Yellow Perch Population Assessment in Southwestern Lake Michigan

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INTRODUCTION

Yellow perch (*Perca flavescens*) is an important commercial and sport fish throughout much of its range in North America. 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 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 in the past few decades. The population in the southern basin increased dramatically in the 1980s (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) only 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). Despite the presence of multiple year classes within the population, lake wide assessments show that current yellow perch abundance remains low, particularly in comparison to abundance observed in the late 1980s and early 1990s (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 yellow perch stocks, fisheries managers should set harvest targets in accordance with fluctuating population sizes. However, the ability to successfully set these harvest targets for yellow perch is hampered by insufficient information about population size, natural mortality, reproductive potential, and factors effecting the growth and survival of juveniles. The continued decline of the yellow perch population due to reduced survival of larvae to the 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 preservation 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 fish feeding behavior and 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 pelagic larval yellow perch drifting offshore, abundance of age-0 yellow perch returning to nearshore habitat in the fall, and abundance and diet of age-1 and age-2 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 decline in larval fish recruitment, zooplankton density in southern Lake Michigan has been consistently lower, 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 huge 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.

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 & RESULTS

<u>Study 101.</u> Yellow perch population assessment in southwestern Lake Michigan

Job 101.1A: Improve annual assessments of the yellow perch spawning population: Spring spawning assessment

<u>Objective:</u> Monitor the age and size structure of the spawning population on spawning grounds and evaluate reproductive potential.

Adult yellow perch were collected from 11 – 23 May, 2011 at Waukegan and Lake Forest, IL using gill nets. We deployed monofilament gill nets consisting of 100-ft panels of 2.0, 2.5, 3.0, and 3.5-in mesh. Gill nets were set in 10, 15, and 20 meters of water on three occasions. Gill nets set on May 11 and 12 were fished for the typical 24 hour period. However, nets set on May 19 were fished for almost 96 hours due to dangerous weather conditions. Yellow perch collected during the May 19 deployment were excluded from calculations of annual effort and CPUE due to possible confounding effects of extra net nights on catch rate. However, these fish were included in analysis that examined the age, size and sex structure of the spawning population.

Annual effort during spring 2011 was six net nights and mean CPUE (fish/net night) was 18.5 ± 15.1 (SD) yellow perch (Figure 1). A total of 111 yellow perch were caught and seventy percent of these fish were females. Mean total length was 268 ± 44 mm for females and 234 ± 34 mm for males. A total of 622 yellow perch were caught during the 96 hour net sets deployed on May 19, and the average length of these females and males was similar to those caught on May 11 and 12. However, the gender composition of fish collected during the May 19 deployment was quite different with 71% of the fish being males.

We collected otoliths from all 733 yellow perch caught during May 2011 and were able to assign ages to 711 of these fish. Otoliths from the remaining fish (N=22) were eliminated from age analysis either due to damage during the preparation process or <75% reader agreement. Fish ranged in age from 3 to 13 years old (Figure 2). The dominant age groups observed in our catch were age 4 (2007 year class) and age 6 (2005 year class) fish followed by 5, 7 and 8 year olds. Mean TL of the 2007 year class at age 4 was 225 ± 25 (SD) mm TL. Mean TL was 236 ± 38 mm TL for age 6 fish. In 2011, ovaries were taken from 42 females that averaged 275 ± 42 (SD) mm in length and ranged in age from 3 to 13 years. Mean fecundity of yellow perch collected during 2011 was 49,960 ± 29,483 (SD) eggs.

In an effort to better understand the distribution of female and male yellow perch during spawning aggregations we compiled CPUE, gender, and total length data for yellow perch caught during 2008-2011 at the Waukegan and North Lake Forest sampling sites (N = 1,413 fish). Mean CPUE was compared among sampling locations and years and no significant differences were observed between Waukegan and Lake Forest or among sampling years using a Repeated Measures ANOVA. Thus, data from both sampling sites and all sampling years were combined for subsequent analysis. To investigate whether CPUE, sex ratio and mean length of females changed throughout the spawning season we divided the 36 day sampling window (30 April – 4 June) across years into three, 12 day periods: 1) 30 April - 11 May, 2) 12 - 23 May, and 3) 24 May - 4 June; referred to as sample periods from this point forward. We then tested for differences in yellow perch CPUE (RM ANOVA), sex ratio, reproductive state (Chi-square) and mean total length (TL) of females (RM ANOVA) among sample periods and water depths (10, 15 and 20 m).

Although mean annual CPUE of yellow perch decreased slightly as sampling depth increased, no significant differences in CPUE were detected among depth stations ($p = 0.78$; Figure 3a). Mean CPUE of yellow perch typically increased as the annual sampling window progressed, but again no significant differences were detected among sample periods ($p = 0.71$; Figure 3b). In total, 693 females and 584 males were caught during 2008 - 2011. Gender composition was similar among sample periods (3.03; df = 2; $p = 0.22$; Figure 4a), but a gender bias was detected among depth stations (28.3; df = 2; $p < 0.001$). A higher proportion of females were caught in 15 and 20 meters of water (sex ratio 1.25:1 and 1.84:1, respectively), while males dominated catches at the 10m depth station (1:1.16; Figure 4b) regardless of sample date.

Mean TL of females did not differ among depth stations ($p = 0.28$) or sample periods ($p = 0.96$), but female TL was affected by a significant interaction between water depth and sample period ($p < 0.001$). More specifically, during the second sample period (12 - 23 May) mean TL of females at the 20 m station was significantly higher than that at the 10 m station, which suggests some size separation among females during the spawning season (Figure 5a). Additionally, the length of females caught at the 20 m station varied temporally. Mean TL of females caught in 20 meters of water during 12 - 23 May was significantly greater than that during the first and third sample periods (Figure 5a). The proportion of green females was high throughout the sampling window with 98% of females being green during 30 April – 11 May and 72-77% of fish being green during subsequent sample periods (Figure 5b). The percentage of spent females increased throughout the sampling window and peaked at 26% during 24 May - 4 June. Spent females were significantly larger (294 ± 50 mm TL) than green (269 ± 47 mm TL) and ripe females (273 ± 36 mm TL) throughout the spawning window (30 April – 4 June), suggesting that larger females may be spawning earlier than their smaller counterparts. Our results indicate that a large proportion of female yellow perch are in deeper water (≥ 15 m) during spawning aggregations and that those caught in shallow water (10 m), particularly during mid-May, tended to be smaller females. However, a longer sampling window (including entire month of June) and video documentation of spawning is necessary before we can conclude that egg deposition is occurring in deeper water than historically observed.

We compiled CPUE, length and fecundity data from 339 yellow perch collected during 2007-2011 to examine annual variation in relative abundance and size of gravid females as well as estimate the relationship between female length and fecundity. Mean CPUE of females was similar among collection years ($p = 0.07$) ranging from 10 – 14 fish/net night annually (Figure 6). However, the length distribution of these fish differed considerably among years ($p < 0.005$; Figure 7). Over the course of the study, we caught mature females ranging from approximately 175 - 365 mm TL. During 2007, the length distribution of females was slightly skewed towards fish less than 270 mm and skewed towards females over 250 mm during 2008. A slightly bimodal distribution was observed in 2009 with a significant contribution from females less than 210 mm and greater than 270 mm. The 2010 length distribution was slightly skewed towards smaller females while in 2011 the majority of females were 230-320 mm. Based on these annual differences we would expect reproductive output to vary annually given that fecundity increased exponentially with length (Figure 8). A slope heterogeneity test showed that the length-fecundity relationship of yellow perch differed among collection years, so regression equations were estimated separately for each year (Table 1). Fecundity ranged from approximately 12,156 eggs for a 178 mm female to 141,067 eggs for a 336 mm female. Our results showed that annual relative abundance of female spawners was similar during 2007-2011, but the size distribution of these fish varied considerably among years. Larger yellow perch produced more eggs and as such temporal changes in the size structure of the spawning stock have the potential to impact egg production at the population level in Lake Michigan.

Job 101.1B: Improve annual assessments of the yellow perch spawning population: Fall assessment

Objective: Monitor the age, size and sex structure of the population during a period when male and female yellow perch are more evenly distributed.

We sampled for adult yellow perch on 11 and 19 September, 2011 at Waukegan, IL using gill nets. We deployed monofilament gill nets consisting of 100-ft panels of 2.0, 2.5, 3.0, and 3.5-in mesh. Gill nets were set in 10, 15, and 20 meters of water and fished for approximately 24 hours. Total effort during the 2011 fall assessment was 6 net nights during which only 45 yellow perch were caught. All fish were processed in the laboratory and ages were assigned to 42 of these fish. Seventy-three percent of the yellow perch collected were females. Mean total length of females was 269 ± 49 mm and 235 ± 34 mm for males, which was similar to the average size of females and males collected during the 2011 spawning season (reported above). Fish ranged in age from 2 to 12 years old (Figure 9). Age 4 (2007 year class) and age 3 (2008 year class) fish dominated our catch comprising 24% and 21%, respectively. Age 6 fish were the next most abundance age class (19%) followed by age 5 fish (14%).

Job 101.2: Develop angler-caught age and sex distribution

Objective: Estimate age composition and, if possible, sex composition of angler-caught fish to better parameterize a lake-wide catch-age model in its final stages of development.

During 2011, anal spines were collected from 21 yellow perch harvested by launched anglers using Waukegan Harbor during 28 April – 19 May. We also collected spines from 102 yellow perch harvested by pedestrian anglers at Waukegan and Montrose Harbors, IL during June and August. All yellow perch spines were cleaned, sectioned, and mounted for age analysis. Three spines were eliminated from age analysis due to damage during the preparation process or <75% reader agreement (N = 120). Yellow perch from this subsample ranged in age from 1 - 13 years and 120 - 370 mm in length (Figure 10). Age 3 and age 4 fish dominated the subsample and each comprised about 29% of the catch. Similar to that detected during 2008 – 2010, mean age of yellow perch harvested by boat anglers using Waukegan launch ramp (7.9 ± 2.5 years, SD) was significantly greater than that of yellow perch harvested by pedestrian anglers at Waukegan and Montrose Harbors (3.9 ± 1.3 years; t-value = 7.04, $P < 0.0001$). Additionally, mean length of yellow perch harvested by boat anglers (303 ± 49 mm TL) was significantly greater than that of yellow perch harvested by pedestrian anglers (229 ± 47 mm TL; t-value = 6.34, $p < 0.0001$).

Job 101.3: Sample pelagic age-0 yellow perch and their food resources in offshore waters

Objective: Monitor the relative abundance of pelagic age-0 yellow perch and their zooplankton prey in offshore waters (≥ 3 miles from shore) of Lake Michigan.

Pelagic age-0 yellow perch and zooplankton were collected at fixed stations about 9 miles offshore of Waukegan, IL on three occasions between 1 – 30 July, 2011. Pelagic, age-0 fish were collected at the surface (0-2 m) using a 1-m x 2-m fixed frame floating neuston net equipped with 1000-µm mesh. A multi-net, opening/closing 1-m x 1.4-m mid-water Tucker trawl was used to sample pelagic, age-0 fish at the depth range of 2 to 38 m of water. This portion of the water column was separated into 6 depth strata (2-8, 8-14, 14-20, 20-26, 26-32, and 32-38 m) and each of these depth bins was sampled for 30 minutes. Both nets on the mid-water trawl were equipped with 1000-µm nitrex mesh nets. Each depth strata was sampled for zooplankton using replicate vertical hauls of a 0.5 diameter plankton net (64-µm mesh) equipped with an opening/closing mechanism. Fish and zooplankton were preserved in the field and sorted to species, enumerated, and measured in the laboratory. In the lab, fish were identified to species and total length was measured. Zooplankton 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, identified to the lowest taxon possible and measured.

In 2011, the most common species collected was burbot (*Lota lota*), followed by bloater (*Coregonus hoyi*), yellow perch, deepwater sculpin (*Myoxocephalus* thompsonii) and alewife (*Alosa pseudoharengus*). Both yellow perch and alewife were only collected within 2-8 meters of water and day time densities of both species were low over all (< 0.1 fish/100m^3; Figure 11). Densities of bloater larvae increased with depth and were collected in water as deep as 32-38 meters. Larval burbot densities decreased with depth, but this species was collected in water as deep as 28-32 meters. Densities of deepwater sculpin larvae increased with depth and were not collected in waters shallower than 26 meters.

Mean annual crustacean zooplankton density was low, 5.14 ind./L ± 7.73 (std), throughout the study period. Overall, copepod nauplii (40%), calanoid copepods (33%), and cyclopoid copepods (27%) represented the majority of zooplankton captured. Few cladocerans were found throughout the study (< 1%) and this group was composed mainly of bosmina, daphnia, and polyphemus. The daytime distribution of crustacean zooplankton was heterogeneously distributed among depths and the highest densities were detected on July 15 at depths ≥ 20 meters (Figure 12).

Job 101.4: Sample demersal age-0 yellow perch and their food resources in nearshore waters
<u>Objective</u>: 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. Daytime bottom trawling for age-0 yellow perch was conducted weekly between 5 August – 5 October, 2011 at four depth stations (3, 5, 7.5 and 10 m). Water temperature was also recorded at each depth station. All fish collected were counted and total length was measured to the nearest 1 mm for a subsample (30 individuals per species) of fish. Total effort during 2011 was approximately 131,016 m^2 and 8 age-0 yellow perch were collected. Mean annual CPUE of age-0 yellow perch during 2011 was 5.5 fish/100,000 m^2 (Figure 13).

Forty-four zooplankton samples were collected at two historical sites near Waukegan Harbor, IL between 2 June – 5 October, 2011. Samples were immediately preserved in 10% sugar formalin. 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. 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, identified to the lowest taxon possible and measured. Mean June-July zooplankton density in 2011 was 7.0 ind./L (Figure 14), which continues to be below the minimum density (10/L) suggested for age-0 yellow perch foraging success (Bremigan et al. 2003). Mean June-July crustacean zooplankton density was only 1.1 ind./L during 2011. Monthly density of total zooplankton was low during June and July and then peaked during August and October at approximately 59 and 50 ind./L, respectively (Figure 15).

Mean monthly density of veligers was low during June (3.2 ind./L), increased to 10.0 ind./L in July, peaked at 83.1 ind./L in August and then declined to about 40.0 ind./L in September and 20.3 ind./L in October. Mean monthly crustacean zooplankton density was also low during June and July (< 2 ind./L), but increased to approximately 12 ind./L during August and September and peaked at around 30 ind./L in October (Figure 15). Copepod nauplii dominated the zooplankton assemblage during June (Figure 16), but densities declined significantly by July. During July and August rotifers dominated the zooplankton assemblage followed by copepod nauplii and bosmina. These taxa remained abundant throughout September and October, and adult calanoid and cyclopoid copepods 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.

