new year-class (likely at least three years away from 2014) recruits to the fishery at age-3.

While assessment of gender has been sporadic based on angler involvement and remains largely unknown, mean total length of angler harvested yellow perch from 2006-2014 is nearly identical to the mean total length of females observed in gill nets collected near Waukegan Harbor, IL during the same time period; differing only at age-3 and age-4 (Figure 6). Given the significant contribution of large females to the overall spawning, additional attempts are required to better assess the demographics of the harvested population. As a strong year-class beyond 2010 has yet to be identified, it is extremely important to protect current age-2 and age-4 yellow perch to ensure a future spawning population and potential for improved year-class strength and to sustain the fishery until another strong year-class is observed.

2014 Year-class

Despite increased effort in 2014, CPUE of age-0 yellow perch was near record lows observed in 2003 and the early 1990's. Previously, relatively high CPUE in 1998 led to a comparatively strong year-class as seen by its dominance in LMBS 2000-2004 fyke netting (previous segments of F-123-R). A similar pattern occurred with the 2002, 2005, and most recently, 2010 year-classes. All of these year-classes were caught in relatively high abundance at age-0 and were detected at significant levels in our adult assessments by age 4. The 2002 year-class contributed significantly to adult assessments and angler catches during 2006-2008, 2009 was the first year the 2005 year-class dominated both our adult assessment and sport harvest collections (previous segments of F-123-R), and presently, the 2010 year-class is dominating both angler harvest and our adult assessment. These results suggest that strong CPUE of age-0 yellow perch is a reasonable indicator of recruitment success. Yellow perch year-class strength remains very erratic from year to year and recent CPUEs are extremely low compared to sampling in the late 1980s (1987 and 1988). Despite measureable year-classes in 2002, 2004, 2005, and 2010, CPUE of age-0 yellow perch is nowhere near that of the late 1980s; as such, yellow perch populations are likely not sufficiently strong to support high overall harvest.

The forage base available to young yellow perch has changed in species composition and abundance over the last several decades, and many of these changes are linked to exotic species invasions. Mean zooplankton densities were significantly higher during 1988 in comparison to 1989-1990 and 1996-2012 (Dettmers et al. 2003, previous segments of F-123-R). Zooplankton densities since 1996 have barely reached even half of the densities found during the late 1980s when multiple strong year-classes were produced. These shifts within the zooplankton community may be related to the establishment of several recent invaders. The spiny water flea (*Bythotrephes longimanus*) was first detected in Lake Michigan during 1986 and was established in offshore waters lake-wide by 1987 (Barbiero and Tuchman 2004). Barbiero and Tuchman (2004) attributed a dramatic reduction in several native cladocerans species to the establishment of this exotic cladoceran in offshore waters of Lake Michigan. Declines in once dominant benthic macroinvertebrate groups such as *Diporeia*, cladocerans and sphaeriids in nearshore waters of Lake Michigan are attributed to bottom-up effects of decreased phosphorus loading during 1980-1987 and continued declines of *Diporeia* coinciding with the invasion of zebra mussels during the 1990s (Madenjian et al. 2002) and quagga mussels during the early 2000s (Nelepa et al. 2009). Dreissenid mussels have drastically reduced phyto- and zooplankton levels (Vanderploeg et al. 2012) and altered the abundance of benthic macroinvertebrates in the Great Lakes (Leach 1993; Stewart et al. 1998). The presence of these invaders and other exotic species have had major impacts on the food web and may exacerbate and alter the complex set of factors that affect yellow perch year-class strength. Over the last three decades, yellow perch year-class strength has been linked to zooplankton availability for first feeding larvae (Dettmers et al. 2003; Redman et al. 2011b). Foraging success of yellow perch larvae in Green Bay was poor when zooplankton density dropped below 10 ind./L (Bremigan et al. 2003) and June-July zooplankton densities in six of the last ten years have been at or below this level within Illinois waters of Lake Michigan. Our results indicate higher densities of rotifers during June and July compared to previous years; in part due to increased detection. While rotifers may be preyed upon by newly hatched yellow perch larvae (Fulford et al. 2006) prolonged consumption may result in reduced growth and survival (Graeb et al. 2004). Thus, continued monitoring of nearshore zooplankton and benthic invertebrate densities is needed to further explore the role of food availability in yellow perch recruitment success.

Juvenile yellow perch

Relative abundance of juvenile yellow perch sampled in small mesh gill nets was greatest during August at 2.2 fish/hr. Age-0 yellow perch return to the benthic nearshore areas during fall months when they possess sufficient swimming capabilities or favorable winds are present (Weber et al. 2011). While the age of juvenile yellow perch captured in small mesh gill nets has been shown to range from age-0 to age-3, previous research suggests that age-0 yellow perch are less than 80 mm at the end of the first growing season in southwestern Lake Michigan (Dub et al. 2014). During August, September and October of 2012 yellow perch less than 80 mm constituted 55% of 300 yellow perch sampled. Comparatively in 2013 and 2014, yellow perch less than 80 mm represented only 3.4% and 10% of all yellow perch collected during the same time frame.

Thus while previous segments (F-123-R) noted that peaks in juvenile yellow perch CPUE during August and September corresponded with the return of age-0 yellow perch to benthic nearshore habitats (Miehls and Dettmers 2011), increased CPUE during August during 2014 appears to be related to increased movement or nearshore abundance of age-1 and older yellow perch. Additionally, the apparent absence of age-0 yellow perch from our collection efforts further highlights the variability of yellow perch recruitment and, specifically, low age-0 yellow perch abundance since 2010. Future efforts are required to better understand the nearshore movements of juvenile yellow perch to identify potential bottlenecks influencing year-class strength.

During ontogeny yellow perch undergo several diet shifts from zooplankton to benthic invertebrates and when gape becomes large enough, to piscivory (Creque and Czesny 2011). Experimentally, yellow perch have been shown to consume piscine prey items as early as 80 mm (Graeb et al. 2006). An examination of yellow perch piscivory from 1984-2002 in southern Lake Michigan, however, revealed that piscivory was not occurring until 150 mm (Truemper and Lauer 2005). While juvenile yellow perch that become piscivorous would have access to novel and energy dense prey items, yellow perch may be limited by predator and prey behavior, gape, as well as presence of suitable prey items at preferred habitats in Lake Michigan.

Round goby are an abundant, non-native, lithophilic, species that reproduce multiple times during a protracted spawning season in southern Lake Michigan (Brussee, 2014). Additionally, diel vertical migrations of larval round goby have been observed in Lake Michigan and may permit easy foraging (Hensler and Jude 2007). Our results suggest that juvenile yellow perch as early as 70 mm are predating upon larval round goby as small as 18 mm (Figure 14). While only a small proportion of yellow perch diets examined (9%) indicated piscivory, our results relied on hard structures retained within stomach contents; therefore, our results could only underestimate actual rates of piscivory in juvenile yellow perch. Additionally, percent composition of piscivorous yellow perch diets was remarkably similar to yellow perch where piscine prey items were not identified (Figure 16). Juvenile yellow perch that incorporate piscine prey items early increase their breadth of prey items and may be more resilient to fluctuating prey composition and abundance. The caloric value of larval round goby relative to alternative, invertebrate, prey items remains unknown. Thus it is difficult to evaluate the benefit of consuming round goby beyond adding an additional “type” of organism to dietary contents. It also remains unknown whether larval round goby were actively pursued or incidentally consumed.

The contribution of round goby to juvenile yellow perch diets represents a novel forage source that may promote increased growth and allow for rapid progression through growth bottlenecks during early life. Continued assessment of the age structure and diet composition of juvenile yellow perch sampled from small mesh gill nets will allow us to examine factors influencing growth, which may be crucial for future survival beyond the first growing season (Dub et al. 2014). Integrating these results with other sampling efforts will allow us to capture a complete view of yellow perch life history in Illinois waters of Lake Michigan.