Benthic invertebrates were collected monthly August through October in 7.5 meters of water at a site north of Waukegan Harbor. When possible, SCUBA divers collected benthic invertebrates using a 7.5-cm (3-in) diameter core sampler. Four replicate samples from the top 7.5 cm (3 in) of the soft substrate were collected and preserved in 95% ethanol. When weather conditions did not allow collection by divers benthic invertebrates were sampled using a petite ponar grab with 232-cm^2 sampling area. During each sampling event, two replicate ponar grabs were collected and preserved in 95% ethanol. During 2011, August samples were collected by SCUBA divers, while September and October samples were collected using a ponar grab. In the lab, all samples were sieved through a 363-μm mesh net to remove sand. Organisms were then sorted from the remaining sediment debris 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. Based on benthic core collections, the most abundant taxa in substrate near Waukegan during August were chironomids followed by ostracods, nematods, and mollusks (Figure 17a). Individuals of Sphaeriidae made up all of the mollusks collected during August. Unlike in 2010, Diporeia were not detected in the substrate near Waukegan during August. Oligochaetes and Hydracarina were also found during August, but in much smaller abundances (collectively <10% of total density). Based on ponar grabs, mollusks, nematods and chironomids dominated the benthic invertebrate community near Waukegan during September and October, but their percent composition varied monthly (Figure 17b). Most of the mollusks (91%) collected during September were identified as members of Pelecypoda; members of Sphaeriidae were also collected, but in much smaller quantities. Conversely, Sphaeriidae was the most dominant mollusk collected during October and densities of Pelecypoda were relatively low. Oligochaetes and ostracods were also collected during September and October with Oligochaetes being most abundant during October and densities of ostracods relatively low during September and October.

We examined the stomachs of all 8 age-0 yellow perch collected during 5 August – 5 October, 2011. Due to such a small sample size seasonal variation in diet was not examined. Mean length of yellow perch used for diet analysis was 69 ± 5 mm TL (SD). Overall, the diet of age-0 yellow perch was dominated by zooplankton (66%) and smaller quantities of benthic invertebrates, which is consist with previous trends. More specifically, age-0 yellow perch primarily consumed copepods, chironomids and smaller quantities of cladocerans (Figure 18). Hydracarina and ostracods were also found in the diet of age-0 yellow perch, but in much smaller quantities (<1% of all items). The majority of copepods consumed by age-0 yellow perch were Calanoida spp.

(94% of copepods consumed) and Chydoridae spp. was the most dominant cladoceran taxa found.

Job 101.5: Sample juvenile (age-0 through age-2) yellow perch in nearshore waters
Objective: Collect age-0 yellow perch in nearshore waters in a manner consistent with guidelines developed by the Yellow Perch Task Group's lakewide age-0 yellow perch assessment. Monitor the abundance and diet of juvenile yellow perch.

2011 sampling

To fulfill our commitment to the Yellow Perch Task Group's lakewide age-0 yellow perch assessment, we sampled yellow perch on three occasions during 1 – 31 August, 2011. We fished 10-m gill net panels of 6, 8, 10, and 12 mm mesh, but to achieve gear consistency among the four jurisdictions only yellow perch caught in 6 and 8 mm mesh are reported to the Yellow Perch Task Group. During each sampling event, nets were fished for approximately four hours in 3-10 meters of water at historical sites near Waukegan Harbor, IL. Total effort during August 2011 was 43.6 hours during which we caught 72 yellow perch in 6 and 8 mm mesh and 444 yellow perch in 10 and 12 mm mesh. We also sampled juvenile yellow perch on two occasions during both September and October. Total effort during September and October was 23.0 hours during which we captured 53 yellow perch and 233 fish from other species (mainly spottail shiner and round goby). All fish collected in these assessments were processed in the laboratory for size information and a subsample of fish was used for diet analysis. CPUE of yellow perch (all mesh sizes combined) peaked in August at 12 fish/hr and then declined to approximately 2 fish/hr in September and October (Figure 19). Yellow perch collected in small mesh gill nets during 2011 ranged from 55-200 mm TL. Mean length of yellow perch caught in 6 and 8 mm mesh panels was 76 ± 19 (SD) and 83 ± 12 mm TL, respectively. Mean length of yellow perch caught in 10 and 12 mm panels was 95 ± 12 and 117 ± 20 mm TL, respectively.

Stomach analysis

We examined the stomachs of a subset of juvenile yellow perch (N=22) collected during August - October, 2011. Length of yellow perch used for diet analysis ranged from 69-162 mm TL and mean length was 107 ± 29 mm TL (SD). Fish were divided into two size classes for diet description: < 80 mm and > 80 mm TL. In 2011 juvenile yellow perch consumed large quantities of chironomids as they comprised 72-89 % of the prey items consumed by fish < 80 mm and > 80 mm TL. Many of these yellow perch had 50-200 larval chironomids packed into their stomachs. Zooplankton, mainly cladocerans, and other benthic invertebrates were also found in the diet of these fish, but in much smaller quantities (Figure 20). One notable difference between the diet of these two size classes of yellow perch that is inconspicuous in Figure 20 was the presence of fish in the diet of perch > 80 mm TL. Several yellow perch ranging in length from 102- 162 mm had consumed round gobies that were approximately 20 mm in length.

Size-at-age and size-selective mortality

A total of 1,404 yellow perch collected in small mesh gill nets from 2006-2010 near Waukegan, Illinois during August and September (collected and processed during previous segments of F-123) and in Muskegon, Michigan during September 2010 were used to examine spatial and temporal size variability and size-selective mortality of juvenile (age-0 to age-2) yellow perch. Total length was measured to the nearest 0.01 mm and sagittal otoliths were removed.

Following a modified version from Secor et al. (1991), otoliths were polished until a clear view of the focus and any annuli were evident using 800 grit sandpaper and 3 µm lapping film. Then, each otolith was photographed using a digital camera attached to a compound microscope and otolith radius as well as distance from focus to any annuli was measured to the nearest 0.001 mm. All otoliths were then aged by counting annuli and a random subset (200) of otoliths was aged by independent readers; 95% agreement was met among readers. During 2006 - 2010, we collected yellow perch ranging from approximately 50 to 160 mm in length and 0 – 2 years old. The 6 mm mesh collected age-0 yellow perch almost exclusively while age-0 and age-1 fish were caught in 8 mm mesh (Figure 21). Most of the yellow perch collected in 10 mm mesh were age-1 while age-1 and age-2 fish were collected in 12 mm mesh. Our small mesh gill net configuration was effective at targeting age-0 through age-2 yellow perch, but it is possible that we are not efficiently sampling some of the biggest age-2 fish with this gear.

Size-at-age was back-calculated for yellow perch older than age-0 using the Dahl-Lea (Direct Proportion) method. Temporal variation of juvenile yellow perch total length at capture was examined each year using a one-way ANOVA with a Tukey-Kramer HSD mean separation test. A two-sample t-test was used to investigate spatial variation of age-0 total length between yellow perch sampled in Illinois and Michigan waters of Lake Michigan in 2011. First-year overwinter mortality was investigated using Kolmogorov-Smirnov (K-S) two-sample asymptotic tests, comparing length-frequency distributions from age-0 yellow perch sampled in the fall to back-calculated length distributions at the start of age-1 the following year (Fitzgerald et al. 2004). Pre and post winter distributions were then converted to quantile distributions (quantiles: 1, 5, 10, 25, 50, 75, 90, 95, and 99); these quantiles have a linear relationship and when plotted against each other (Q-Q plot) and allow for a separation of growth and mortality by testing whether the slope and intercept are different from 1 and 0 respectively (Fitzgerald et al. 2004; Post and Evans 1989). Annual size-selective mortality of a given year-class between age-1 and age-2 was examined by first back-calculating total length at the start of age-1 from fall caught age-1 fish. The same year-class was then resampled a year later, at age-2, and used to back-calculate total length at the start of age-1. By comparing total length at the same point in time, start of age-1, influences of growth between sampling events are eliminated and, as a result, distributions and mean total length were compared directly using K-S tests and t-tests, respectively. Significant differences in the distributions and mean back-calculated total lengths are indicative of size-selective mortality between sampling events (Sinclair et al. 2002).

Within Illinois, mean total length of age-0 yellow perch differed significantly between years ranging from 60.2 mm to 64.6 mm ($p < 0.001$) with the largest age-0 fish observed during 2006 and 2008 (Table 2). Although annual differences in mean total length at capture were not detected at age-1 ($P=0.24$), length at capture varied significantly for age-2 yellow perch ($p = 0.003$). The largest age-2 total length at capture was observed during 2008 (124.6 mm) and the smallest during 2010 (113.4 mm). Mean total length of age-0 yellow perch during 2010 differed spatially between the eastern and western shores of Lake Michigan with yellow perch sampled near Muskegon, Michigan 20 mm on average, larger than those sampled near Waukegan, Illinois ($p < 0.001$; Table 2).

Overwinter mortality was not observed for any year-class; however, pre- and post-winter length frequency distributions differed significantly each year with Q-Q plots suggesting this difference was largely due to growth between sampling events (Figure 22). Pre-winter length distribution of the 2006 year-class was bimodal with peaks at 55 mm and 65 mm, which differed significantly from the unimodal post-winter distribution that was shifted up the length axis (Figure

22a). The Q-Q plot of these distributions indicated a line shifted above the 1-1 line with a slope not significantly different from 1 and an intercept different from 0 (Figure 22a). A proportionate shift of all quantiles above the 1-1 line is most likely indicative of a scenario where there is equal growth of all size-classes between sampling events (Post and Evans, 1989). Pre- and post-winter distributions of the 2007 year-class were distinctly unimodal and differed significantly with the post winter distribution, positively drawn out along the length axis (Figure 22b). Examination of the Q-Q plot of these distributions revealed a slope significantly greater than 1 and an intercept different from 0 (Figure 22b). A disproportional increase of the upper quantiles relative to the lower quantiles is often indicative of size-specific growth where larger individuals are growing faster than their smaller counterparts (Post and Evans, 1989). Pre- and post-winter distributions of the 2008 year-class were significantly different though few age-1 yellow perch were captured in 2009 (Figure 22c). The Q-Q plot of these distributions revealed a similar trend to the 2007 year-class with a slope significantly greater than 1 and an intercept not significantly different from 0, indicating size-specific growth between sampling events. Lastly, pre- and post-winter distributions of the 2009 year-class differed significantly, with the post winter distribution again shifted up the length axis (Figure 22d). The Q-Q plot revealed a slope significantly greater than 1 and an intercept significantly different from 0, which again suggest size-specific growth between sampling events.

Total length distribution of the 2005 year-class at age-1 did not differ significantly from the back-calculated age-1 total length distribution from collections of the 2005 year-class in 2007 at age-2 (Figure 23a). Similarly, comparisons of mean total length between the sampling events revealed no significant differences, providing little evidence of size-selective mortality between ages-1 and ages-2 (Figure 23a). Conversely, the 2006 year-class provided strong evidence of size-selective mortality between ages-1 and ages-2. Examination of the age-1 distribution in 2007 and age-1 distribution back-calculated from age-2 in 2008 revealed significant differences between distributions with an abrupt truncation at less than 70 mm of yellow perch surviving to age-2. These results suggest that yellow perch less than 70 mm at the start of age-1 were not surviving to age-2 (Figure 23b). Further evidence of size-selective mortality was observed when comparing back-calculated mean total lengths. On average, fish from the 2006 year-class sampled at age-1 were 6.8 mm smaller than those sampled at age-2 and back-calculated to age-1; this is indicative of a scenario where small individuals have been removed resulting in a back-calculated size-at-age that is larger than what was actually observed. Lastly, the age-1 distribution of the 2008 year-class differed significantly from the age-1 back-calculated distribution from age-2 yellow perch sampled in 2010 with the length distribution shifting towards smaller sizes on the length axis. This suggests removal of the largest individuals between sampling events, though a similar trend was not observed when comparing back-calculated mean total lengths (Figure 23c). Disagreement between length distribution and mean total length comparisons may be partially attributed to small sample size, making inferences regarding annual mortality in 2008 ambiguous.

Job 101.6: Data analysis and report preparation
Objective: Analyze data and prepare reports, manuscripts and presentations.

Data from the above jobs were processed, analyzed, and summarized. This annual report was prepared from the data.

CONCLUSIONS

Spawning stock

To improve our annual assessments of the yellow perch population we targeted fish in deeper waters (10-20m) with gill nets during spring and fall. Mean CPUE was 18.5 fish per net night in the spring and 7.5 fish per net night during the fall. The dominate year-classes observed in our spring assessment were the 2007 and 2005 year classes while the 2005, 2007 and 2008 year-classes were most abundant during the fall. Based on high CPUE during the fall of 2009 and very low fall CPUE during 2010 and 2011, utilization of the nearshore zone by adult yellow perch during September seems quite variable. Although few fish were caught during September 2011 (N=45), the sex ratio of yellow perch was highly skewed towards females. Similarly, the Wisconsin Department of Natural Resources reported has an increase in the percent of female yellow perch collected during their winter assessment since 2007. More specifically, female yellow perch made up 50% of the catch in 2007 and this increased to 70% by 2010 which surpasses that detected in the late 1980s and early 2000s (Makauskas and Clapp 2010). Overall, lakewide CPUEs show a long-term decline in the abundance of adult yellow perch and current abundance remains well below levels detected in the late 1980s and early 1990s.

Investigation of the female spawning stock in southwestern Lake Michigan during 2007-2011 indicated that fecundity increased exponentially with length. Fecundity ranged from approximately 12,000 eggs for a 178 mm female to over 140,000 eggs for a 336 mm fish. Our results also indicated that relative abundance of female spawners was similar among years, but the size distribution of these fish differed considerably on an annual basis. As such the size composition of the female spawning stock can potentially impact reproductive potential at the population level. Our data set does support the contention that estimates of population level reproductive potential should account for size composition of spawners rather than spawner biomass alone.

Analysis of yellow perch catch data from 2008-2011 (spring assessment) suggest that larger females may be spawning earlier than their smaller counterparts and that females are dominating our catch in 15 and 20 meters of water between 30 April – 4 June. The latter result may provide some evidence that egg deposition is occurring in deeper water than historically observed. However, an extended sampling period and video documentation of spawning events are needed to corroborate this theory. If a shift to deeper spawning habitat is occurring than this finding may partly explain why divers could no longer find egg skeins on the Waukegan Wiremill intake pipe during the mid-2000s (previous segments of F-123-R) and raises concerns about how hatching success and larval survival might be affected by deeper egg deposition. Williamson et al. (1997) found that yellow perch egg deposition was deeper in a lake with high-damaging solar ultraviolet radiation (UVR), which is associated with low dissolved organic carbon and high water clarity. The establishment and expansion of Dreissenid mussels has been linked to significant increases in water clarity across the Great Lakes (Dobiesz and Lester 2009) and as such, these invasive mussels may be indirectly affecting the spawning behavior of yellow perch in Lake Michigan through increased levels of UVR. Given our recent evidence that female size may influence the timing of egg deposition and the potential that egg deposition is occurring in deeper water within southwestern Lake Michigan it is imperative that we continue to monitor the spawning stock and learn more about the availability of yellow perch spawning habitat in the deeper, understudied portions of the lake bottom surrounding historical spawning grounds.