Nearshore spawning grounds

Examination of nearshore spawning grounds near Lake Forest, IL indicated that the majority of complex rocky substrate preferred by yellow perch for spawning was found in waters less than 12 m deep (Figure 15). Vast expanses of gravel and sand occupied the majority of the mapped area. Future mapping along with ground truthing, will allow us to delineate and quantify areas suitable for yellow perch spawning. While an evaluation of yellow perch spawning grounds is the primary objective, habitat suitability for juvenile yellow perch and other fishes will also be evaluated. Identification of critical habitats will allow for the protection of key resources for this valuable native sport fish.

Management Implications

In 2005, bottom trawl surveys indicated the greatest CPUE of age-0 yellow perch recorded since 1988. The 2005 year-class recruited to LMBS sampling gear at age-4 and significantly contributed to our assessment of angler harvest in both 2009 and 2010 and continued to dominate our population assessment until age-7 in 2012. The 2010 year-class appears to be following a similar trajectory as bottom trawl surveys indicated the greatest CPUE of age-0 yellow perch since 2005 (F-123-R). Therefore it is unsurprising that the 2010 year-class has been the most prominent year-class observed in both our fishery independent (gill net) and fishery dependent (F-52-R) surveys during 2013 and 2014. In 2013, the fishable yellow perch population was predominately supported by two consecutive year-classes (2009-2010), while in 2014 a single (2010) year-class appears to be supporting the recreational fishery and spawning population. We have shown that total length is highly correlated with fecundity; given the low abundance of adult yellow perch, there is a need to protect these young spawners so they can reach their full reproductive potential. Poor recruitment during 1999-2001, 2008-2009, and 2011-2014 taken with the continued trend of low abundance of adult yellow perch throughout Lake Michigan (Makauskas and Clapp 2010) raises concerns about the growth and future survival of yellow perch. Our long-term data still clearly demonstrate that recruitment is highly variable and low when compared to recruitment during the 1980s. Thus, it remains important to conserve the adult stock to the greatest degree possible to promote a sustainable fishery and so that the spawning stock can reach full reproductive potential and their offspring can take advantage of beneficial recruitment conditions when they occur. Given the current population characteristics, management for limited harvest is necessary to protect the future of the Lake Michigan yellow perch population.

ACKNOWLEDGEMENTS

We would like to thank both the permanent and temporary staff of the Lake Michigan Biological Station who assisted with data collection, sample processing, and data entry for this project. We also thank D. Wudi for administrative support.

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TABLES

Table 1. Relationship between cleithra length and total body length for five potential yellow perch prey items.

Species	N	Total Length (mm)	Cleithra Length (mm)	Equation	R^2
Yellow Perch	95	57.3-213.0	6.99-32.28	TL=6.32CL+14.41	0.99
Round Goby	150	22.0-150.0	3.10-24.59	TL=5.65CL+7.92	0.98
Alewife	199	23.9-179.0	2.11-27.15	TL=6.56CL+3.87	0.99
Rainbow Smelt	25	32.2-151.0	2.73-12.45	TL=11.56CL+4.67	0.98
Spottail Shiner	95	35.8-133.1	3.93-15.82	TL=8.19CL+6.01	0.96

FIGURES

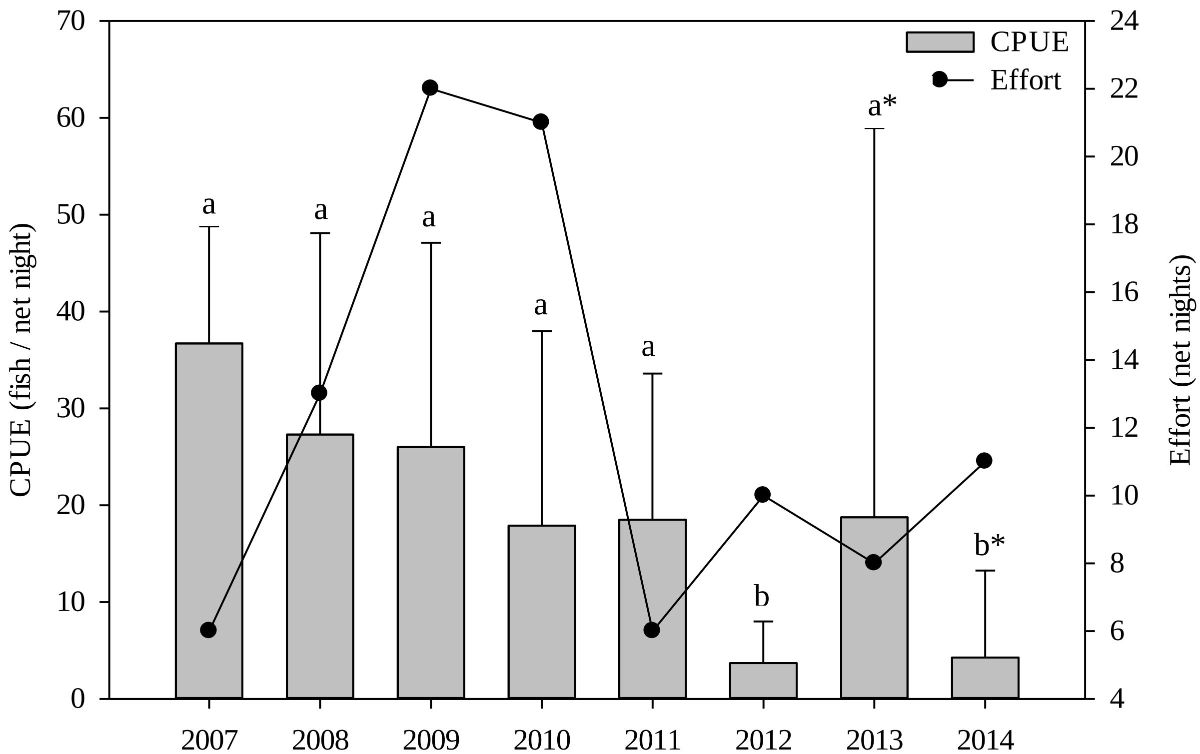

Figure 1. Annual mean CPUE (+ 1 SD) of yellow perch collected in gill nets during May and June at Waukegan and Lake Forest, Illinois during 2007-2014. *A 100-ft panel of 1.5-in and 1.0-in mesh was added in 2013 and 2014, respectively.