To determine the age structure of yellow perch caught by boat anglers, anal spines were collected from fish at the Waukegan launch ramp between late April and mid-May. Fish harvested by boat anglers during 2011 were 5-13 year old and data collected since 2008 (previous segments of F-123R) indicates that this harvest is skewed towards larger females. Collection of yellow perch spines from pedestrian anglers at Waukegan and Montrose harbors was conducted during June and August 2011 and 97% of these fish were harvested at Montrose harbor. Pedestrian anglers primarily harvested age 3, 4 and 5 fish. Overall, sport anglers (boat and pedestrian combined) primarily harvested yellow perch from the 2006-2008 year-classes and fish from these year classes will be extremely important for future spawning and should be protected.

2011 Year class

CPUE of age-0 yellow perch collected in bottom trawls during 2011 was low compared to that detected with 2005 and 2010. 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 and 2005 year classes. Both 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 and 2009 was the first year the 2005 year class dominated both our adult assessment and sport harvest collections (previous segments of F-123-R). These results suggest that strong CPUE of age-0 yellow perch is a reasonable indicator of recruitment success. Thus, because CPUE levels were higher in 2010 compared to during 1998, within a few years hopefully the 2010 year class will appear more readily in our adult assessments as we saw with the 1998, 2002 and 2005 year classes. Despite all this, 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). So even with measureable year classes in 2002, 2004, 2005, and 2010, their levels were nowhere near that of the late 1980s; as such, they probably are not sufficiently strong to support extensive fishing pressure.

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 1996-2011 (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. 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

Our results from investigation of age and length data from yellow perch collected in small mesh gill nets during 2006-2010 revealed that mean total length of age-0 yellow perch varied annually, over winter mortality was not observed for any year-class and indicated size-selective mortality occurred only for the 2006 year class between age-1 and age-2. Within Lake Michigan, investigations into the juvenile life-stage of yellow perch have been rare, limited to the first growing season or based off back-calculations from adults. Earliest predictors of year-class strength are of the most use to management, however there is a trade-off between early notice and quality of data (Bradford 1992; Makauskas and Clapp 2006). As such, CPUE of age-0 yellow perch may not provide the most accurate representation of year-class strength if significant mortality occurs beyond the first growing season like that observed for the 2006 year class. Additionally inferences into the juvenile life-stage based off back-calculations from adult otoliths may be significantly biased if size-selective mortality occurred between back-calculated and sample dates. Future research should provide a better understanding of the unique contributions and magnitude of size-selective mortality spatially and temporally during the juvenile life stage and Efforts should be made to incorporate results of the juvenile life-stage dynamics to those found at earlier points in development.

Management Implications

In summary, the fishable yellow perch population consisted of multiple consecutive year classes (2005-2008) with the 2007 year class being the dominate age group. During 2011, our age data from sport harvested yellow perch suggested that anglers primarily harvested fish from the 2006-2008 year classes. Based on annual creel surveys, yellow perch harvest in Illinois waters of Lake Michigan was near a record low in 2011 (<40,000 fish); harvest has not been that low since the enforcement of the slot limit during 1997-2000 (based on results from previous segments of F-52-R). Our long-term data still clearly demonstrate that recruitment is highly variable and low, particularly when compared to that in the 1980s. While we show evidence that the Lake Michigan yellow perch population is being supported by multiple year classes, the production of strong year classes is only occurring periodically (2005 and 2010). Poor recruitment taken with the continued trend of low abundance and harvest of adult yellow perch in Illinois waters as well as lakewide (Makauskas and Clapp 2010) raises concerns about the growth and survival of yellow perch. Thus, it remains important to conserve the adult stock to the greatest degree possible 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.

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REFERENCES

Barbiero, R. P. and M. L. Tuchman. 2004. Changes in the crustacean communities of Lakes Michigan, Huron, and Erie following the invasion of the predatory Cladocerans Bythotrephes longimanus. Can. J. Fish. Aquat. Sci. 61:2111-2125.

Bradford, M. 1992. Precision of recruitment predictions from early life stages of marine fishes. Fish. B-NOAA 90:439-453.

Brazo, D. C., P. I. Tack, and C. R. Liston. 1975. Age, growth, and fecundity of yellow perch, Perca flavescens, in Lake Michigan near Ludington, Michigan. T. Am. Fish. Soc. 1975(4):726-730.

Brazo, D. C. 1990. Fisheries research and management report for the Indiana waters of Lake Michigan, 1989. Report to the Great Lake Fishery Commission. Lake Michigan Committee Meeting, March 1990.

Bremigan, M. T., J. M. Dettmers, and A. L. Mahan. 2003. Zooplankton selectivity by larval yellow perch in Green Bay, Lake Michigan. J. Great Lakes Res. 29:501-510.

Brofka, W. A. and J. E. Marsden. 1993. Creel survey of the Illinois waters of Lake Michigan. Annual report to Illinois Department of Natural Resources. INHS Technical Report 93/4. 40 p.

Clapp, D. F. and J. M. Dettmers. 2004. Yellow perch research and management in Lake Michigan: evaluating progress in a collaborative effort, 1997-2001. Fisheries 29(11):11-19.

Czesny, S. J., B. D. S. Graeb, and J. M. Dettmers. 2005. Ecological consequences of swim bladder noninflation for larval yellow perch. T. Am. Fish. Soc. 134:1011-1020.

Dettmers, J. M., M. J. Raffenberg, and A. K. Weis. 2003. Exploring zooplankton changes in southern Lake Michigan: implications for yellow perch recruitment. J. Great Lakes Res. 29:355-364.

Dobiesz, N. E., and N. P. Lester. 2009. Changes in mid-summer water temperature and clarity across the Great Lakes between 1968-2002. J. Great Lakes Res. 35:371-384.

Fitzgerald D.G., Clapp D.F., Belonger B.J., 2004. Characterization of growth and winter survival of age-0 yellow perch in southeastern Lake Michigan. J. Great Lakes Res. 30 (2), 227-240.

Graeb, B. D. S., J. M. Dettmers, D. H. Wahl, and C. E. Cáceres. 2004. Fish size and prey availability affect growth, survival, prey selection, and foraging behavior of larval yellow perch. T. Am. Fish. Soc. 133:504-514.

Hess, R. 1990. Fisheries research and management report for the Illinois waters of Lake Michigan, 1989. Report to the Great Lake Fishery Commission. Lake Michigan Committee Meeting, March 1990.

Hess, R. 1998. Status of Yellow Perch in Lake Michigan and Yellow Perch Task Group Progress report. Annual report to the Lake Michigan Technical Committee. Great Lakes Fishery Commission meeting, May 1997, Thunder Bay, ONT. 19 p.

Heyer, C. J., T. J. Miller, F. P. Binkowski, E. M. Caldarone, and J. A. Rice. 2001. Maternal effects as a recruitment mechanism in Lake Michigan yellow perch (Perca flavescens). Can. J. Fish. Aquat. Sci. 58:1477-1487.

Leach, J. H. 1993. Impacts of the zebra mussel (Dreissena polymorpha) on water quality and fish spawning reefs in western Lake Erie. In: T. F. Nalepa and D. Schloesser, eds. Zebra mussels: biology, impacts, and control. Lewis Publishers, Boca Raton, FL.

Madenjian, C. P., G. L. Fahnenstiel, T. H. Johengen, T. F. Nalepa, H. A. Vanderploeg, G. W. Fleischer, P. J. Schneeberger, D. M. Benjamin, E. B. Smith, J. R. Bence, E. S. Rutherford, D. S. Lavis, D. M. Robertson, D. J. Jude, M. P. Ebener. 2002. Dynamics of the Lake Michigan food web, 1970-2000. Can. J. Fish. Aquat. Sci. 59:736-753.

Makarewicz, J. C., P. Bertram, T. Lewis, and E. H. Brown, Jr. 1995. A decade of predatory control of zooplankton species composition of Lake Michigan. J. Great Lakes Res. 21:620-640.

Makauskas, D. & Clapp, D. 2006. Status of Yellow Perch in Lake Michigan, and Yellow Perch Task

Group Progress Report. Minutes of the Lake Michigan Committee.
Makauskas, D., and D. Clapp. 2010. Status of yellow perch in Lake Michigan, 2009. Annual Report to the Lake Michigan Committee. 20 p.
Marsden, J. E., and S. R. Robillard. 2004. Decline of yellow perch in southwestern Lake Michigan, 1987-1997. N. Am. J. Fish. Manage. 24(3):952-966.
McComish, T. S. 1986. A decade of dramatic change in the yellow perch population in Indiana waters of Lake Michigan. Presented to a joint meeting of the Indiana, Illinois, and Michigan chapters of the American Fisheries Society, March 1986.
Muench, B. 1981. 1979 sport fishing creel survey on the Illinois portion of Lake Michigan. Technical Report, Division of Fisheries and Wildlife, Illinois Department of Conservation. 17p.
Nelepa, T. F., D. L. Fanslow, and G. A. Lang. 2009. Transformation of the offshore benthic community in Lake Michigan: recent shift from native amphipod Diporeia spp. to the invasive mussel Dreissena rostriformis bugensis. Freshwater Biol. 54:466-479.
O'Farrell, M. R., and L. W. Botsford. 2006. The fisheries management implications of maternal-age-dependent larval survival. Can. J. Fish. Aquat. Sci. 63:2249-2258.
Post, J., and D., Evans. 1989. Size-dependent overwinter mortality of young-of-the-year yellow perch (Perca flavescens): laboratory, in situ enclosure, and field experiments. Can. J. Fish. Aquat. Sci. 46:1958-1968.
Redman, R. A., S. J. Czesny, and J. M. Dettmers. 2011a. Yellow perch population assessment in southwestern Lake Michigan. Annual report to Illinois Department of Natural Resources. INHS Technical Report. 36 p.
Redman, R. A., S. J. Czesny, J. M. Dettmers, M. J. Weber, D. Makauskas. 2011b. Old tales in recent context: current perspective on yellow perch recruitment in Lake Michigan. T. Am. Fish. Soc. 140:1277-1289.
Secor, D., Dean, J., Laban, E., Institute, E. P. R. & Research. 1991. Manual for otolith removal and preparation for microstructural examination.
Sinclair A.F., D. P., Swain, and J. M. Hanson. 2002. Disentangling the effects of size-selective mortality, density, and temperature on length-at-age. Can. J. Fish. Aquat. Sci. 59: 372-382.
Stewart, T. W., J. G. Miner, and R. L. Lowe. 1998. Quantifying mechanisms for zebra mussel effects on benthic macroinvertebrates: organic matter production and shell-generated habitat. J. N. Am. Benthol. Soc. 17:81-94.
Vanderploeg, H. A., S. A. Pothoven, G. L. Fahnenstiel, J. F. Cavaletto, J. R. Liebig, C. A. Stow, T. F. Nalepa, C. P. Madenjian, D. B. Bunnell. 2012. Seasonal zooplankton dynamics in Lake Michigan: disentangling impacts of resource limitation, ecosystem engineering, and predation during a critical ecosystem transition. J. Great Lakes Res. 38: 336-352.

TABLES

Table 1. Linear regression equations describing the relationship between female total length and fecundity of yellow perch collected in gill nets during 2007-2011.

Year	No. Ovaries	Slope (α)	Intercept (β)	P-value	Adj. R^2
2007	13	3.921	-4.925	<0.001	0.87
2008	75	3.500	-3.936	<0.001	0.83
2009	104	3.120	-3.153	<0.001	0.92
2010	105	3.768	-4.502	<0.001	0.92
2011	42	3.345	-3.517	<0.001	0.79

Table 2. Number, mean total length at capture, and standard error (in parenthesis) of juvenile yellow perch sampled each year and location within Lake Michigan. Letters denote annual differences in total length between years within an age group and an asterisk indicates length differences between age-0 fish collected in Waukegan, Illinois and Muskegon, Michigan during 2010.

	Age 0		Age 1		Age 2	
Year-class	N	TL	N	TL	N	TL
Waukegan						
2005	-	-	12	99.72 (2.25)	8	119.00[ab] (5.70)
2006	244	64.07[a] (0.46)	75	92.65 (1.13)	42	124.58[a] (1.95)
2007	65	60.15[b] (0.61)	257	91.86 (0.84)	-	-
2008	43	64.58[ac] (1.08)	12	90.28 (2.86)	23	113.38[b] (1.93)
2009	43	61.18[bc] (0.77)	22	94.40 (2.90)	-	-
2010	121	61.18[b] (0.48)	-	-	-	-
Muskegon						
2010	437	81.17* (0.48)	-	-	-	-

FIGURES

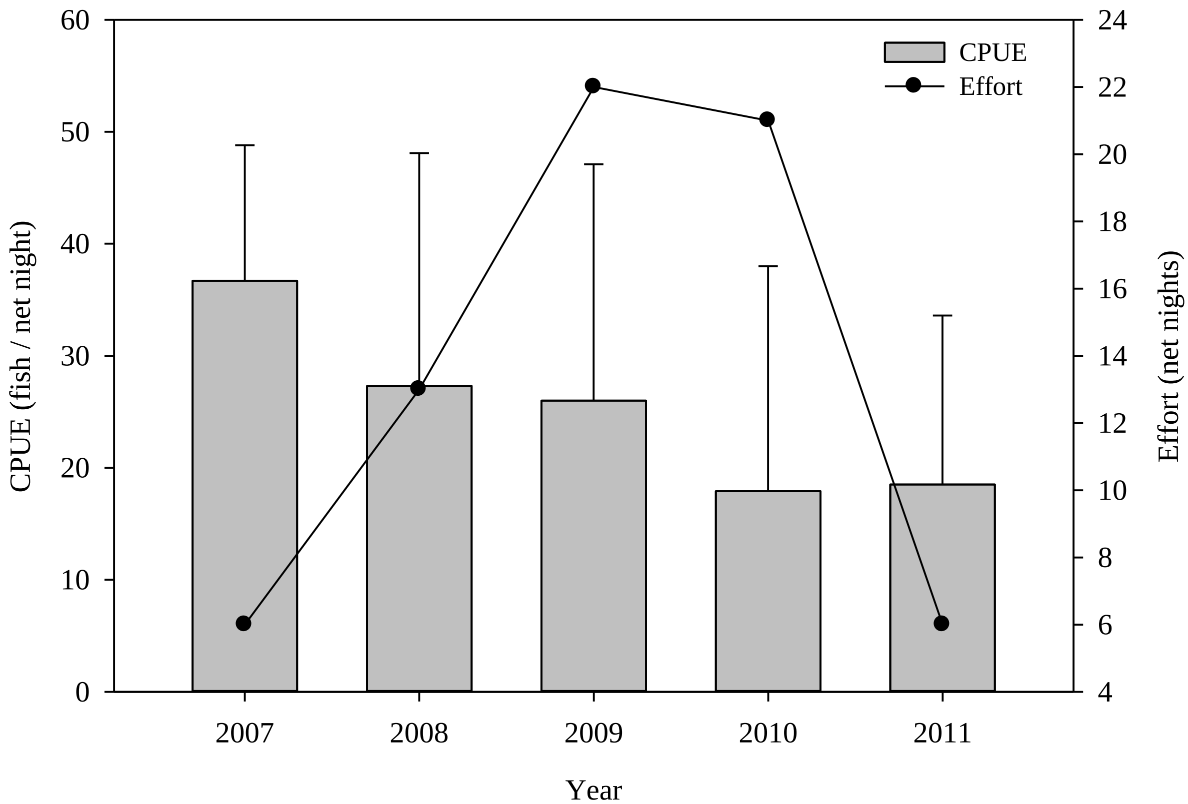

Figure 1. Annual mean CPUE (+ 1 SD) of yellow perch collected in gill nets at Waukegan and Lake Forest, Illinois during spring 2007-2011.

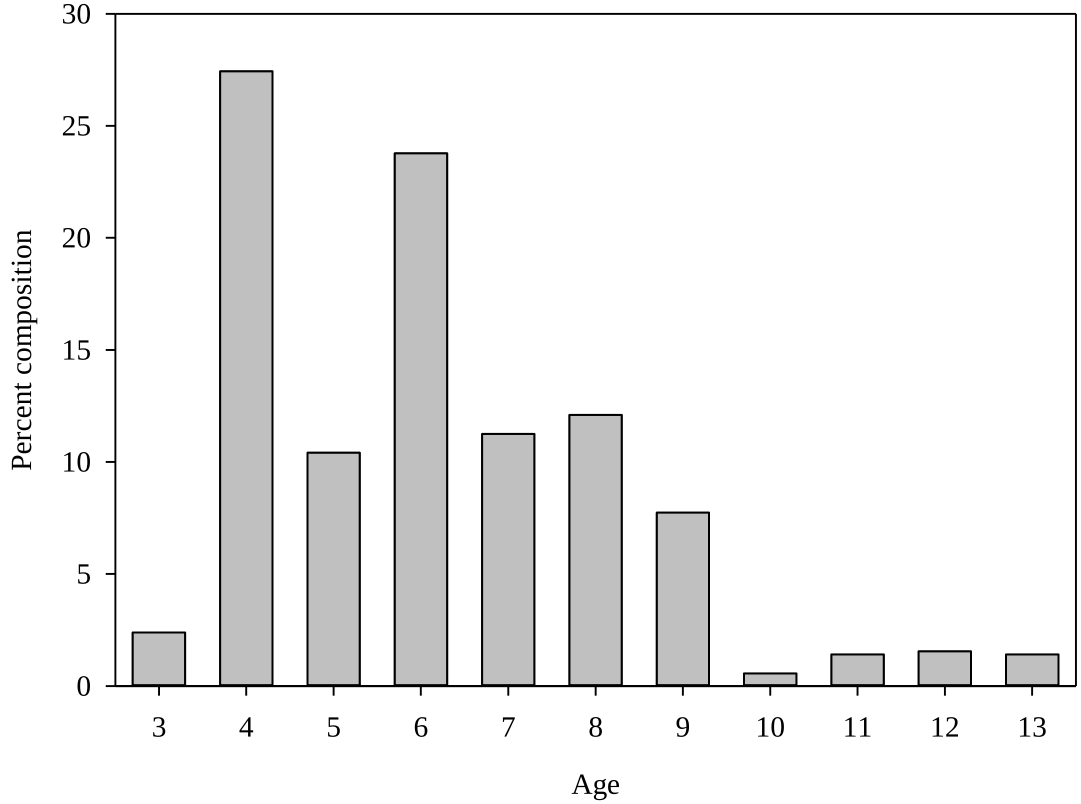

Figure 2. Age composition of adult yellow perch collected using gill nets at Waukegan and Lake Forest, IL during the spring of 2011.

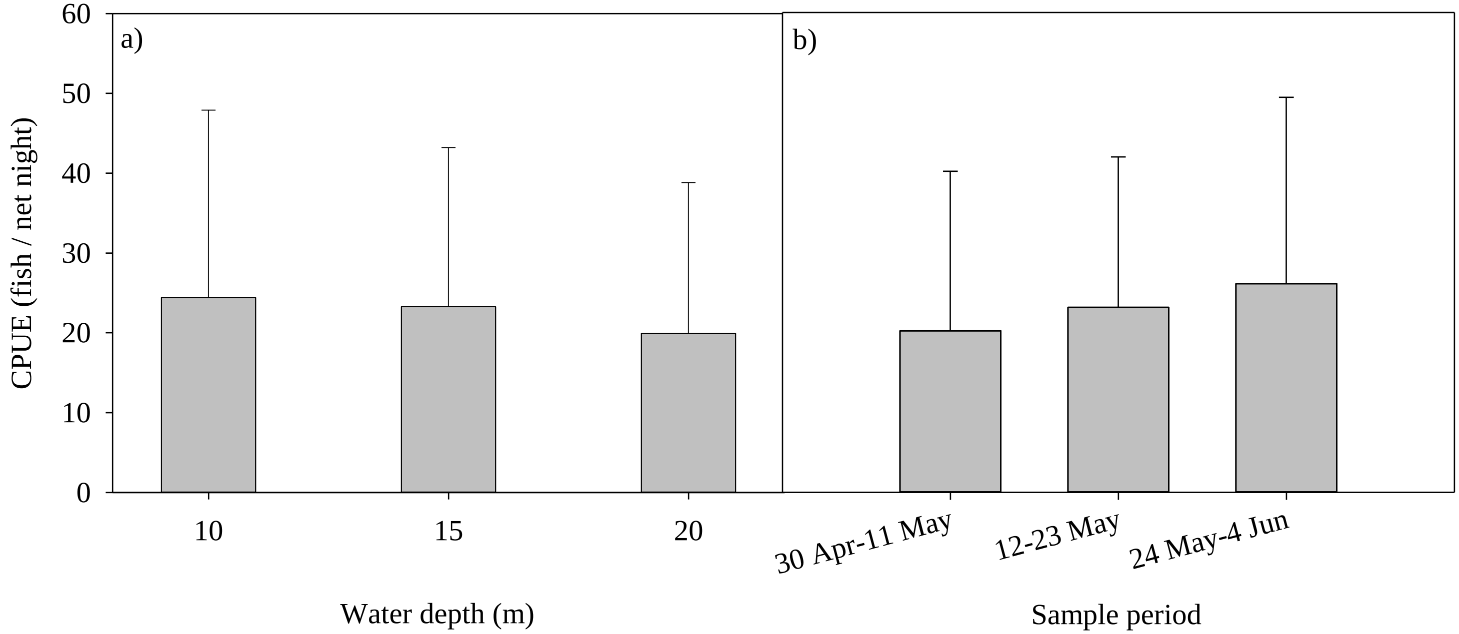

Figure 3. Mean CPUE (+ 1 SD) of yellow perch collected near Waukegan and Lake Forest, Illinois during 2008-2011 by a) water depth and b) sample period.

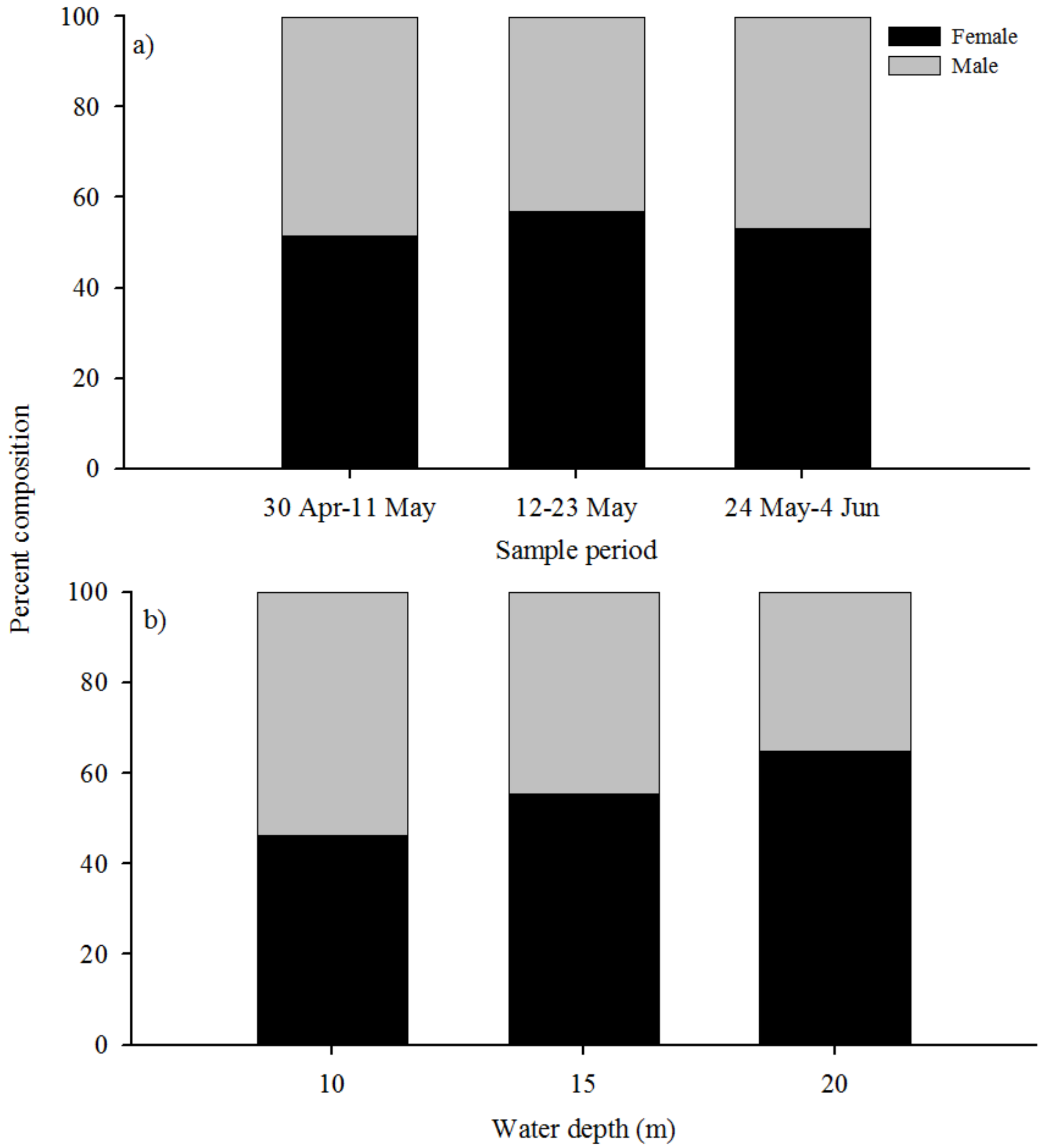

Figure 4. Gender composition of adult yellow perch collected in gill nets during 2008-2011 among a) sample periods and b) depths.

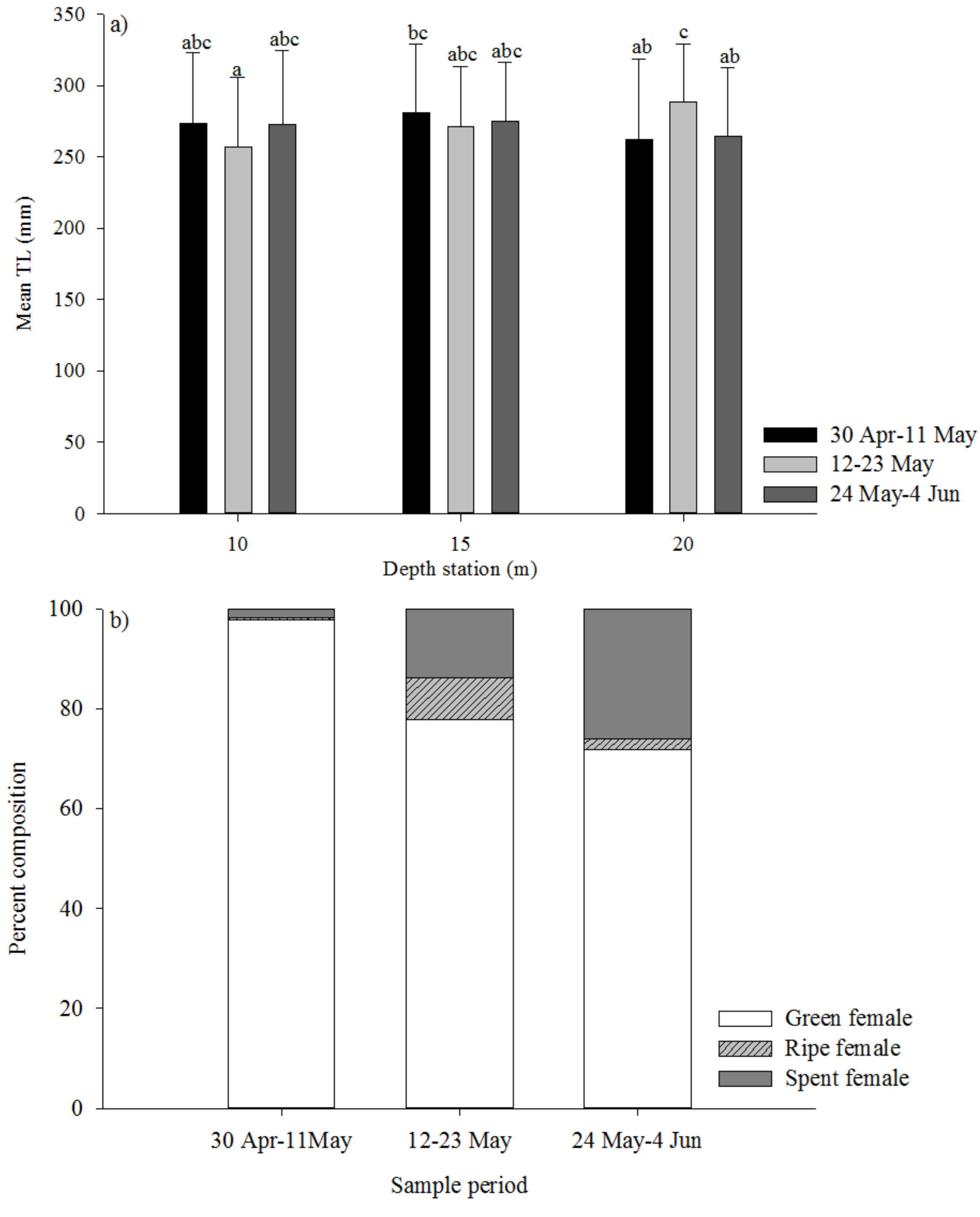

Figure 5. a) Mean total length (+ 1 SD) of female yellow perch among sample depths and periods and b) reproductive status of females among sample periods.