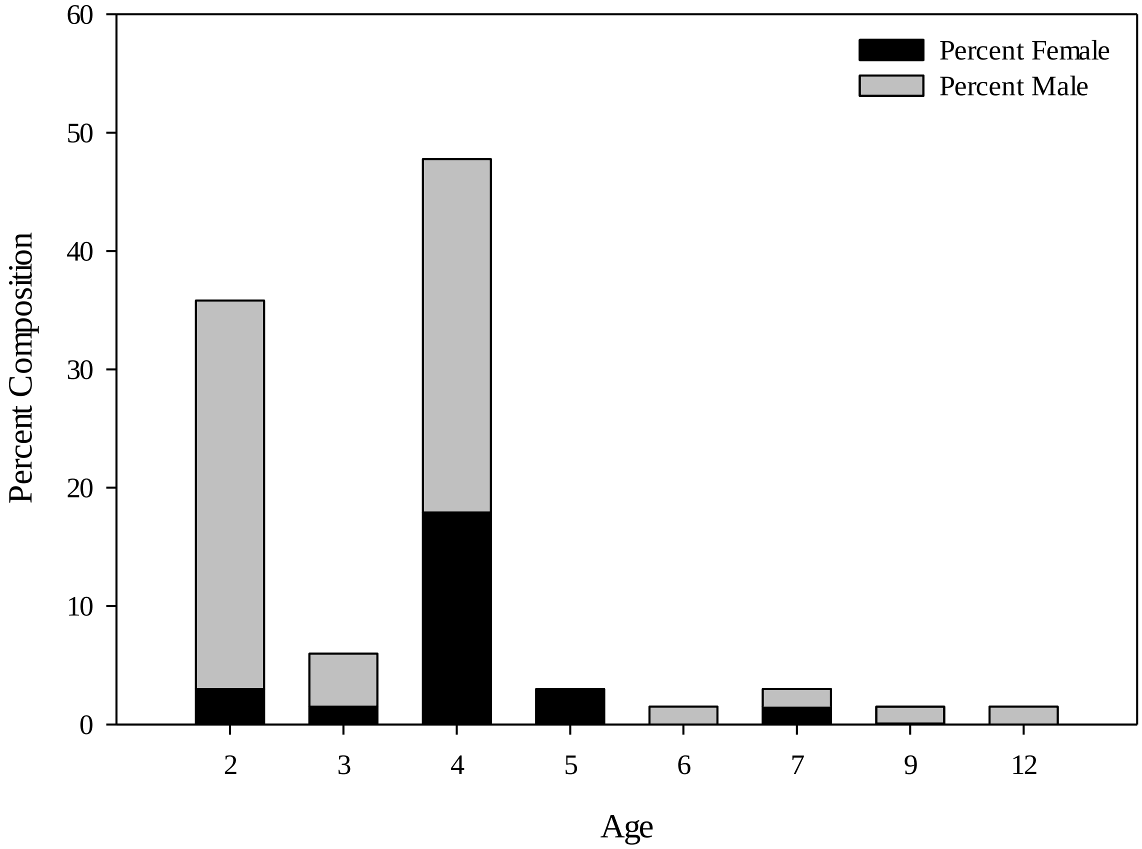

Figure 2. Age composition of adult female and male yellow perch collected using gill nets at Waukegan and Lake Forest, IL during May-July of 2014.

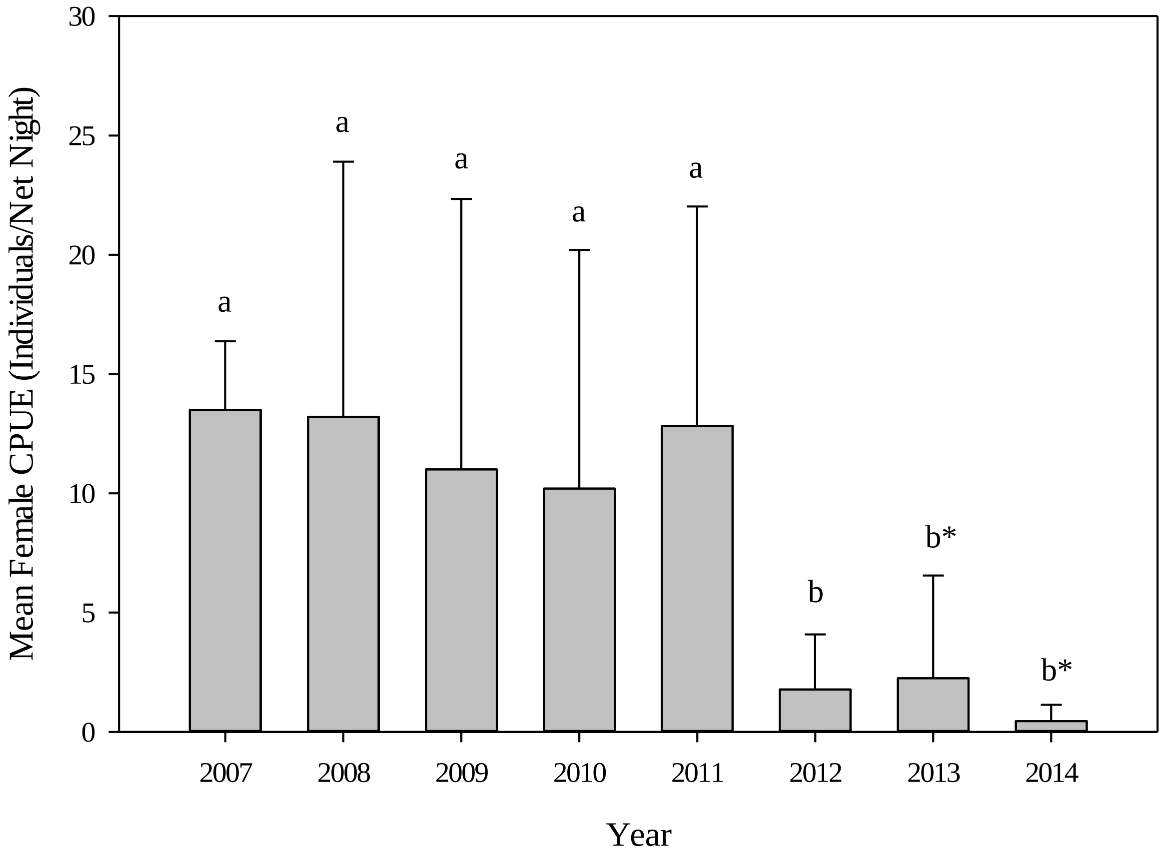

Figure 3. Mean CPUE (+ 1 SD) of female yellow perch collected in gill nets at Waukegan and Lake Forest, Illinois during the spring from 2007-2014. *A 100-ft panel of 1.5-in and 1-in mesh was added in 2013 and 2014 respectively.

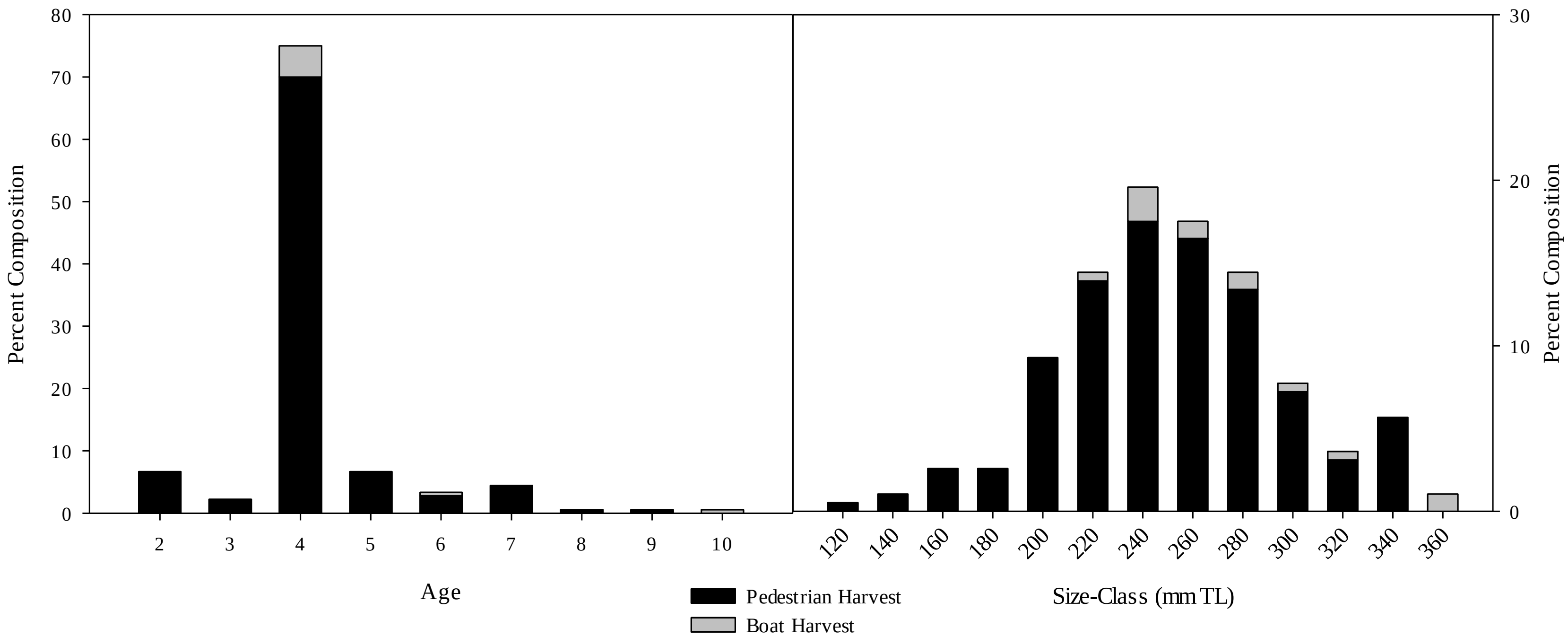

Figure 4. Age and length distributions of yellow perch harvested by pedestrian and boat anglers at Montrose Harbor during 2014.

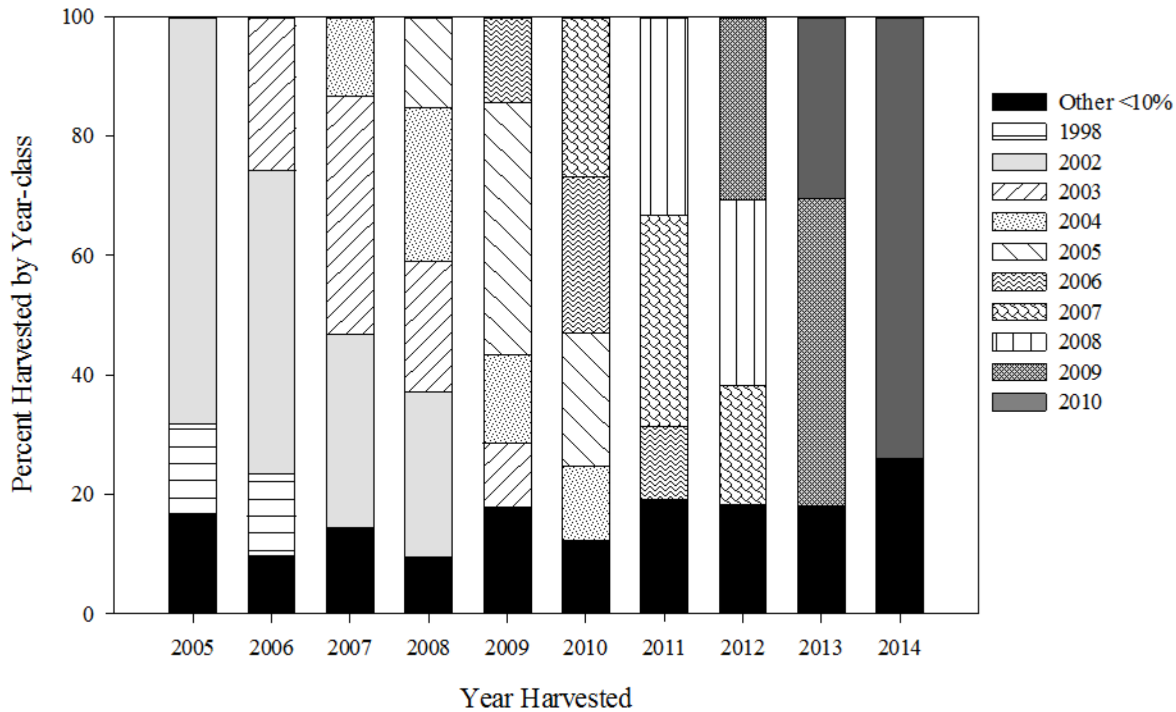

Figure 5. Relative contribution of yellow perch year-classes to pedestrian angler harvest. Year-classes with less than 10% contribution are included in the “other” category.

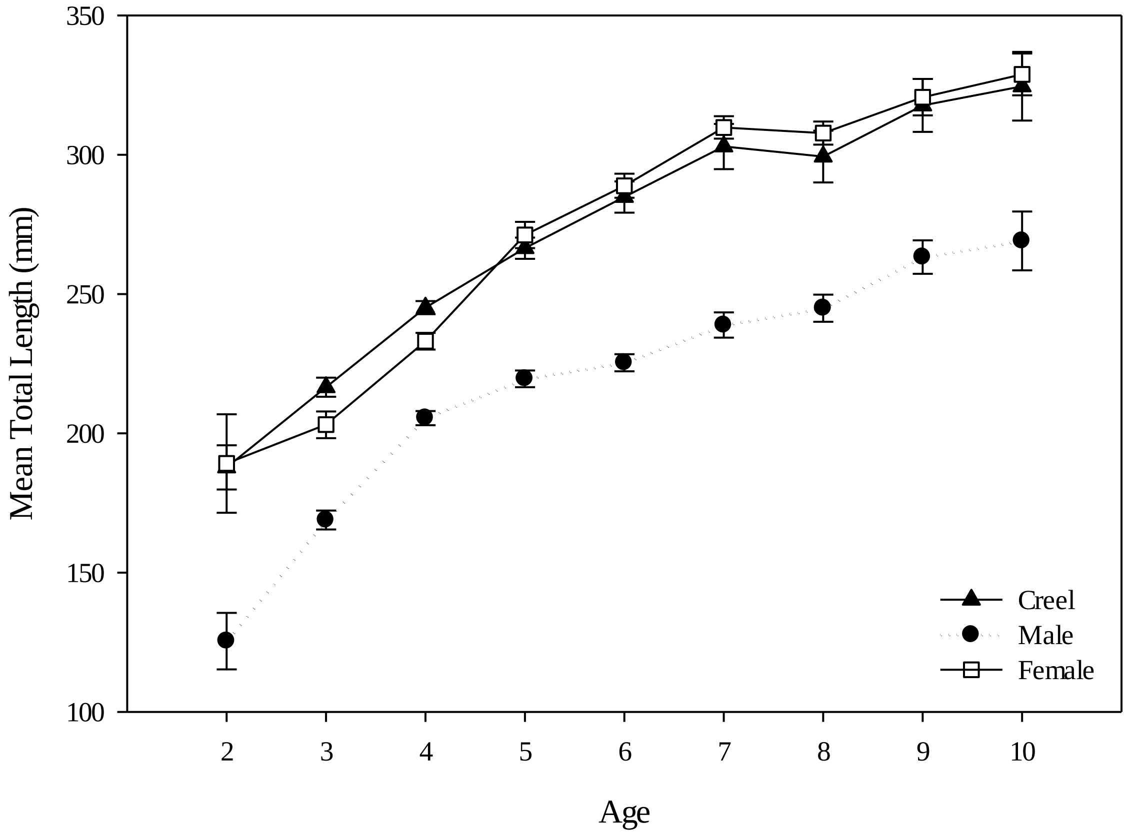

Figure 6. Mean total length-at-age of angler harvested yellow perch relative to mean total length-at-age of male and female yellow perch collected in gill nets from 2006-2014. Error bars represent 95% confidence intervals.