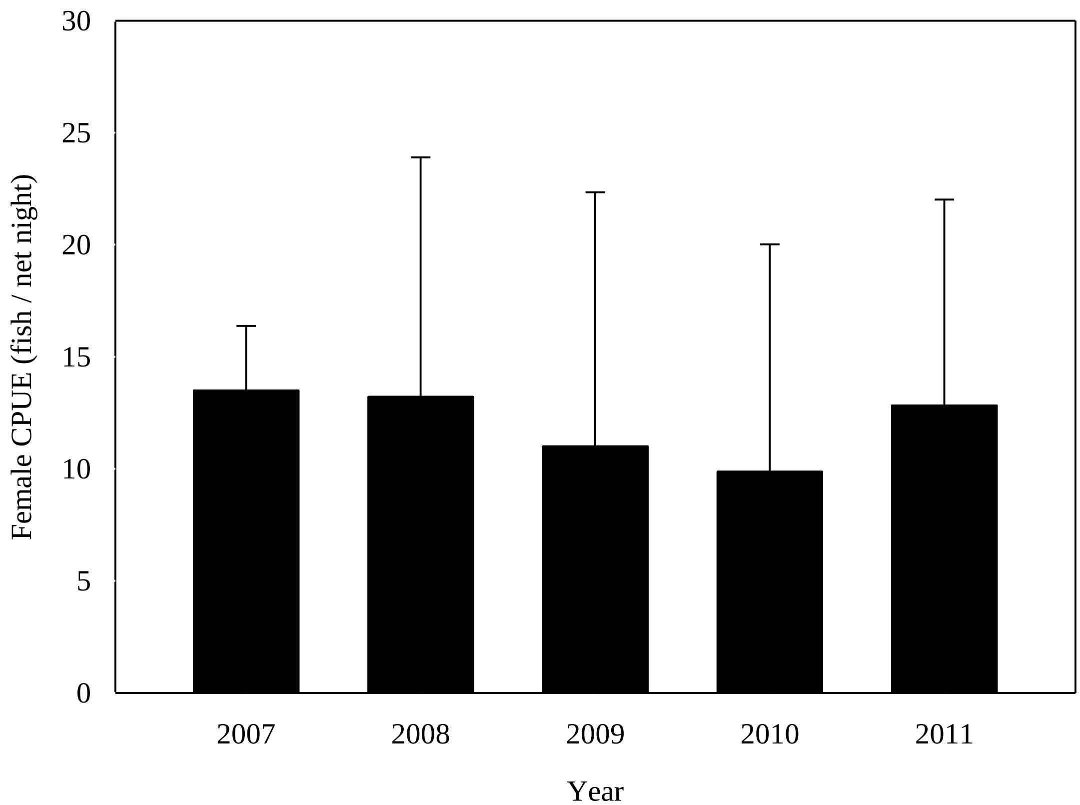

Figure 6. Annual mean CPUE (+ 1 SD) of female yellow perch collected using gill nets at Waukegan and Lake Forest, IL during 2007-2011.

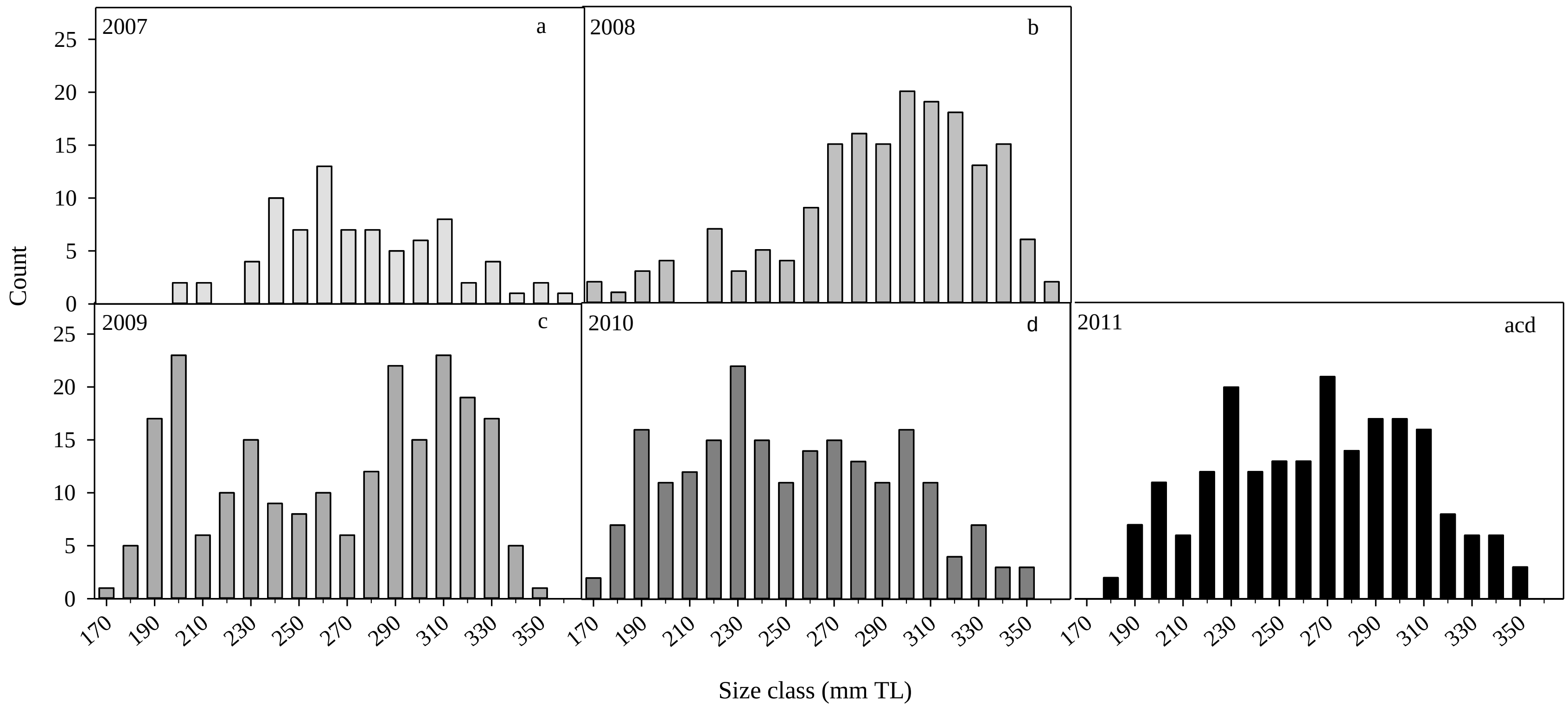

Figure 7. Annual length distributions of gravid females collected during 2007-2011 using gill nets at Waukegan and Lake Forest, IL. Length distributions with different letters were significantly different.

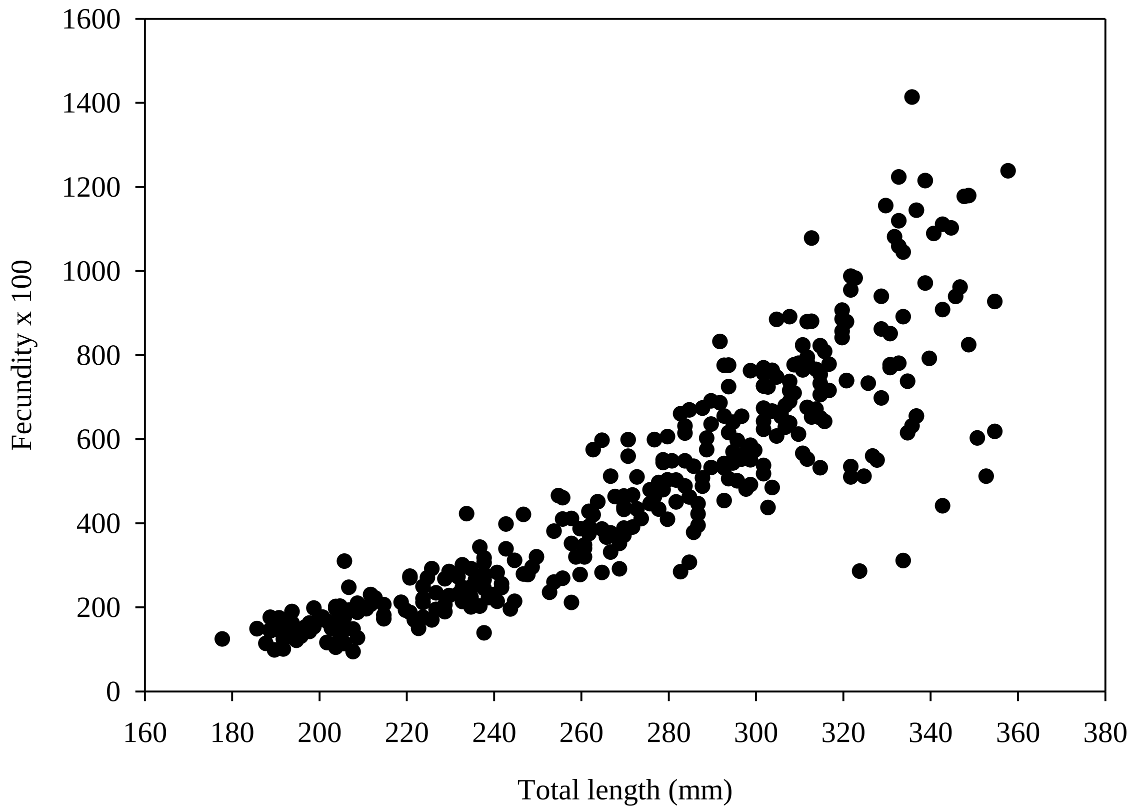

Figure 8. Relationship between total length and fecundity of yellow perch collected in gill nets during 2007-2011.

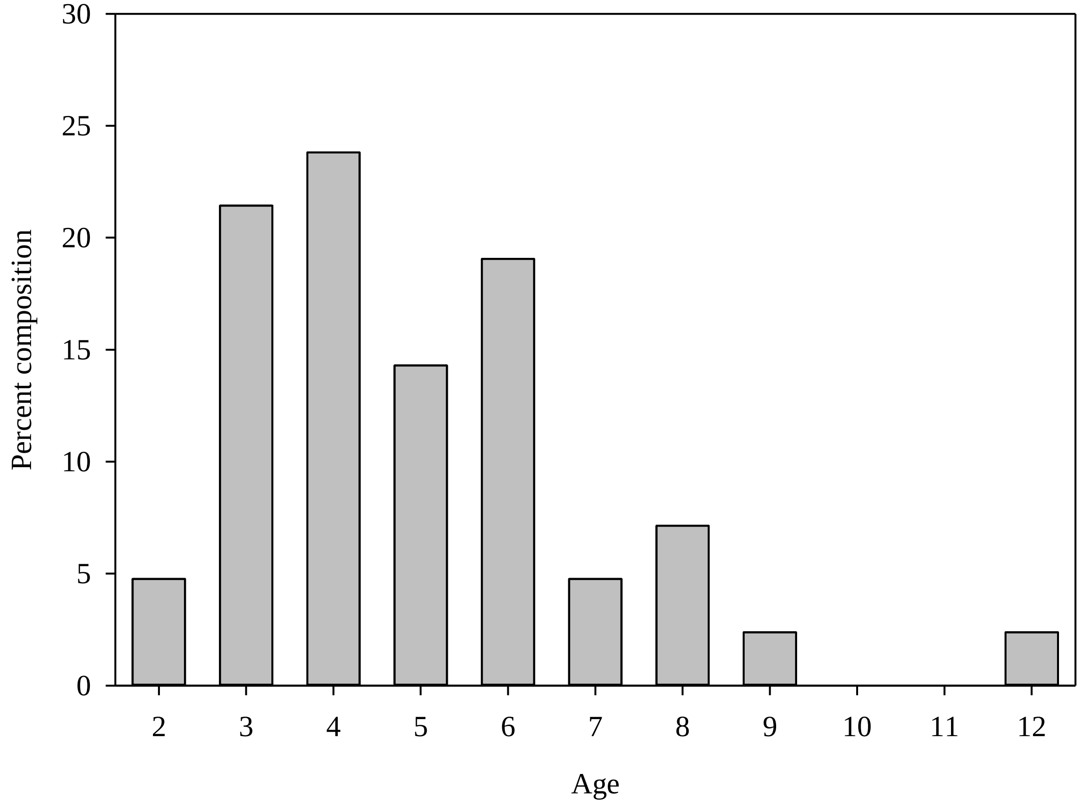

Figure 9. Age composition of adult yellow perch collected using gill nets at Waukegan, IL during the fall of 2011.

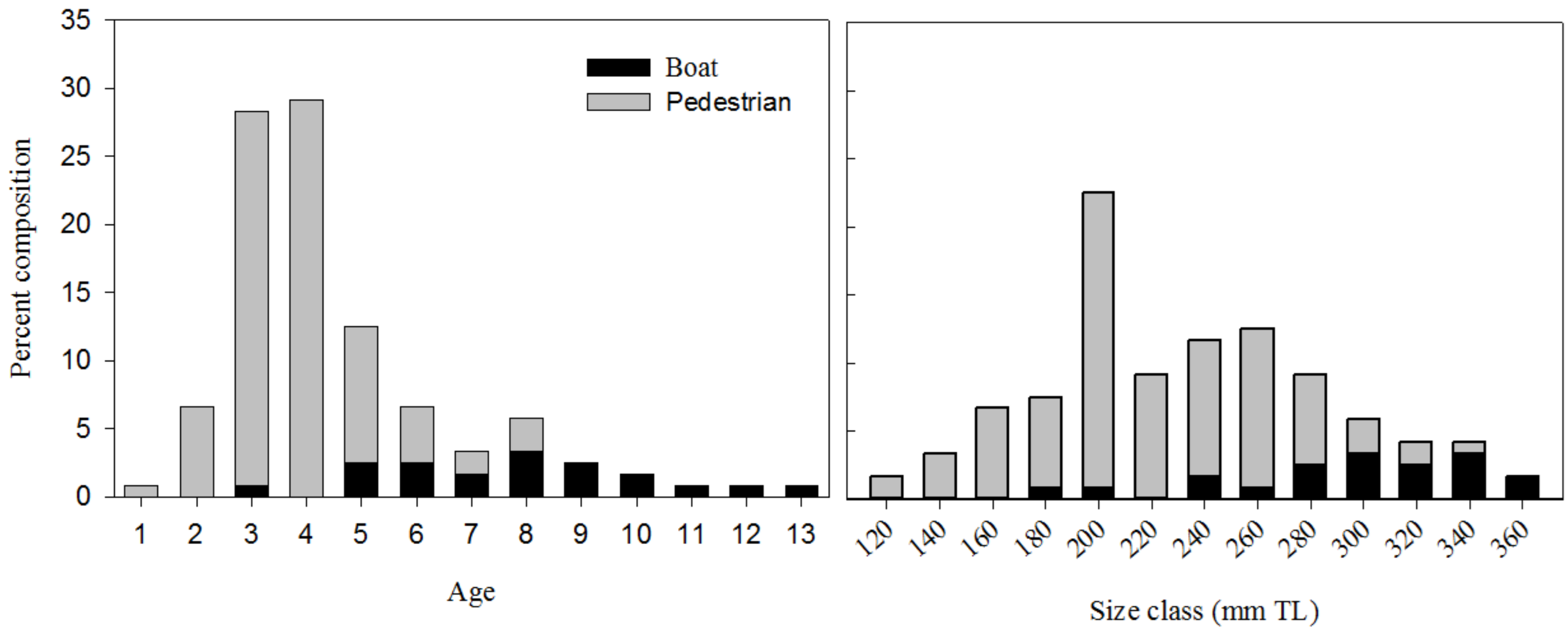

Figure 10. Age and length distributions of yellow perch harvested by boat anglers using the launch ramp at Waukegan Harbor and pedestrian anglers at Waukegan and Montrose Harbors during 2011.

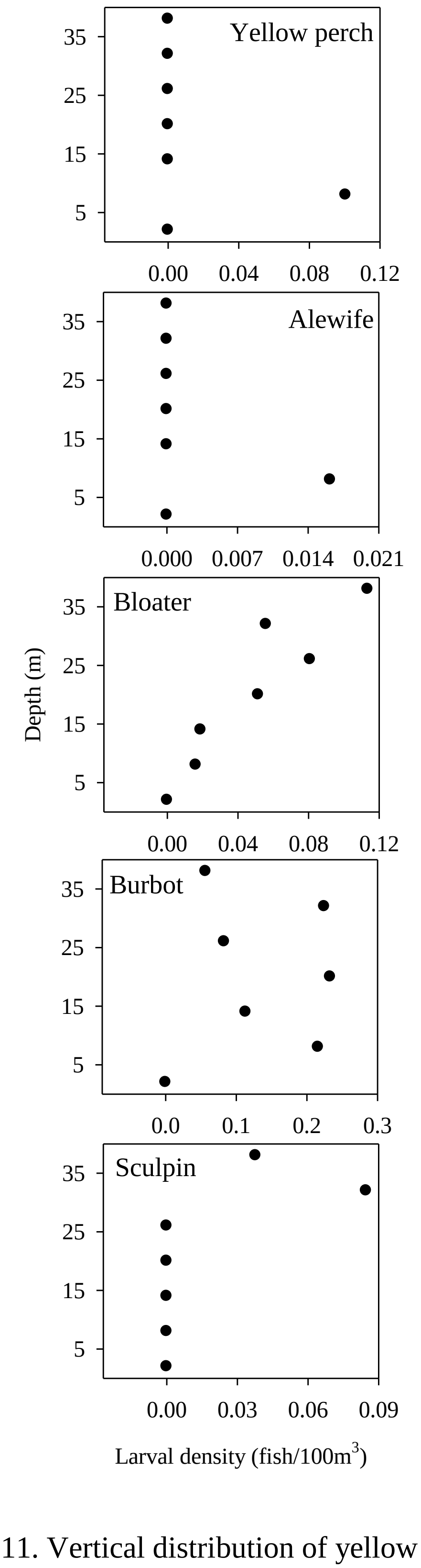

Figure 11. Vertical distribution of yellow perch, alewife, bloater, burbot and deepwater sculpin larvae collected 9 miles offshore of Waukegan during July 2011.

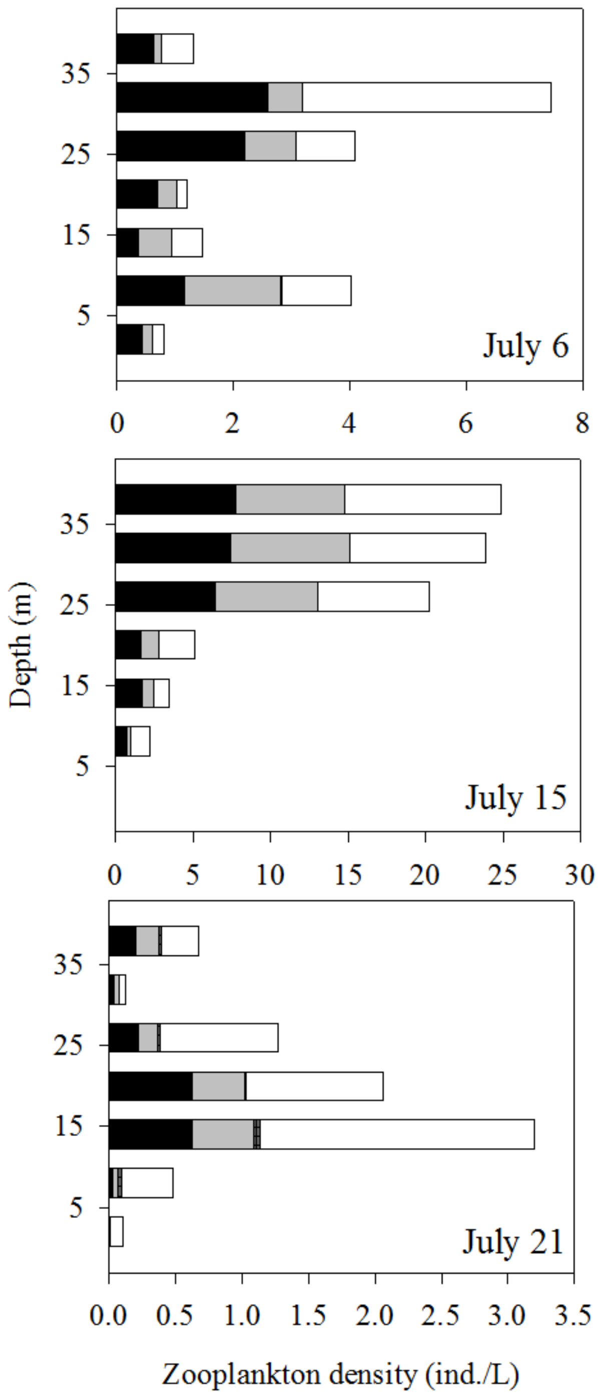

Figure 12. Vertical distribution of crustacean zooplankton collected 9 miles offshore of Waukegan during each sampling event in 2011. Bar colors represent the composition of each zooplankton group: calanoid copepods (black), cyclopoid copepods (grey), copepod nauplii (white), cladocerans (dark grey, cross-hatched).

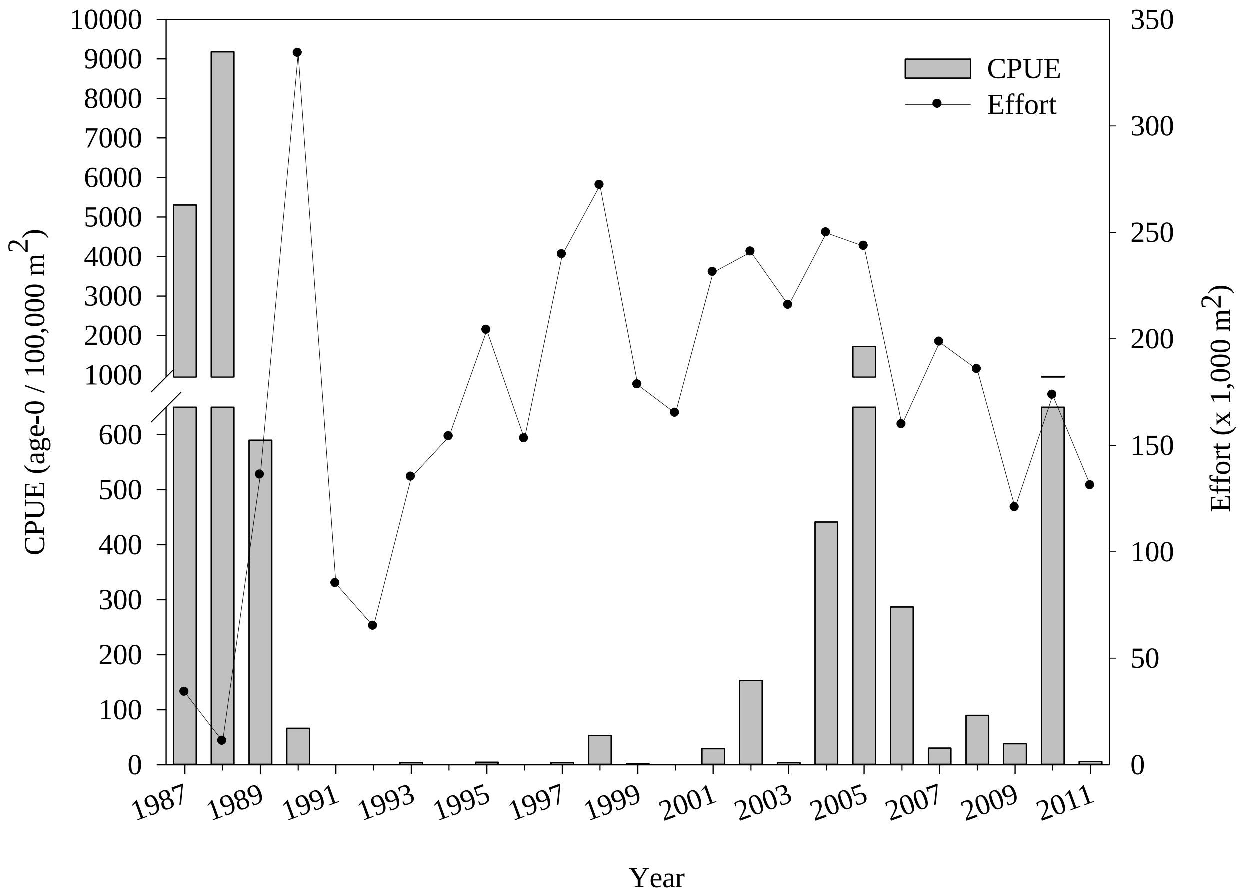

Figure 13. Relative abundance of age-0 yellow perch collected by daytime bottom trawls north of Waukegan Harbor, IL during 1987-2011.

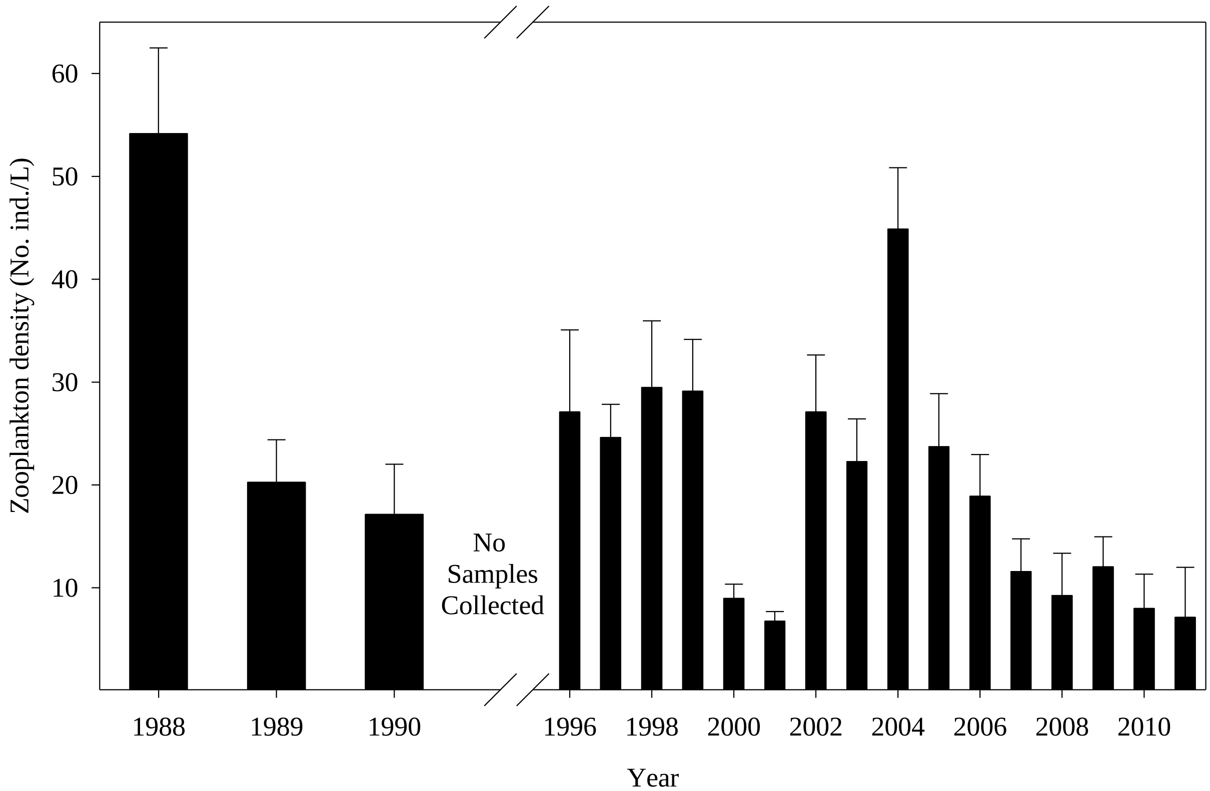

Figure 14. Mean density of zooplankton (+ 1 SE) present in Illinois waters of Lake Michigan near Waukegan during June-July for years 1988-2011.

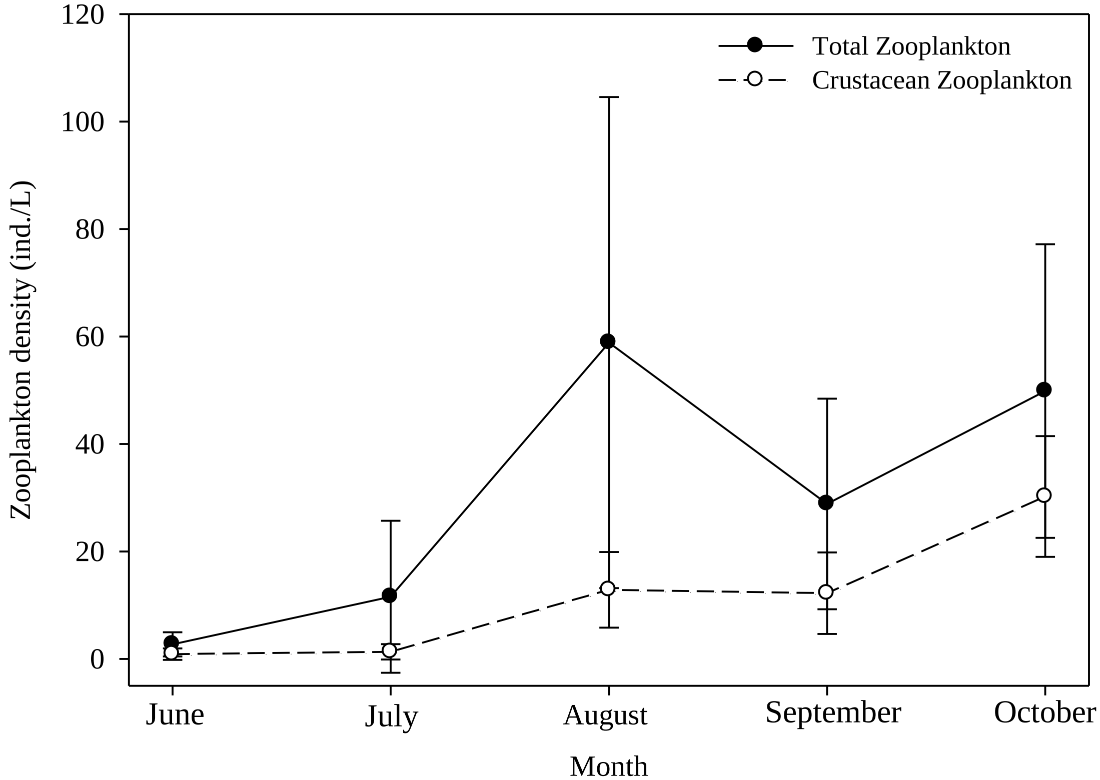

Figure 15. Mean monthly zooplankton density (± 1 SD) in nearshore Illinois waters of Lake Michigan near Waukegan during June-October 2011. Closed circles (●) represent total zooplankton, whereas open circles (○) represent crustacean zooplankton.