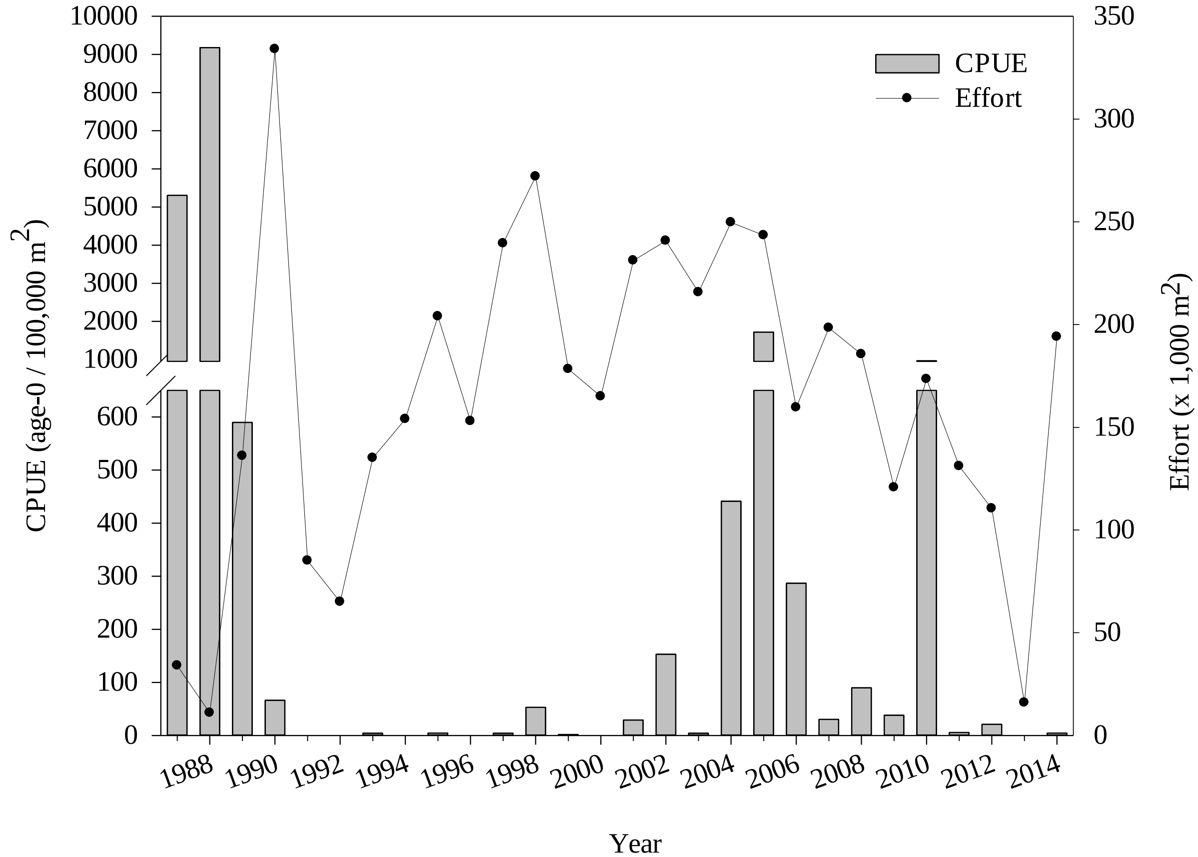

Figure 7. Relative abundance of age-0 yellow perch collected by daytime bottom trawls north of Waukegan Harbor, IL during 1987-2014.

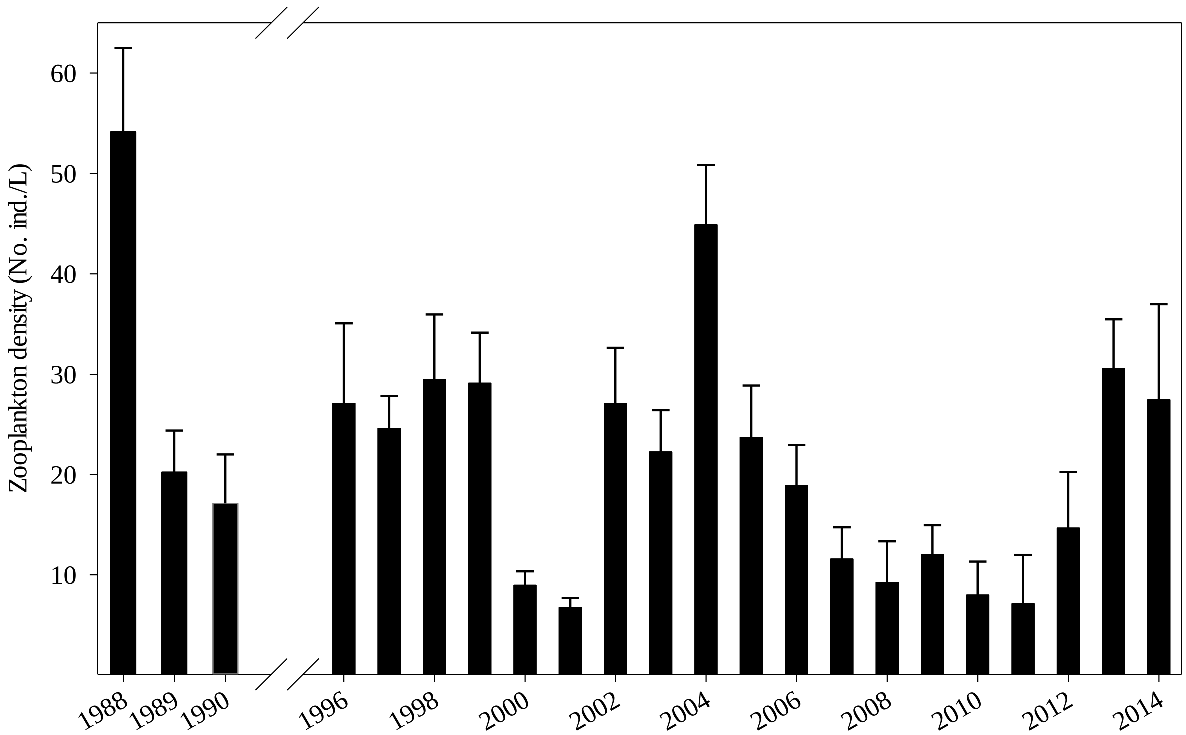

Figure 8. Mean density of zooplankton (+ 1 SE) present in Illinois waters of Lake Michigan near Waukegan during June-July for years 1988-2014.

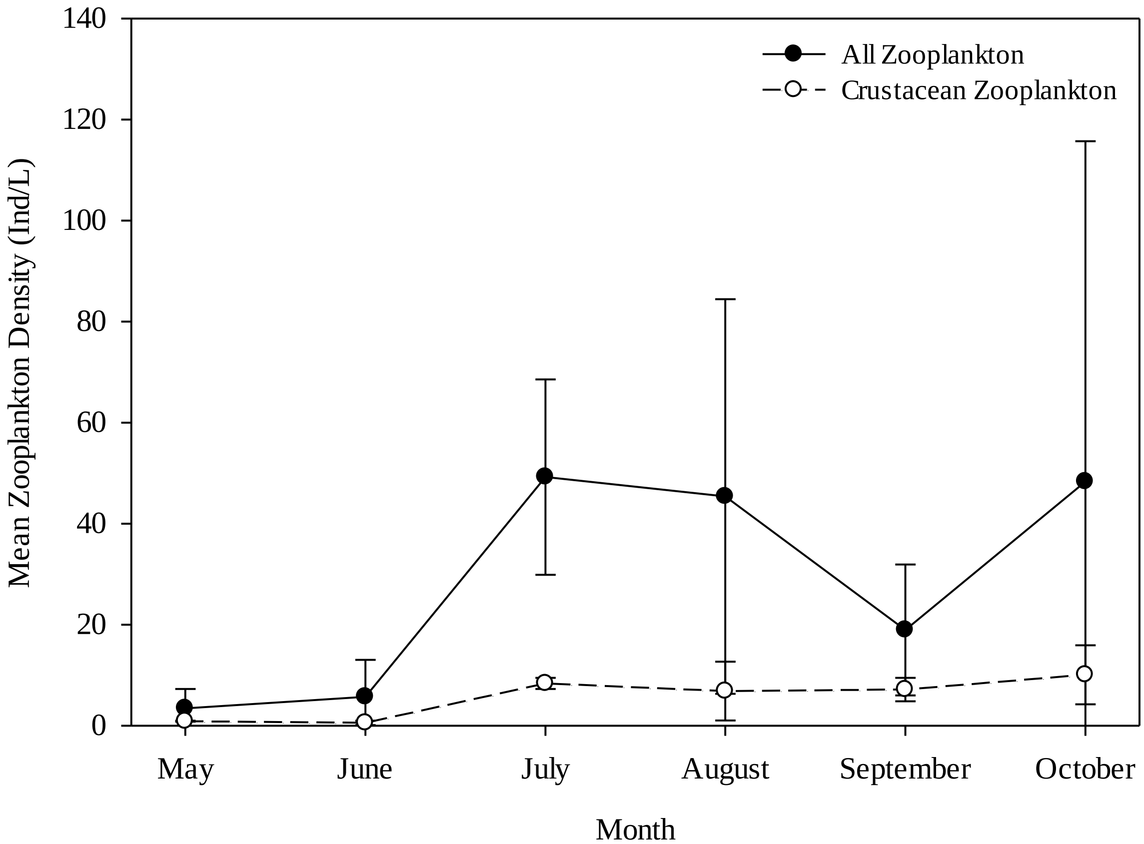

Figure 9. Mean monthly zooplankton density (± 1 SD) in nearshore Illinois waters of Lake Michigan near Waukegan during May – October, 2014. Closed circles (●) represent all zooplankton, whereas open circles (○) represent crustacean zooplankton.