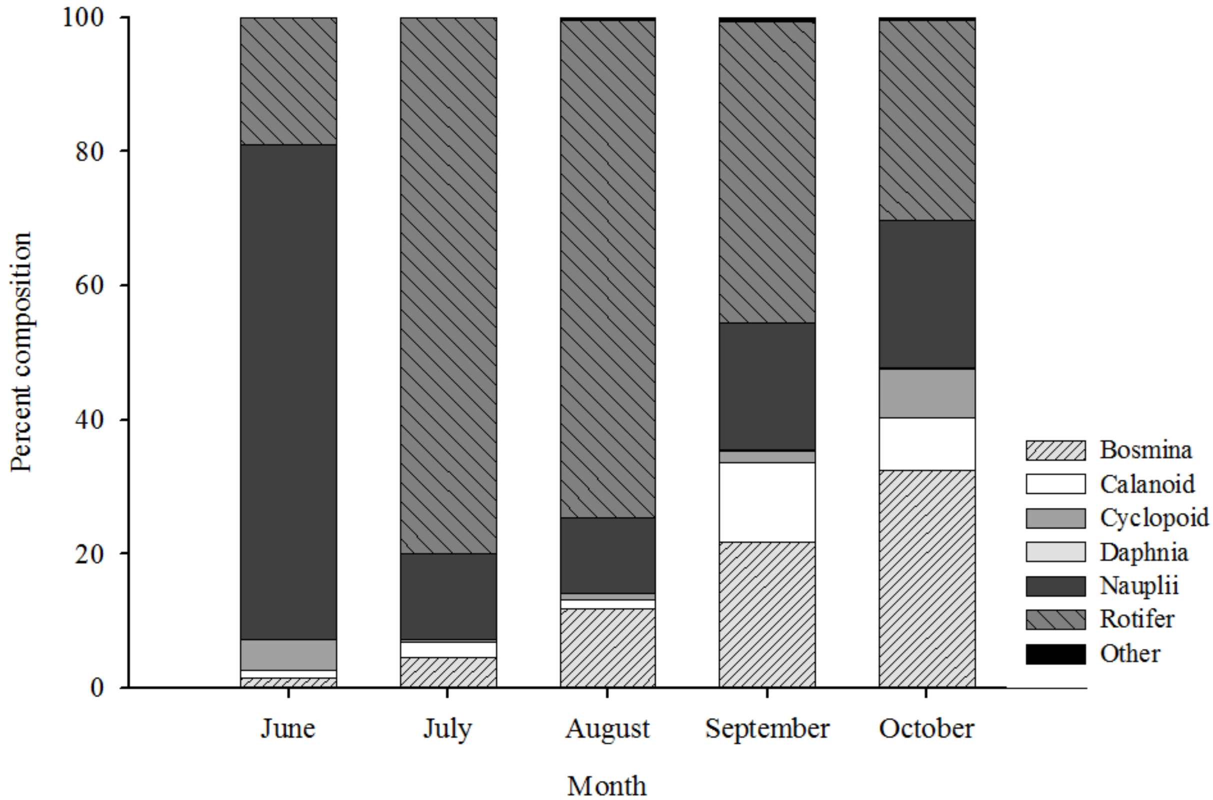

Figure 16. Monthly percent composition of zooplankton found in nearshore Illinois waters of Lake Michigan near Waukegan during June-October 2011.

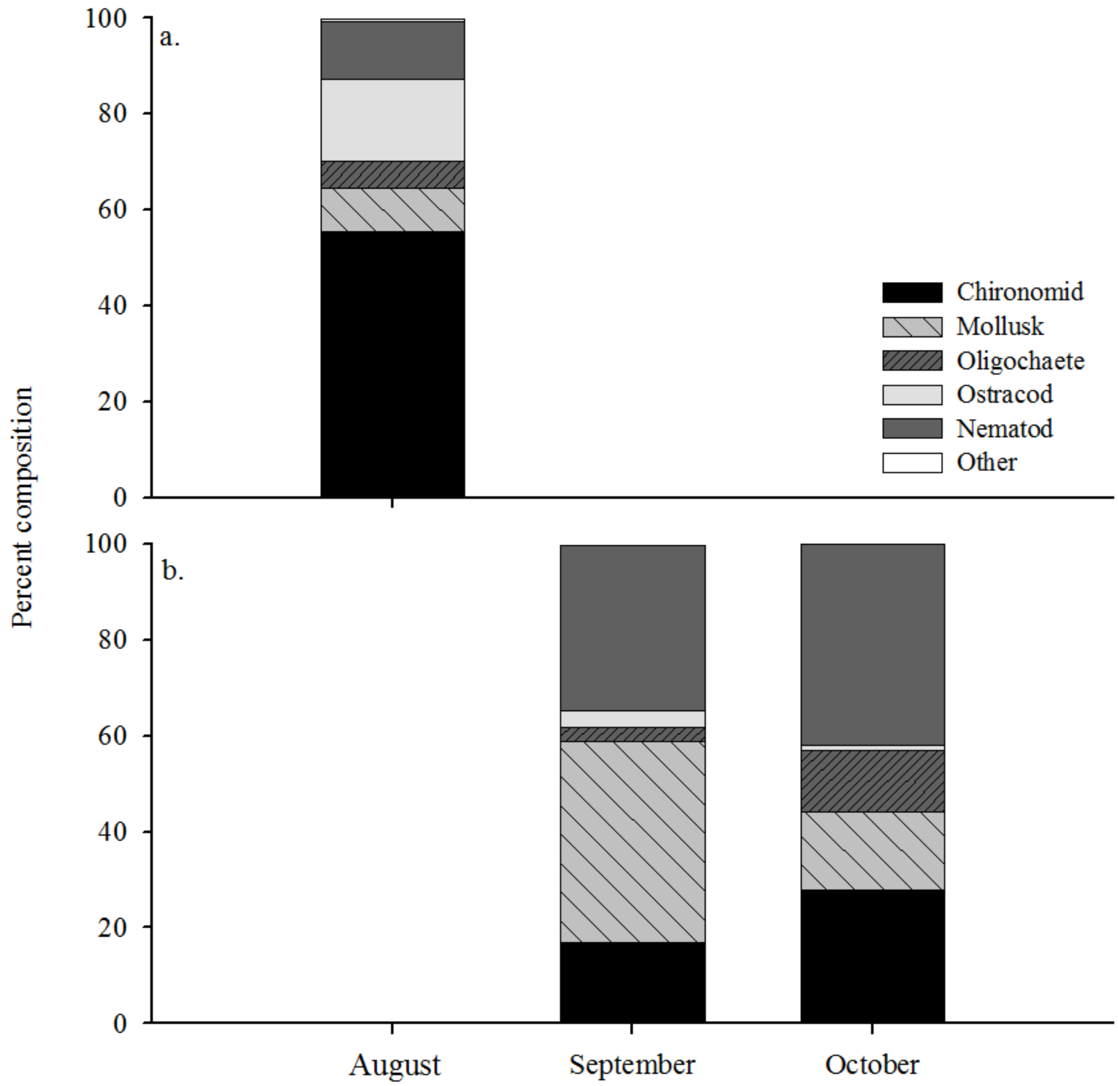

Figure 17. Percent composition of benthic invertebrates found in substrate of Lake Michigan near Waukegan using a) benthic core collection methods during August and b) a ponar grab during September and October 2011.

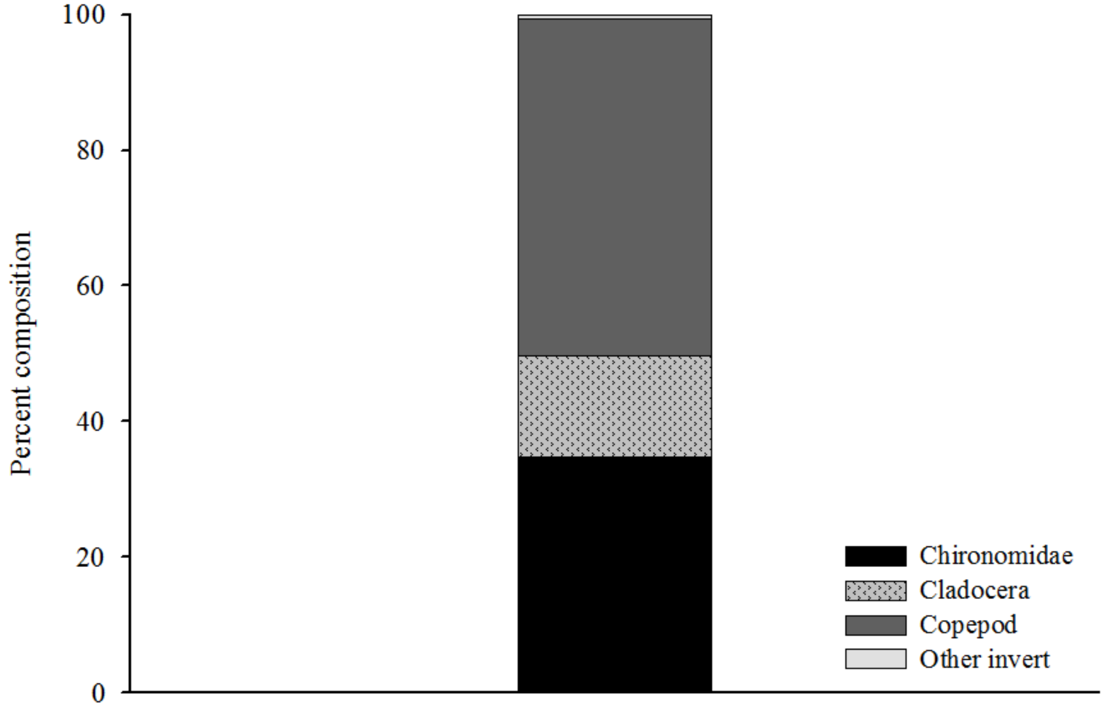

Figure 18. Diet composition of age-0 yellow perch collected in a bottom trawl north of Waukegan Harbor, IL during late July - October, 2011.

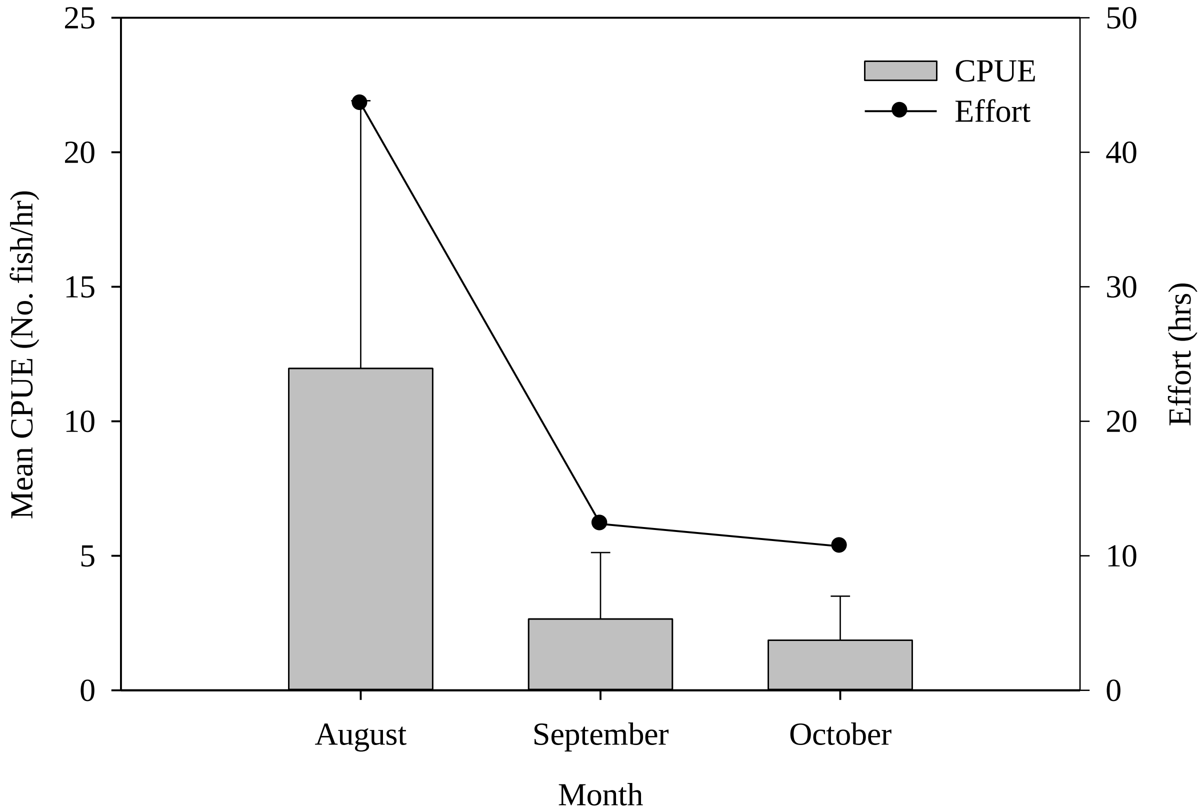

Figure 19. Mean monthly CPUE (+ 1 SD) of yellow perch collected in small mesh gill nets fished in 3-10 meters of water near Waukegan Harbor, IL during August - October, 2011.

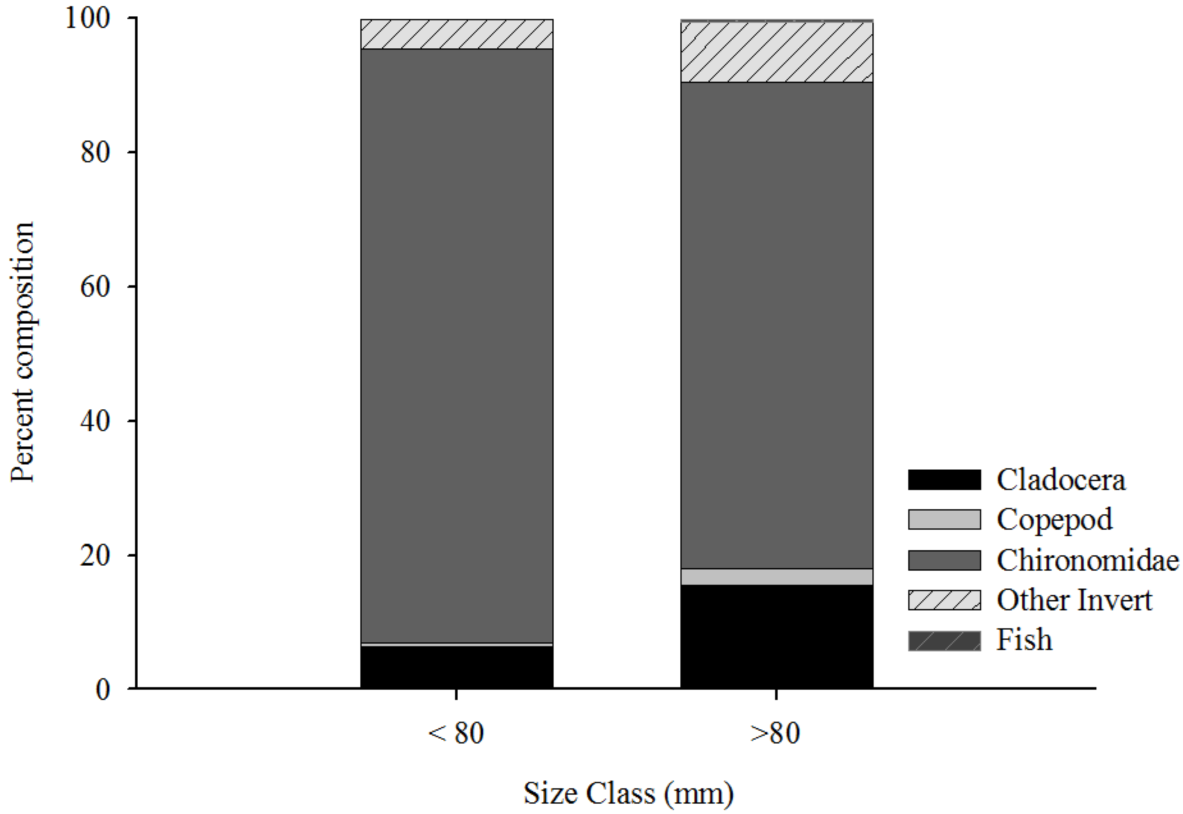

Figure 20. Diet composition of juvenile yellow perch collected in small mesh gill nets near Waukegan Harbor, IL during August -October, 2011. Size classes represented are ≤ 80 mm and > 80 mm TL.

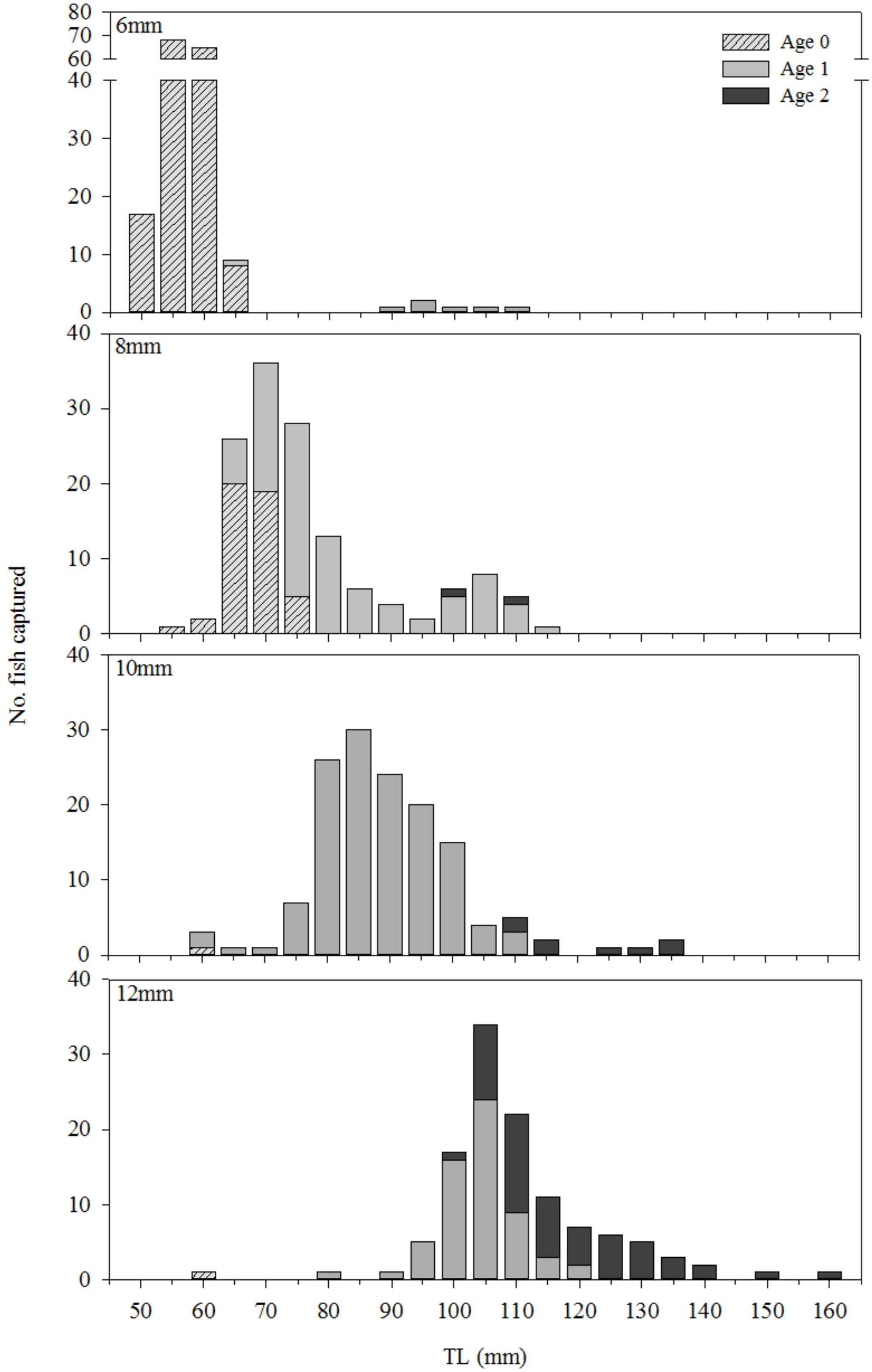

Figure 21. Age and length of yellow perch captured in each mesh size of small mesh gill nets fished near Waukegan, IL during 2008-2010.

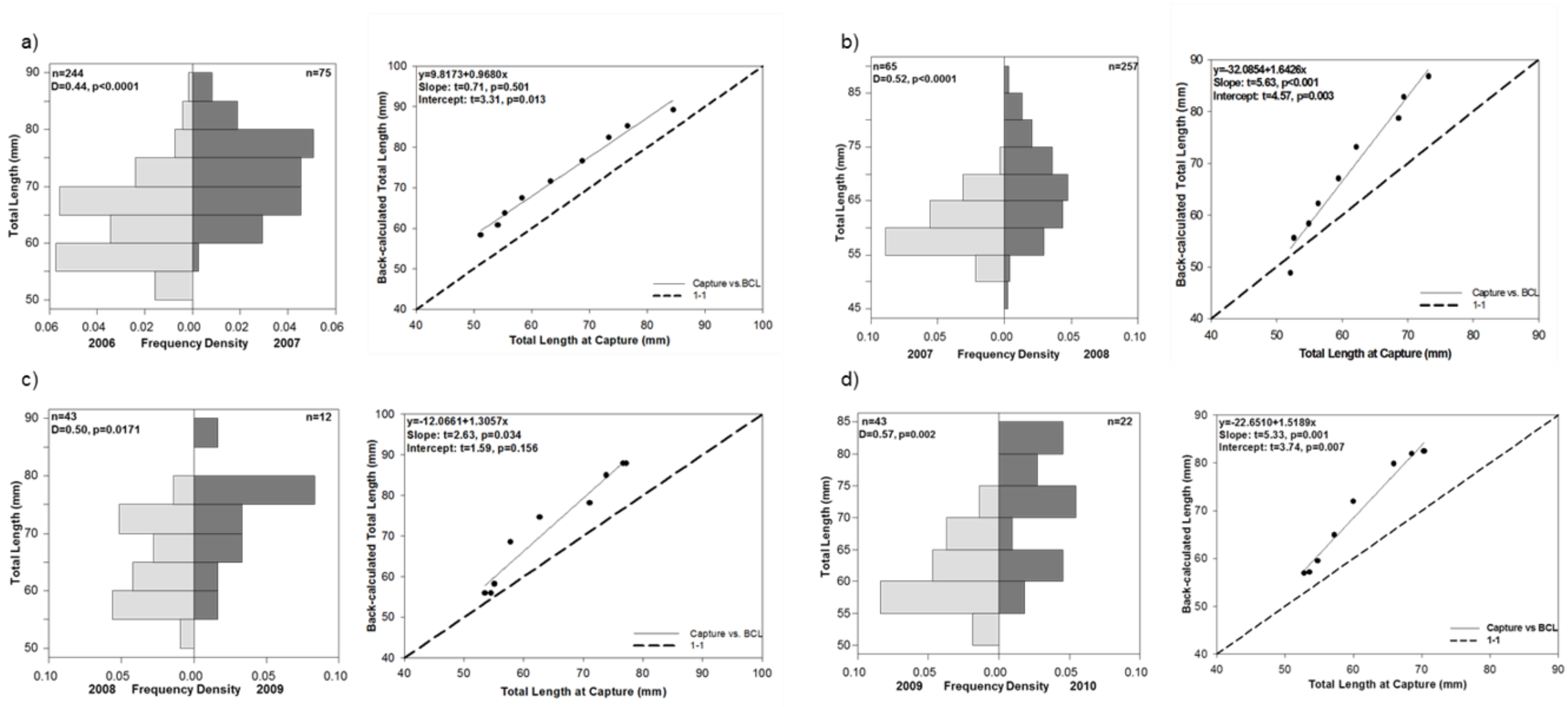

Figure 22. First-year overwinter comparison of length distributions and quantile-quantile plots of the a) 2006, b) 2007, c) 2008, and d) 2009 year-classes. Significant differences of distributions (Kolmogorov-Smirnov tests) and slope ≠1 and intercept ≠0 (t-tests) of the quantile-quantile plots were declared at α=0.05 and are indicated within each panel.

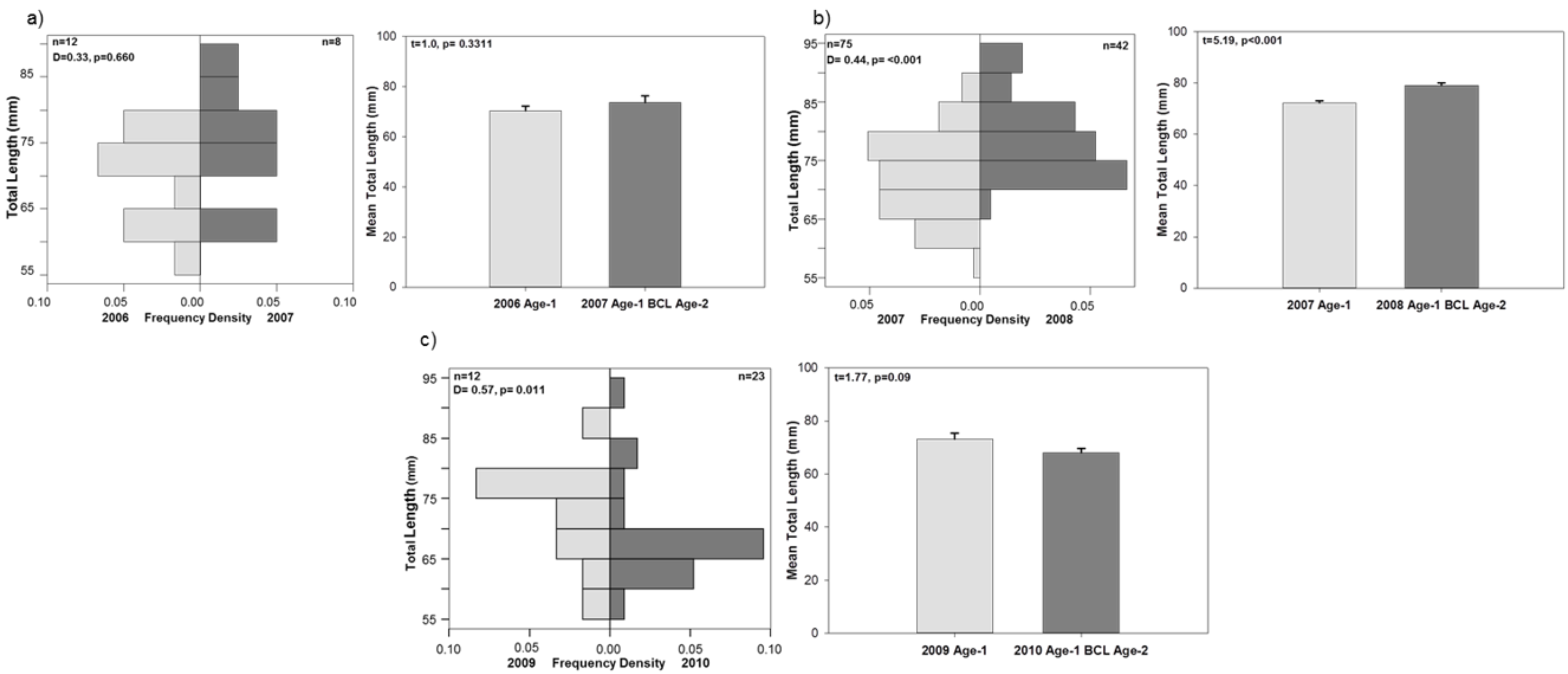

Figure 23. Annual comparison of length distributions and mean total length at age of age-1 yellow perch back-calculated to the start of age-1 and age-2 yellow perch sampled a year later and back-calculated to the start of age-1 from the (a) 2005, (b) 2006, and (c) 2008 year-classes. Significant differences of distributions (Kolmogorov-Smirnov KSa) and differences in mean back-calculated total lengths (two-sample t-tests) were declared at α=0.05 and are indicated within each panel. Error bars denote one standard error.