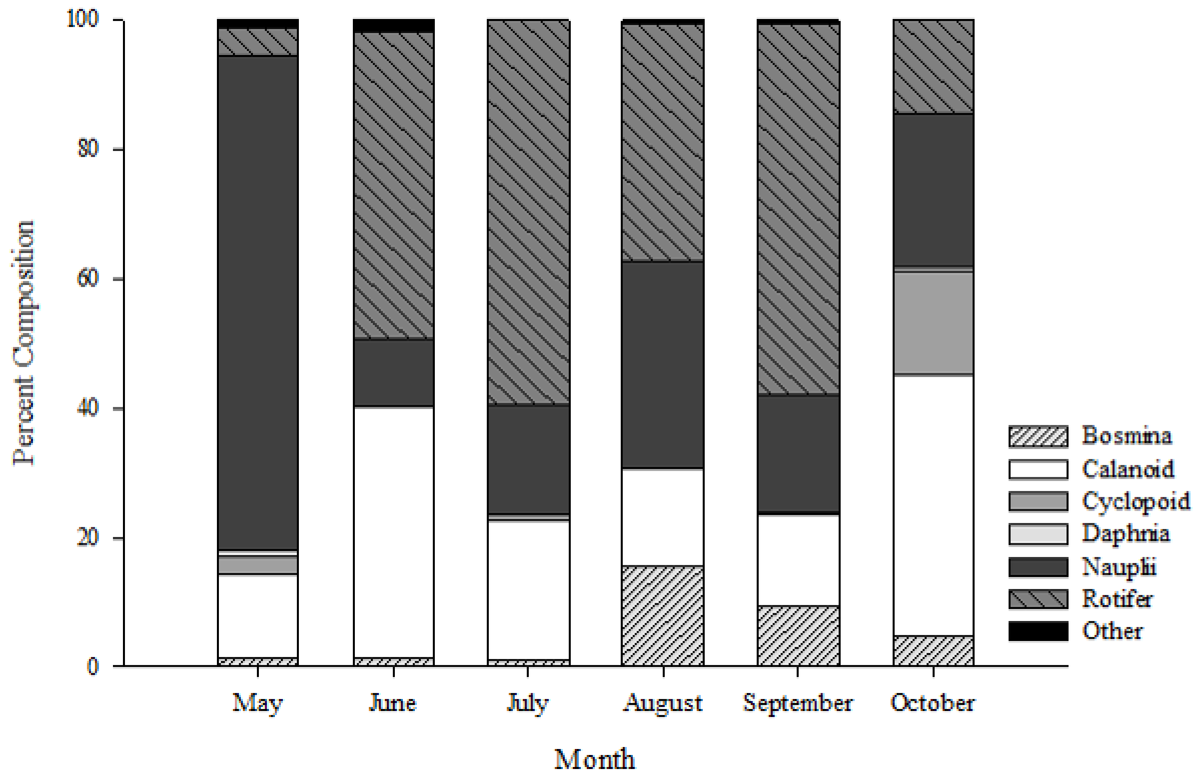

Figure 10. Monthly percent composition of zooplankton found in nearshore Illinois waters of Lake Michigan near Waukegan during May – October, 2014.

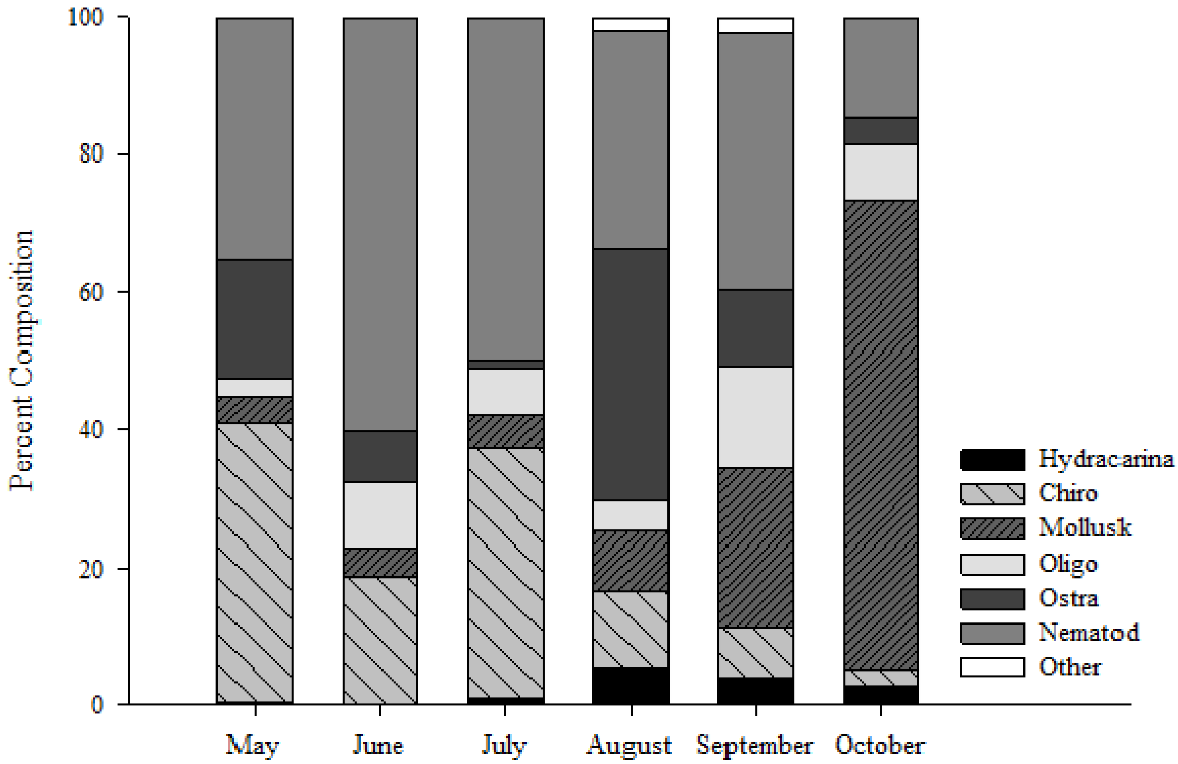

Figure 11. Percent composition of benthic invertebrates found in Lake Michigan substrate near Waukegan using monthly ponar grabs from May through October, 2014.

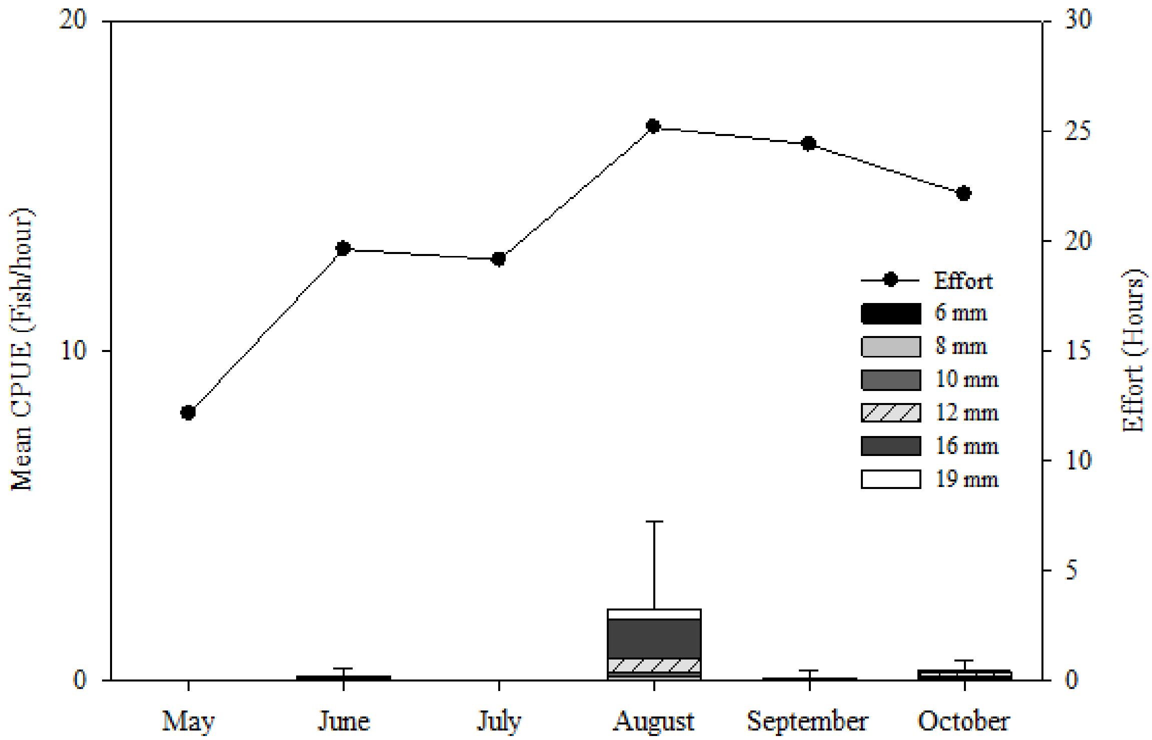

Figure 12. Mean monthly CPUE (+ 1 SD) of yellow perch collected in small mesh gill nets fished in 3-10 meters of water near Waukegan Harbor, IL during May - October, 2014.

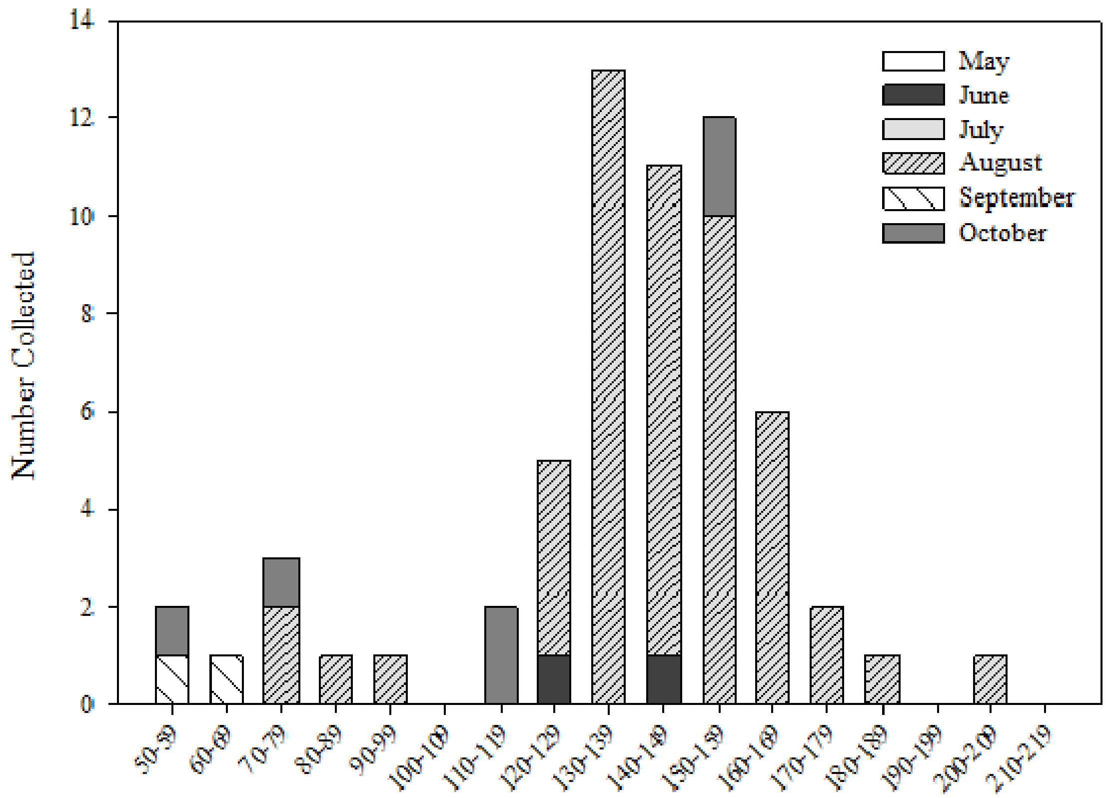

Figure 13. Total length distribution of yellow perch collected in small mesh gill nets fished in 3-10 meters of water near Waukegan Harbor, IL during May - October, 2014.

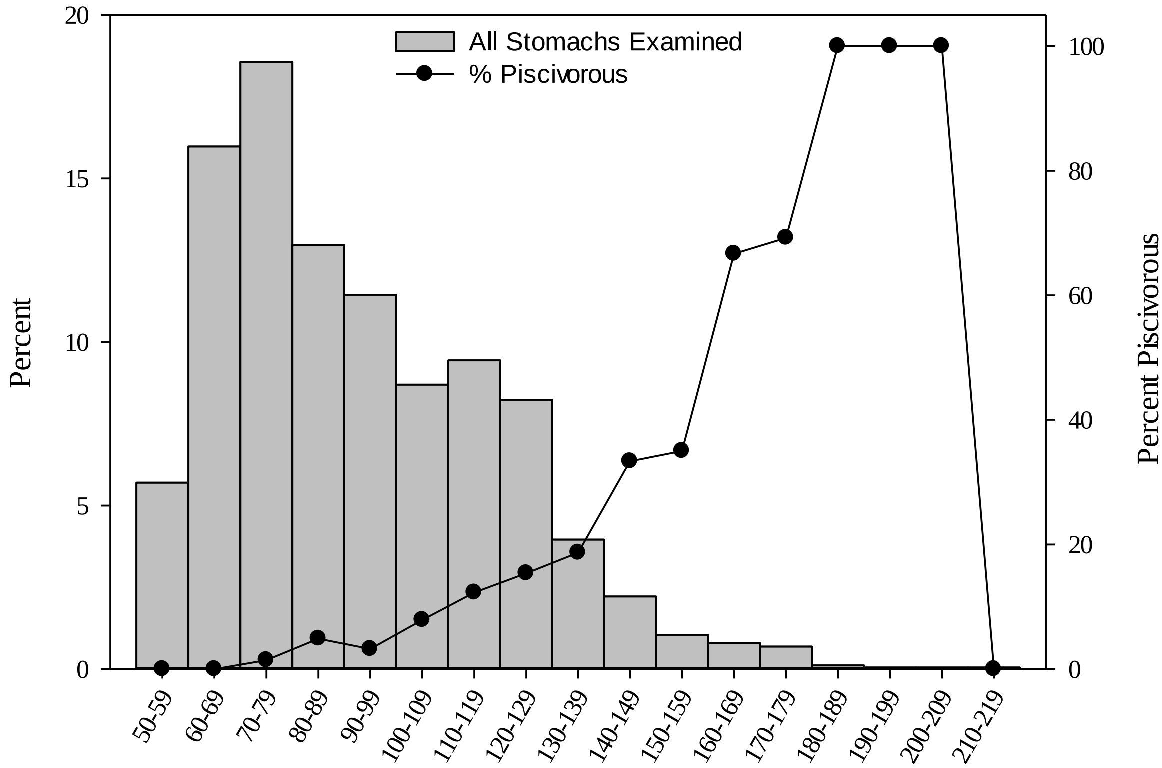

Figure 14. Length distribution and percent of piscivorous yellow perch collected in small mesh gill nets in Illinois waters of Lake Michigan from 2010-2012.

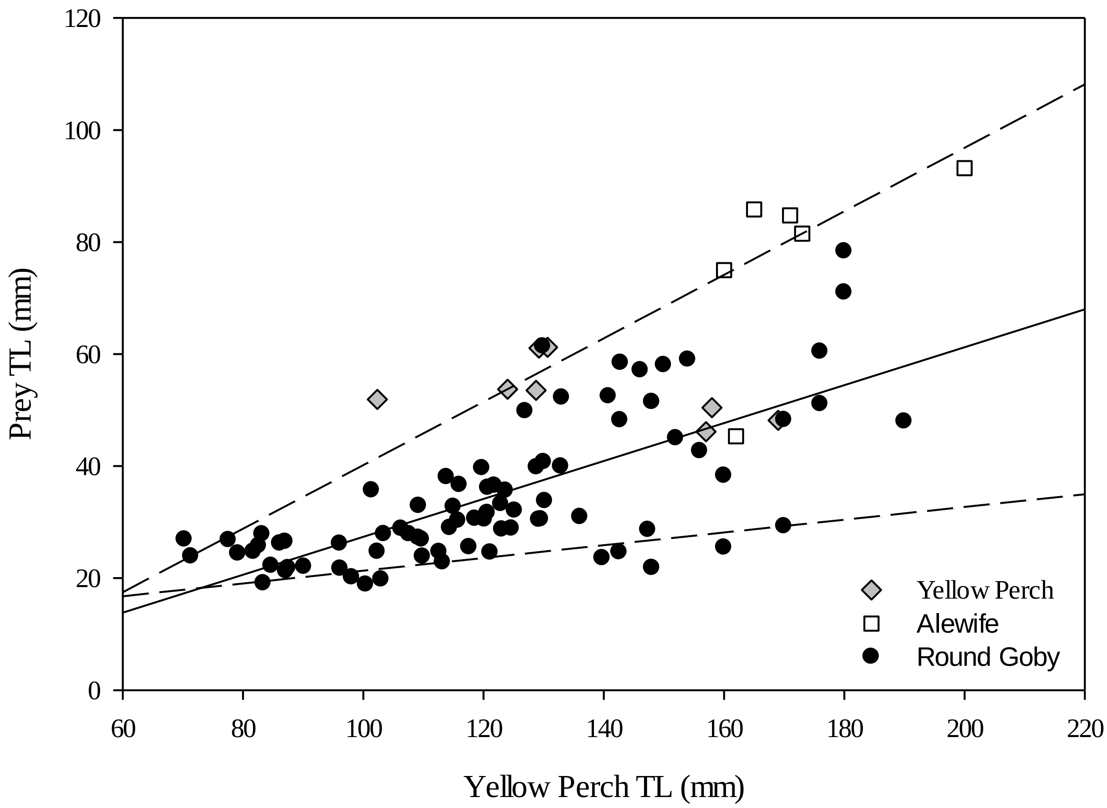

Figure 15. Relationship between yellow perch total length and estimated total length of piscine prey items from 2010-2012. Lines describe this relationship at 10th, 50th, and 90th quantiles while different symbols indicate species position within the relationships.

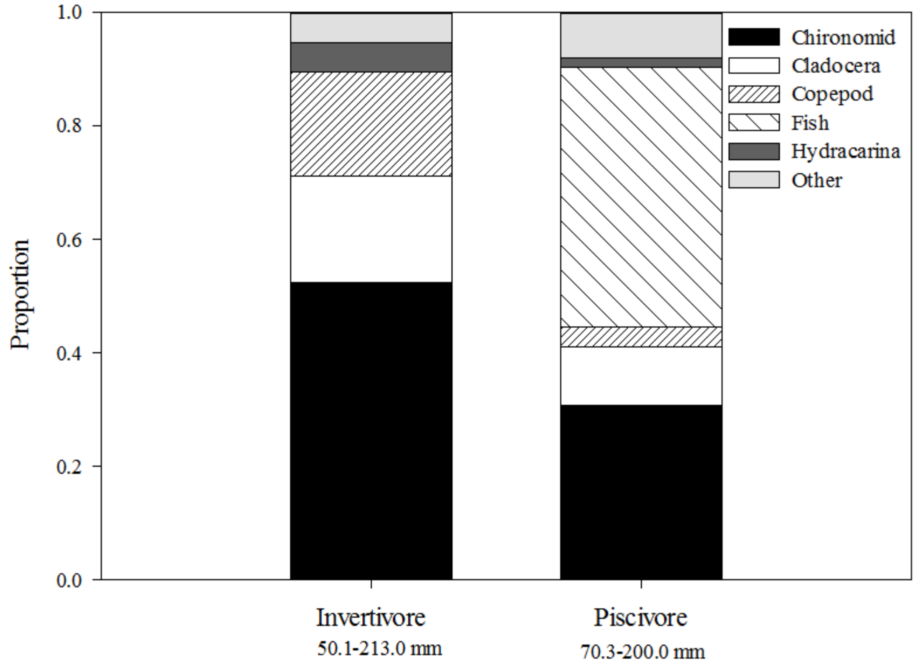

Figure 16. Percent composition of diet items in piscivorous and non-piscivorous yellow perch.

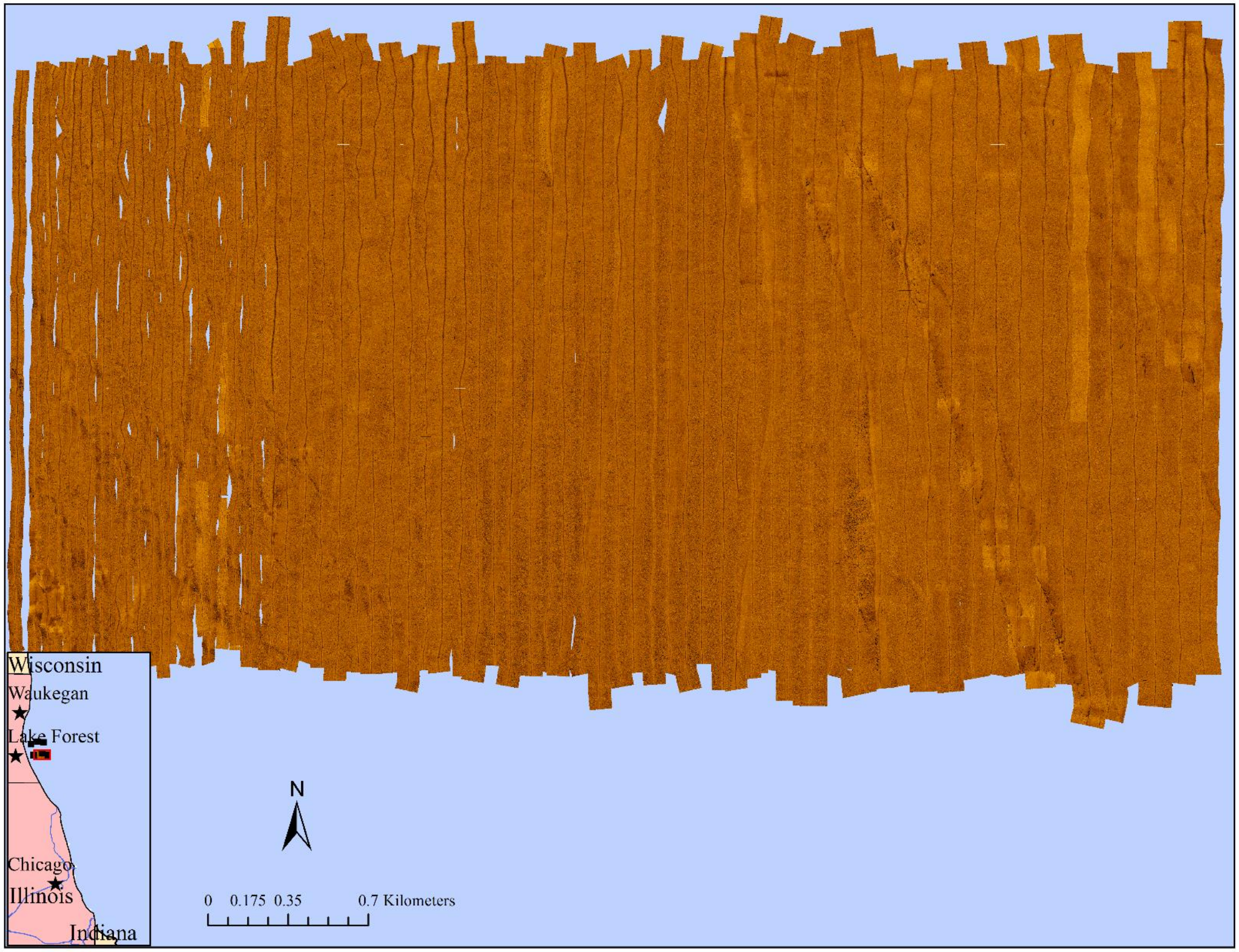

Figure 17. Mosaic of side scan transects completed near Lake Forest, IL during 2014 and 2015. Location of large mesh gill net sites are indicated by black squares within the inset.